Search for SUSY at the LHC using the E_T^{miss} signature

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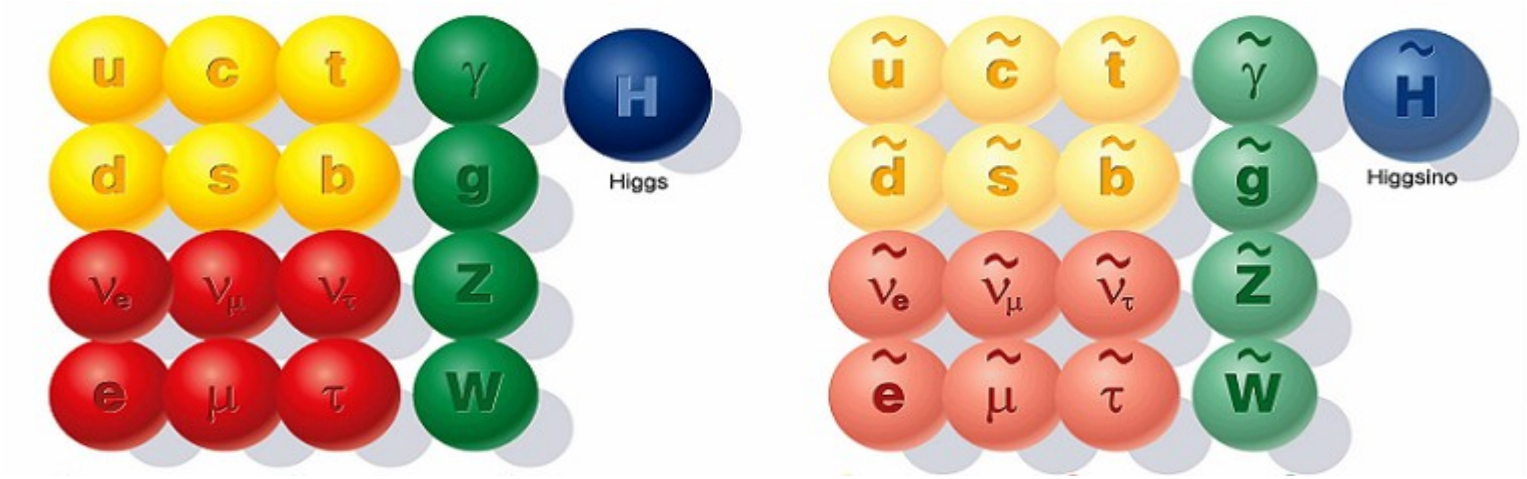
24th Rencontres des Blois, France

SUSY Introduction

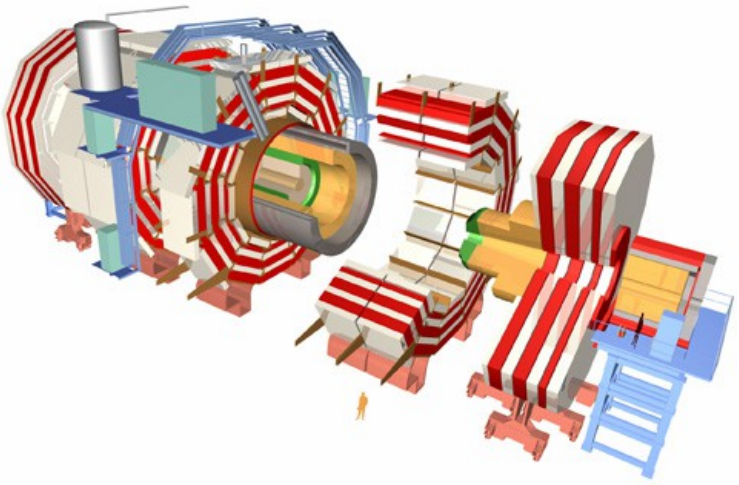


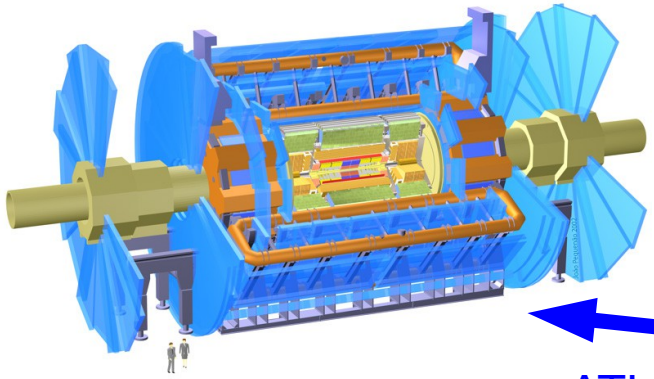
- Symmetry between fermions and bosons
- Many models assume R-Parity conservation
  - Means SUSY particles are produced in pairs
  - Stable lightest SUSY particle (LSP) which escapes the detector unseen
  - But not the only way for SUSY to cause large E_T^{miss}

The Detectors

- 3.8T solenoid
- Silicon tracker
- Lead tungsten crystal ECAL
- Brass scintillator HCAL
- Iron return yoke muon spectrometer

CMS



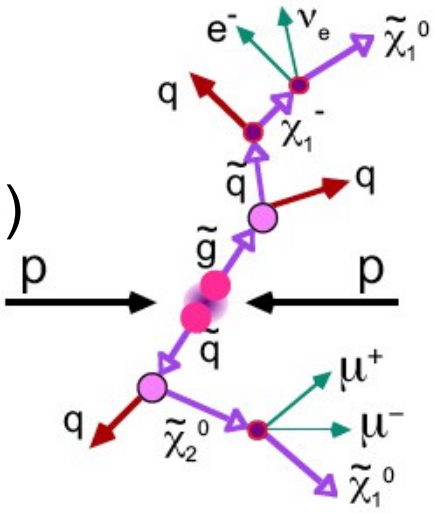


ATLAS

- 2T solenoid for tracker
- Silicon & transition radiation tracker
- Lead-Ar sampling ECAL
- Fe-scint + Cu-Ar sampling HCAL
- Air toroid for muon spectrometer

Inclusive searches for strong squark & gluino production

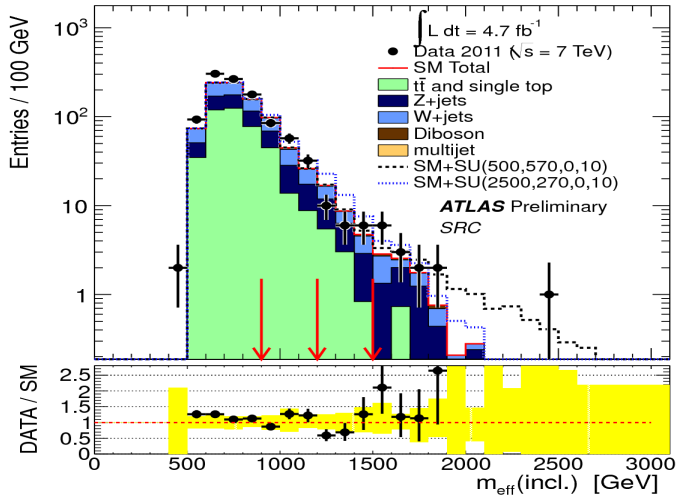
- Strong production of 1st, 2nd gen $\tilde{q}$, $\tilde{g}$, decay chains ending in χ^0_1
  - Length of decay chain depends on SUSY model
- Common variables to select $\tilde{q}$, $\tilde{g}$ cascades:
  - E_T^{miss}, jet multiplicity, light lepton multiplicity
  - H_T := scalar sum of jet p_T (and e/μ/γ p_T for ATLAS)
  - Effective mass: $m_{eff} = H_T + E_T^{miss}$
  - M_T: transverse mass of leptons and E_T^{miss}

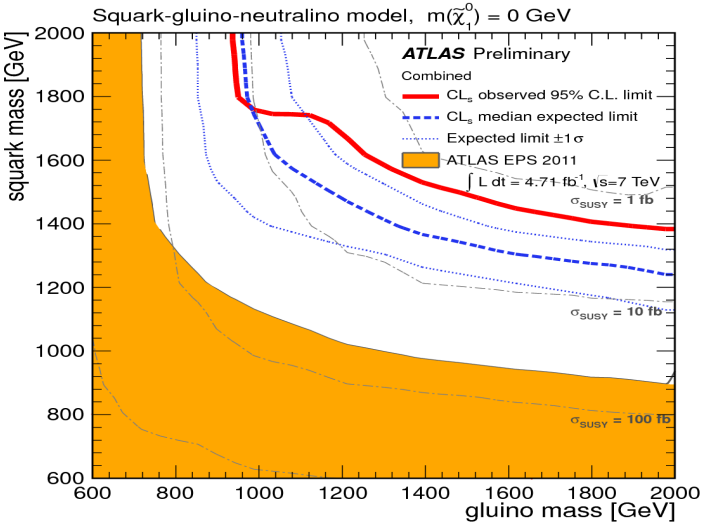


- Multijet+fake E_T^{miss} backgrounds from data-driven methods
- Z, W and leptonic top often estimated using control regions in data
  - transferred to signal region using simulation

ATLAS: 2-6 Jets + E_T^{miss}

ATLAS-CONF-2012-033

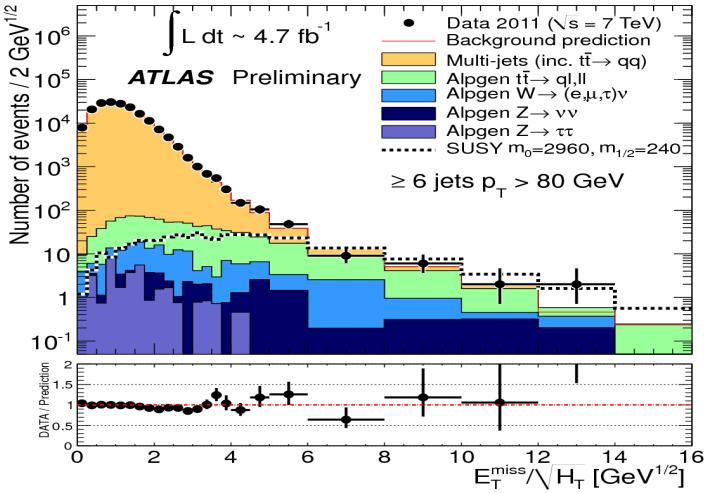


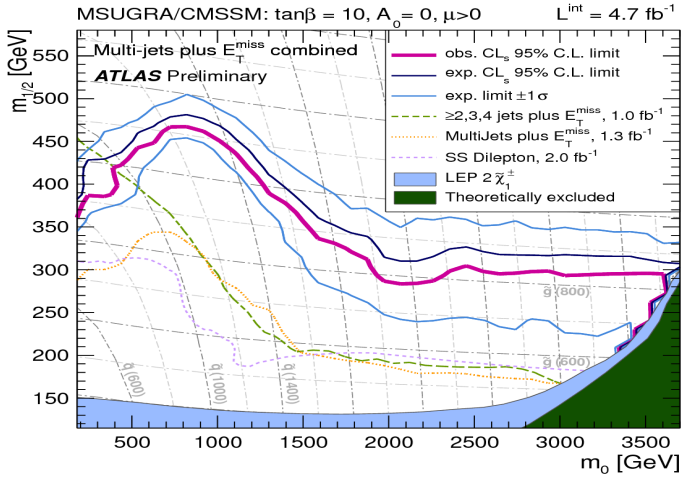


- Fully hadronic decay chains
  - Low jet multiplicity for squark production
  - higher jet multiplicities for gluino production
- Use m_{eff} and E_T^{miss} to define signal region depending on jet multiplicity
- Backgrounds: Top,W,Z,multijets
- Limits from 4.7fb^{-1} in
  - minimal super gravity (mSUGRA)
  - constrained minimal super-symmetric standard model (CMSSM)
  - phenomenological models

ATLAS: 6-9 Jets + E_T^{miss}

ATLAS-CONF-2012-037



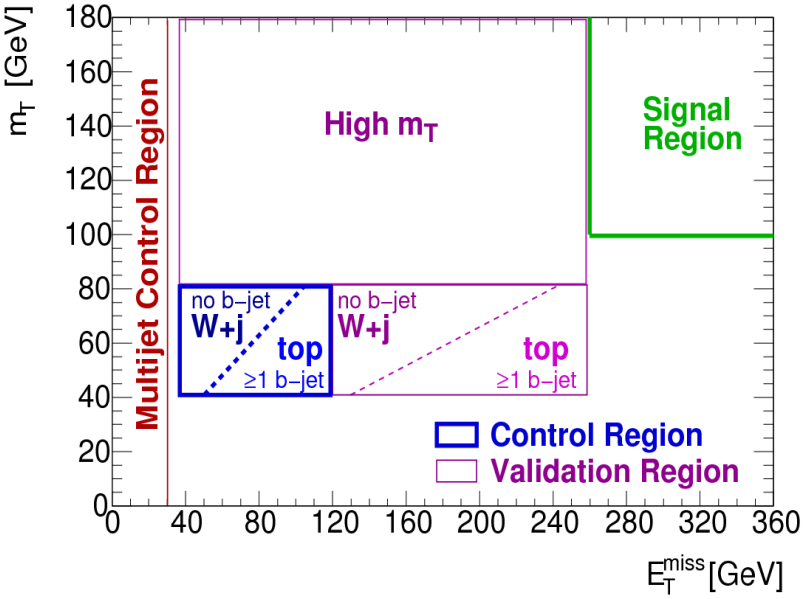


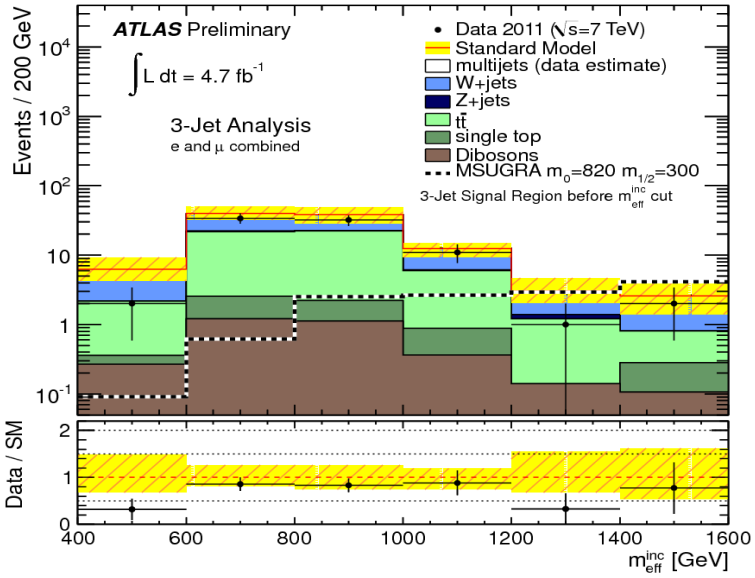
- Longer fully hadronic decay chains from gluinos
- Many high p_T jets, no E_T^{miss} required at trigger level
- Only additional cut on E_T^{miss} significance: $E_T^{miss}/\mathrm{sqrt}(H_T)$
- Backgrounds: top,multijet (W,Z)
- Limits from 4.7fb^{-1} in mSUGRA, CMSSM and simplified models

ATLAS: Jets + e/μ + E_T^{miss}

ATLAS-CONF-2012-041

- require one light lepton with p_T < 25 GeV and low number of jets
- Further cuts on E_T^{miss}, m_T and m_{eff} to select signal
- Backgrounds: W, top

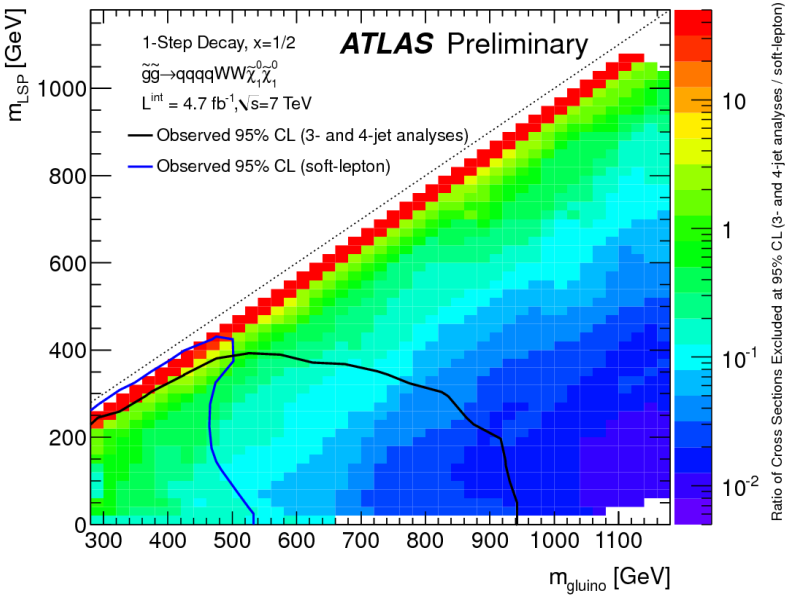


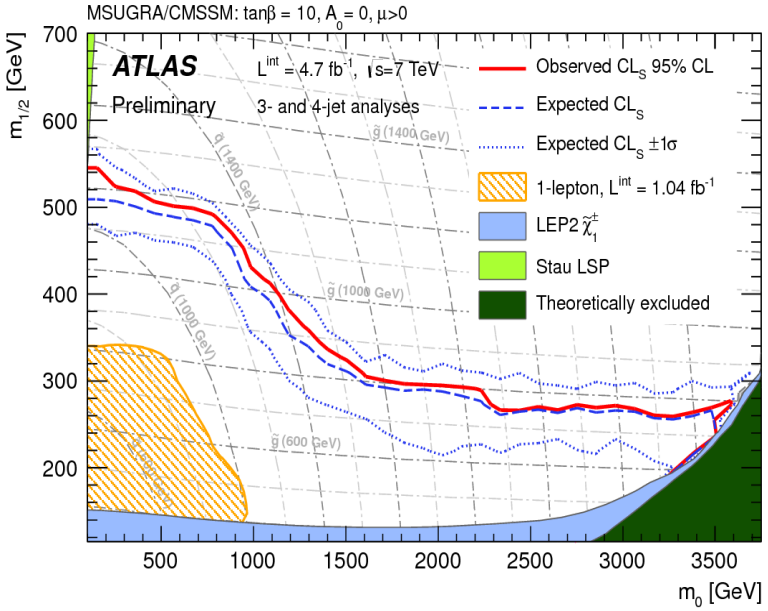


ATLAS: Jets + e/μ + E_T^{miss}

ATLAS-CONF-2012-041

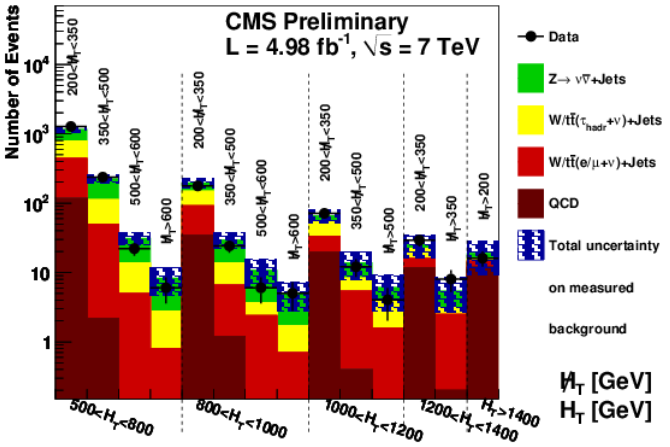
- Limits from 4.7fb^{-1} in mSUGRA, CMSSM and simplified models with decay gluino → $q\bar{q}\chi^{+-}_1 \rightarrow q\bar{q}W(*)\chi^0$
- Additional SR with soft leptons (7 < p_T < 25) GeV

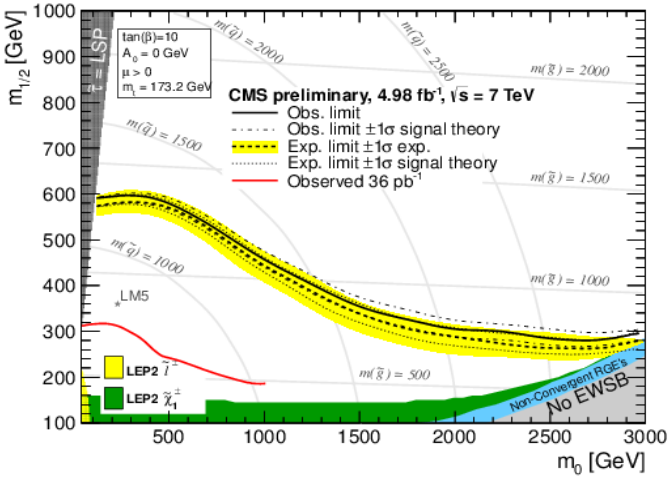




CMS Jets + E_T^{miss} with H_T/MH_T

CMS PAS SUS-11-004

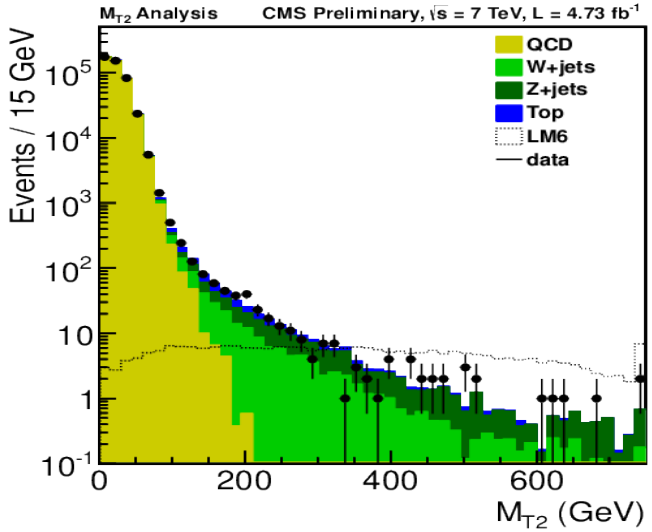


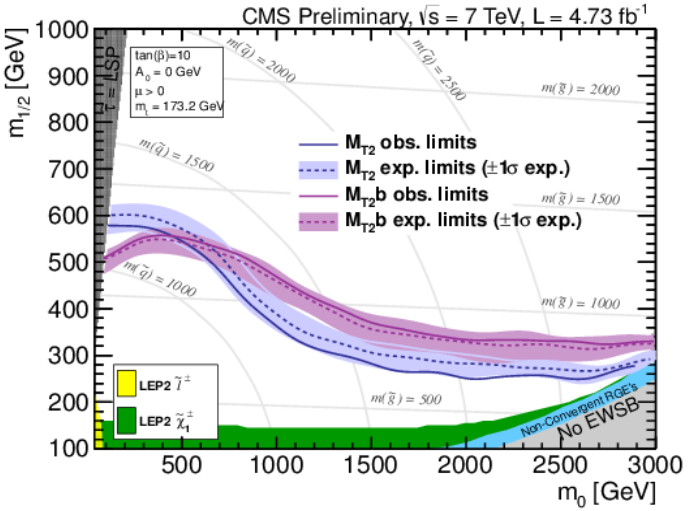


- Only require 3 jets → Sensitive to short (full had.) decay chains
- Use H_T and MH_T to select signal
- MH_T := vectorial p_T sum of all jets p_T>30GeV
- Select signal in 14 exclusive bins in H_T vs. MH_T plane
- Backgrounds: W,Z,top,multijets
- Limits from 4.98fb^{-1} in mSUGRA, CMSSM and simplified models

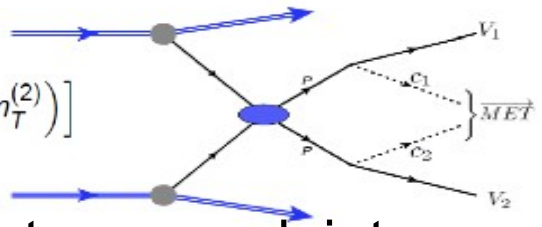
CMS Jets + E_T^{miss} with M_{T2}

CMS-PAS-SUS-12-002





$$M_{T2} = \min_{p_T^{c1}+p_T^{c2}=\not{p}_T} \left[\max\left(m_T^{(1)}, m_T^{(2)}\right)\right]$$

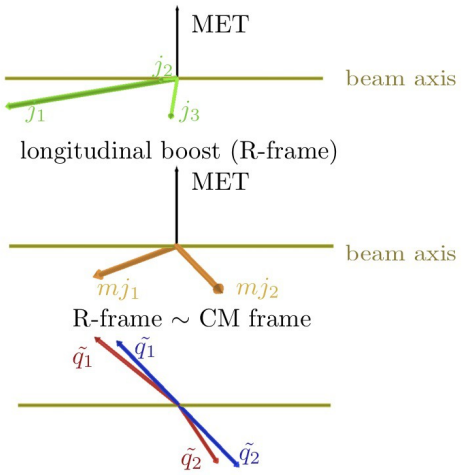


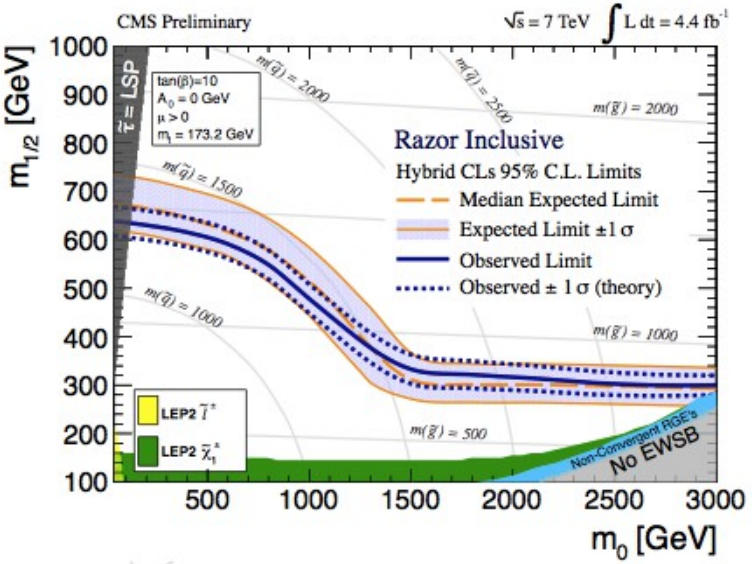
- Combine jets into two pseudojets
- M_{T2} close to 0 for balanced dijet like events
- Proportional to E_T^{miss} in SUSY events

- Select signal by requiring only 3 jets and split analysis in 2 bins of H_T
- Backgrounds: W,Z,multijets
- Limits from 4.73fb^{-1} in CMSSM and simplified models

CMS Jets (+ e/μ) + E_T^{miss} with Razor

CMS-PAS-SUS-12-005

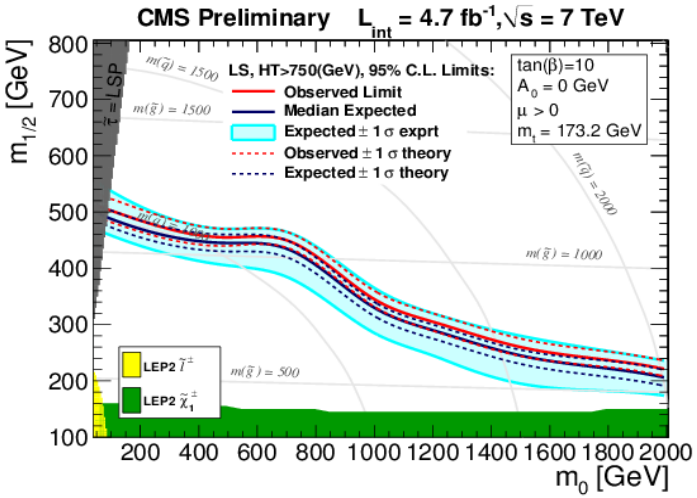


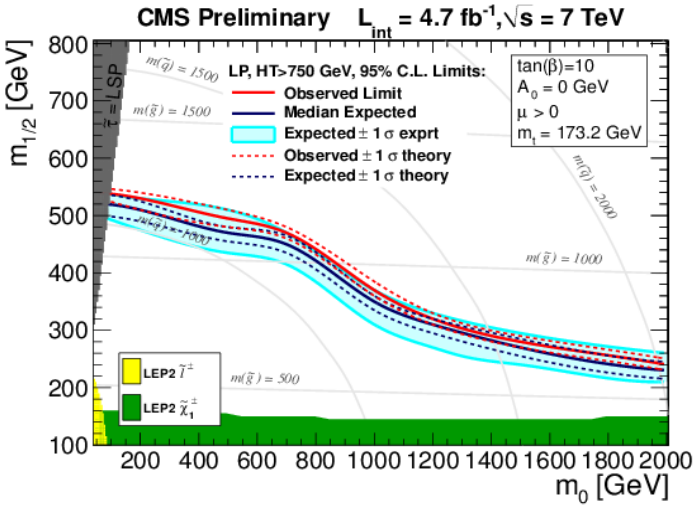


- Combine jets into two pseudo-jets using hemisphere algorithm
- invariant and transverse masses of pseudo-jet pair discriminate between heavy pair production and Standard Model background
- extrapolate exponential fit of background to signal region
- Includes channels with any number of light leptons
- Limits from 4.4fb^{-1} in mSUGRA, CMSSM and simplified models

CMS Jets + single e/μ + E_T^{miss}

CMS-PAS-SUS-12-010

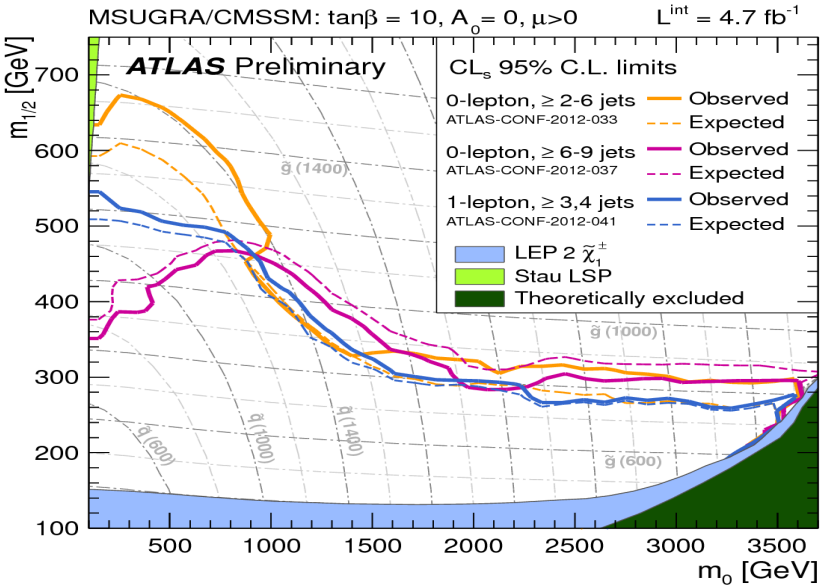


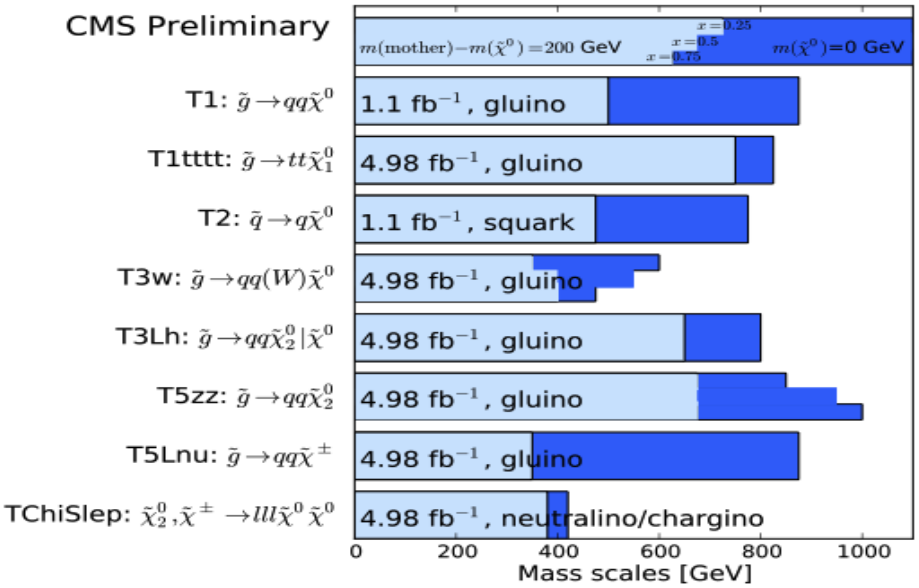


- Two methods used
- Lepton spectrum:
  - Use correlation between e/μ p_T and E_T^{miss} in SM BG
- Lepton projection
  - Search variable correlated to helicity angle of lepton from W decay
- Use H_T in both to define signal region
- W and top are dominant backgrounds
- Limits on CMSSM from 4.7fb^{-1}

Overview of Current Status

- Searches for squarks and gluinos in final states with Jets (+ lepton) + E_T^{miss} performed
- ATLAS and CMS interpret results in CMSSM (+simpl. models)
- Gluino masses up to 800-900 GeV excluded
- Squark masses up to ~1.5 TeV excluded for many gluino masses





Searches for gauge-mediated SUSY breaking (GMSB) inspired scenarios

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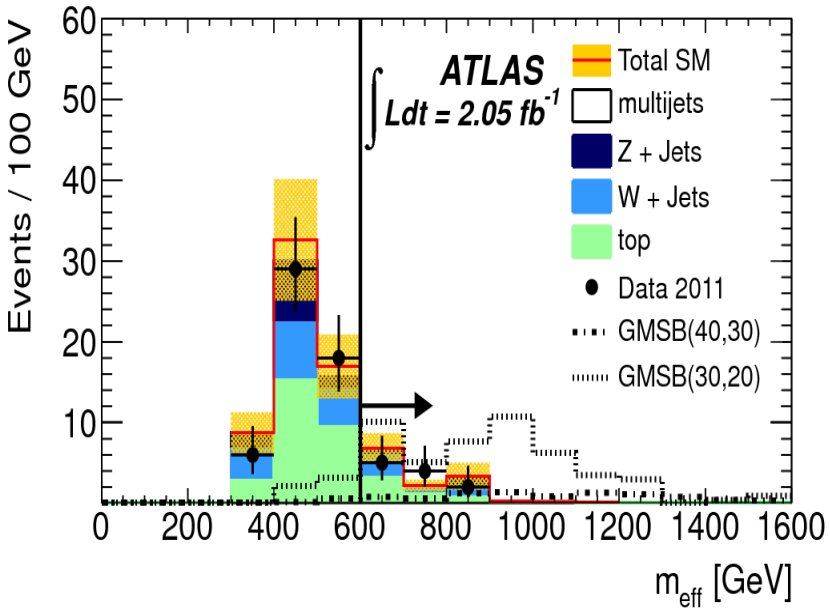
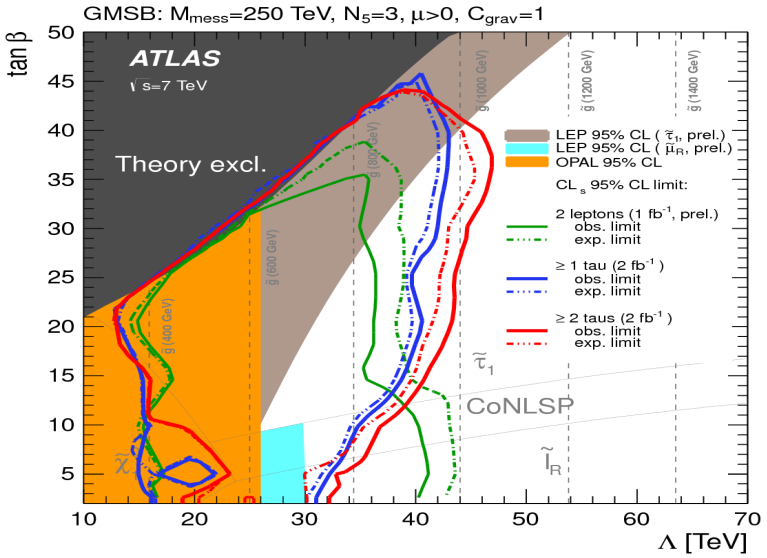
- LSP is almost massless (gravitino)
- Next-to-lightest SUSY particle (NLSP) determines phenomenology:
- Possible NLSPs: $\tilde{\tau}$, χ, $\tilde{l}$, $\tilde{g}$
  - $\tilde{\tau}$ NLSP: final states with τ leptons (discussed here)
  - X^0,$\tilde{l}$ NLSP: final states with leptons, depending on X^0
  - X^0 bino like: decay to $\gamma\gamma$
    - (arXiv:1111.4116 ,CMS result discussed here)
  - X^0 higgsino like: decay to $Z+E_T^{miss}$
    - (ATLAS-CONF-2012-047,arXiv:1204.3774)

ATLAS GMSB Searches

ArXiv:1204.3852, arXiv:1203.6580,ATLAS-CONF-2011-156



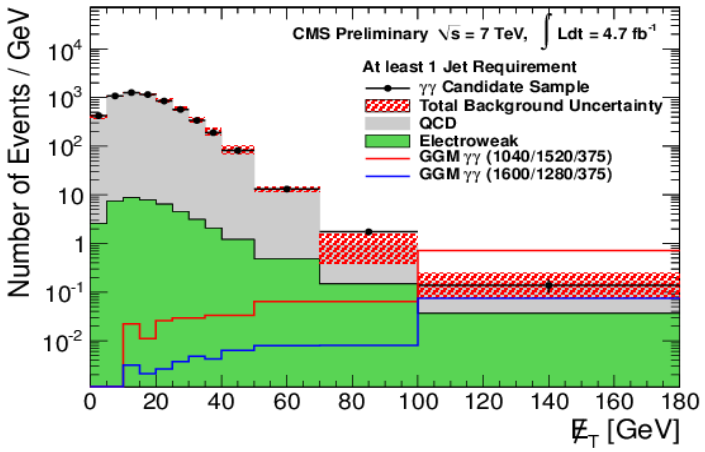


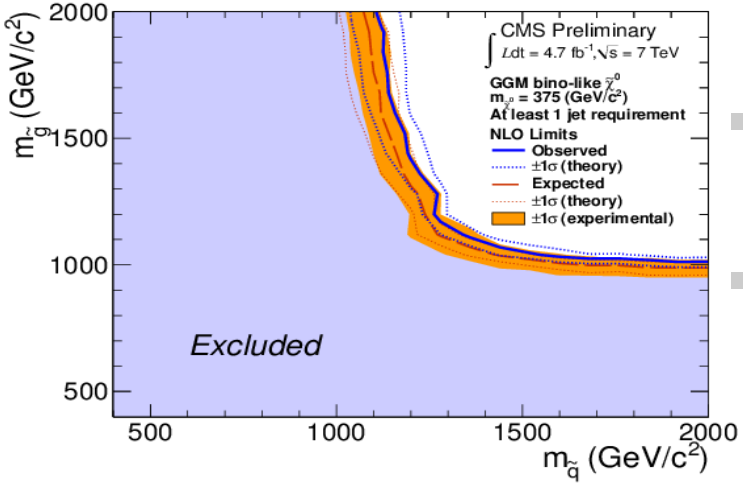
- $\tilde{\tau}$ search with 1 or 2 hadronically decaying taus
- Select signal with jets, E_T^{miss}, m_{eff} and M_T
- Backgrounds: W,top,Z

- $\tilde{l}$ search in dilepton + jets + E_T^{miss} final state
- Performs better at low tanβ
- Backgrounds: Top, dibosons

CMS Diphoton Search

CMS-PAS-SUS-12-001





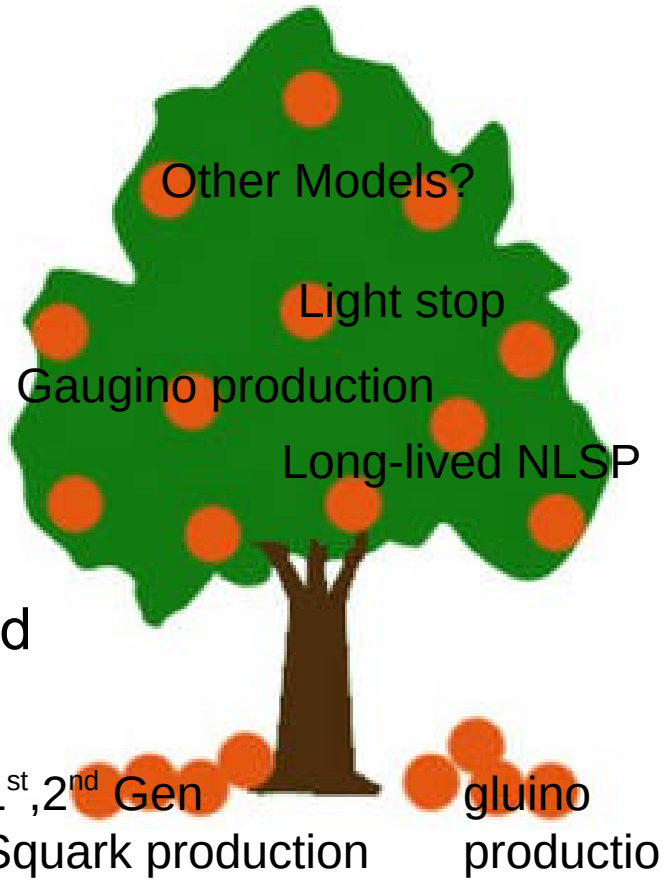
- Search in single and di-photon final states with large E_T^{miss}
- Backgrounds:
  - real photon, fake E_T^{miss}
  - Real or fake photon together with W→ev decay
- Limits set in simplified models for squark/gluino/neutralino masses
- But also interesting channel for general gauge mediation (GGM) and GMSB

Outlook

- First searches at LHC designed to find „light“ squarks and gluinos in channels with:
  - Jets + E_T^{miss}
  - Jets + leptons + E_T^{miss}
  - Jets + taus + E_T^{miss}
  - Z + E_T^{miss}
  - photons + E_T^{miss}

→ all the low-hanging fruit has been picked

- Many other models are being considered now



Backup

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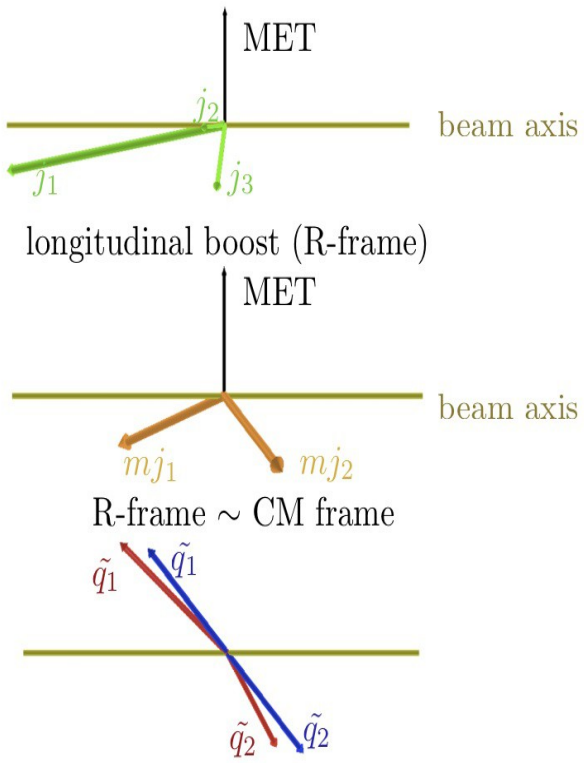
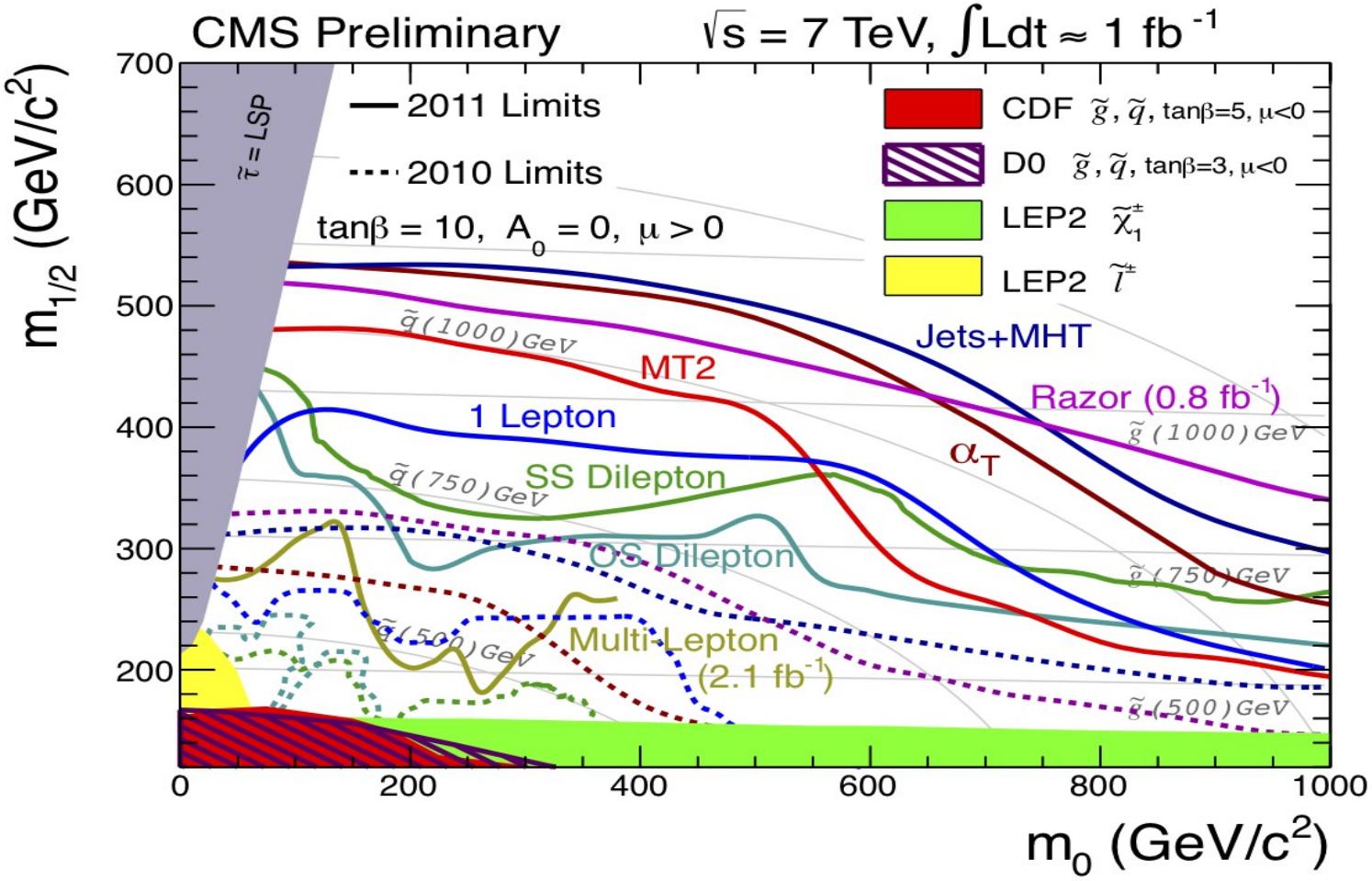
CMS Jets + ETMiss with Razor

CMS-PAS-SUS-12-005

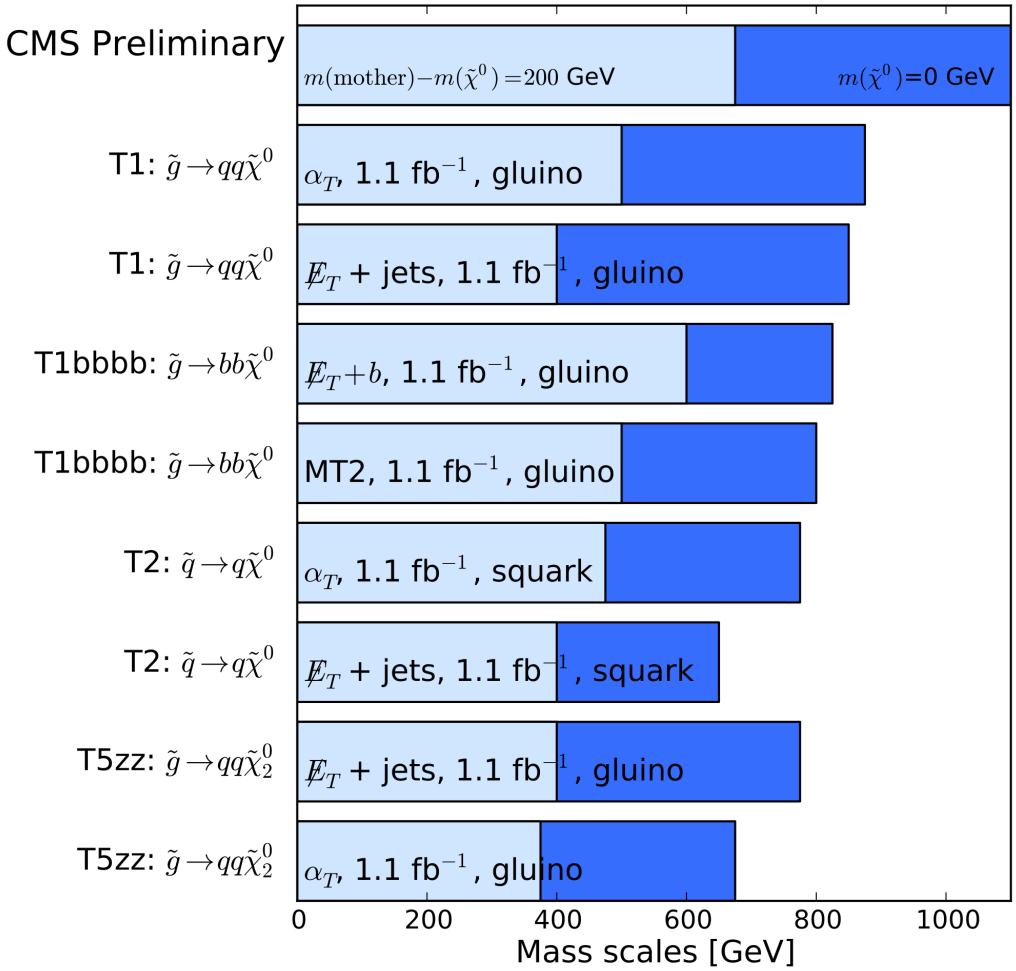


- j1,j2,j3= jets in lab frame,
- mj1,mj2 = megajets in R-frame (p1=p2)
- q1,q2 (red) = squarks generator level at the R-frame
- q1,q2 (blue) = squarks generator level at their CM frame

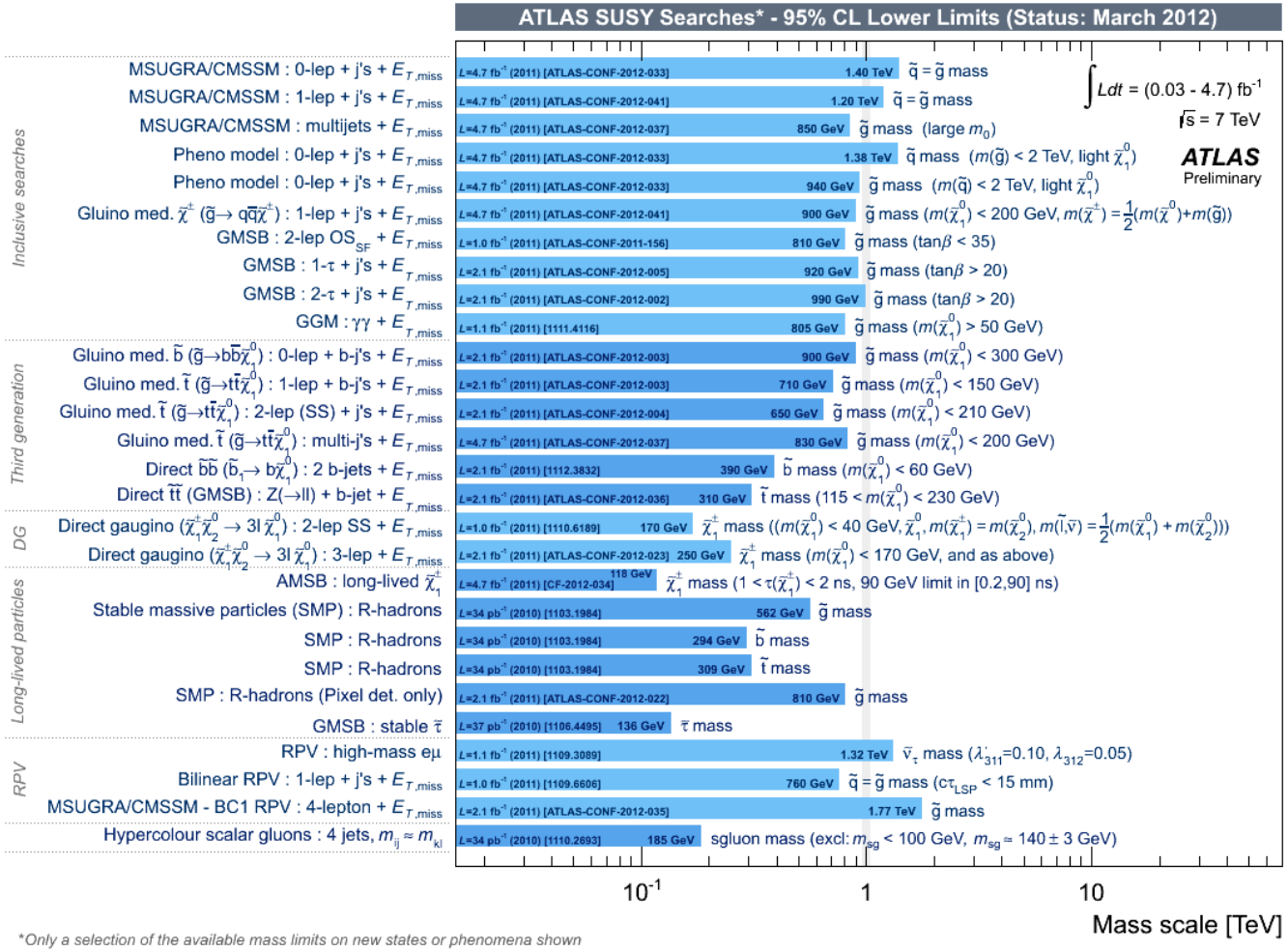
Summary


CMS Preliminary
$\sqrt{s}$ = 7 TeV, $\int$Ldt ≈ 1 fb^{-1}
2011 Limits
2010 Limits
tanβ = 10, A$_0$ = 0, μ > 0
$\tilde{\tau}$ = LSP
CDF $\tilde{g}$, $\tilde{q}$, tanβ=5, μ<0
D0 $\tilde{g}$, $\tilde{q}$, tanβ=3, μ<0
LEP2 $\tilde{\chi}_1^{\pm}$
LEP2 $\tilde{l}^{\pm}$
Jets+MHT
MT2
Razor (0.8 fb^{-1})
1 Lepton
α_T
SS Dilepton
OS Dilepton
Multi-Lepton (2.1 fb^{-1})
$\tilde{q}$(1000)GeV
$\tilde{q}$(750)GeV
$\tilde{q}$(500)GeV
$\tilde{g}$(1000)GeV
$\tilde{g}$(750)GeV
$\tilde{g}$(500)GeV
m$_{1/2}$ (GeV/c^2)
m$_0$ (GeV/c^2)
700
600
500
400
300
200
0
200
400
600
800
1000

Summary


CMS Preliminary
$m(\text{mother})-m(\tilde{\chi}^0)=200$ GeV
$m(\tilde{\chi}^0)=0$ GeV
T1: $\tilde{g}\to qq\tilde{\chi}^0$
α_T, 1.1 fb^{-1}, gluino
T1: $\tilde{g}\to qq\tilde{\chi}^0$
$\not{E}_T$ + jets, 1.1 fb^{-1}, gluino
T1bbbb: $\tilde{g}\to bb\tilde{\chi}^0$
$\not{E}_T+b$, 1.1 fb^{-1}, gluino
T1bbbb: $\tilde{g}\to bb\tilde{\chi}^0$
MT2, 1.1 fb^{-1}, gluino
T2: $\tilde{q}\to q\tilde{\chi}^0$
α_T, 1.1 fb^{-1}, squark
T2: $\tilde{q}\to q\tilde{\chi}^0$
$\not{E}_T$ + jets, 1.1 fb^{-1}, squark
T5zz: $\tilde{g}\to qq\tilde{\chi}^0_2$
$\not{E}_T$ + jets, 1.1 fb^{-1}, gluino
T5zz: $\tilde{g}\to qq\tilde{\chi}^0_2$
α_T, 1.1 fb^{-1}, gluino
0
200
400
600
800
1000
Mass scales [GeV]

Summary



*Only a selection of the available mass limits on new states or phenomena shown

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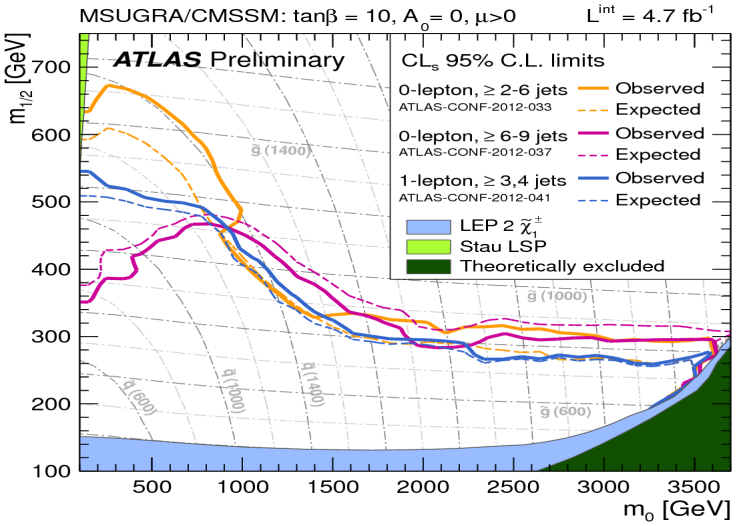
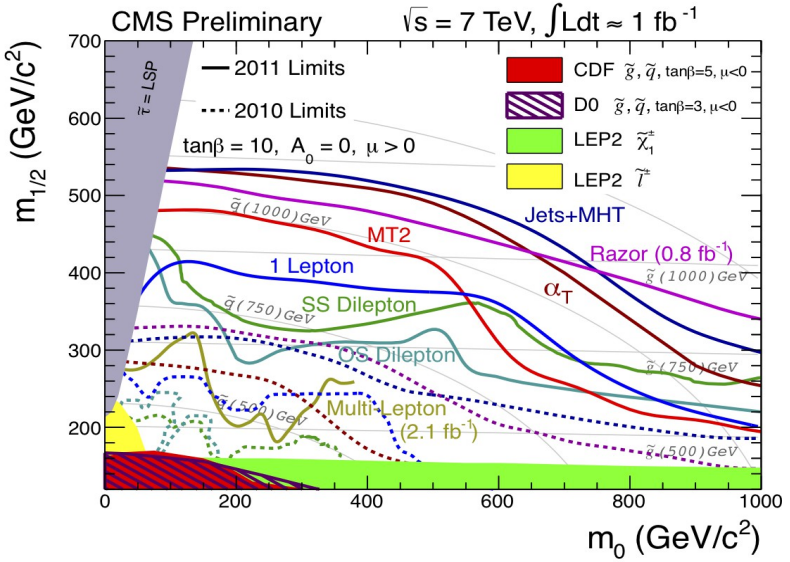
- ATLAS and CMS interpret results in CMSSM (+simpl. models)
- Gluino masses up to 800-900 GeV excluded
- Squark masses up to ~1.5 TeV excluded for many gluino masses





Background Estimation Strategies

- Multijet and fake E_T^{miss} backgrounds estimated from data-driven methods
- Z, W and leptonic top often estimated using control regions in data, transferred to SR using simulation:

$$N_{est,\,SR} = N_{MC,\,SR} / N_{MC,\,CR} \times (N_{obs,\,CR} - N_{bkg,\,CR})$$

- Control regions depend on analysis, i.e.:
  - M_T ($+E_T^{miss}$) for backgrounds with leptons from W (from top)
  - Separate W from top with b-quark tagging
  - $Z \rightarrow \nu\nu$ + jets from γ + jets control sample