# Searches for SUSY in Z+met+jets final states with ATLAS

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ATLAS

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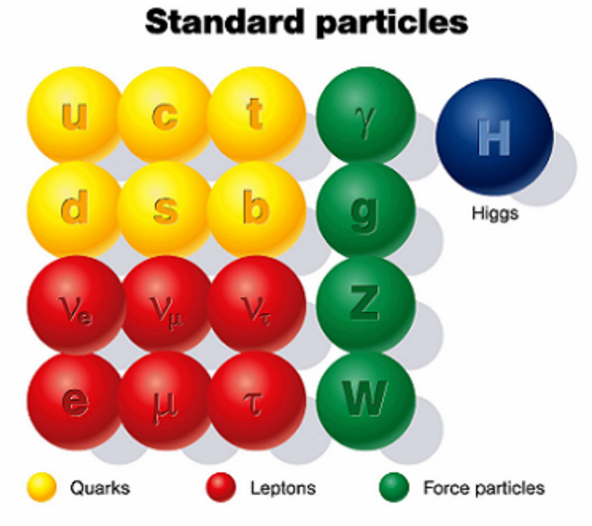
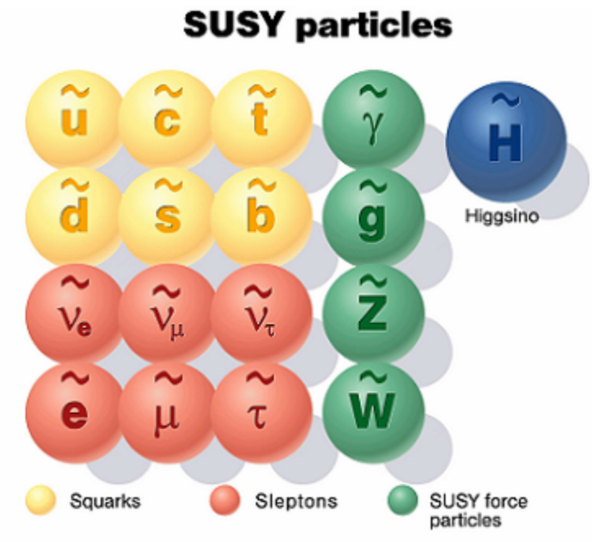
# Introduction

# Supersymmetry (SUSY)

- **SUSY = global symmetry between fermions & bosons**
  - all SM particles have SUSY-partners with spin difference of ±1/2
  - SUSY has to be a broken symmetry (superpartners heavier than SM particles)
- **Theoretical motivation**
  - Higgs mass stabilization against loop corrections (fine-tuning problem)
  - unification of gauge couplings at single scale
  - dark matter candidate:
    Lightest supersymmetric particle (LSP)





# R-Parity

$$R = (-1)^{3B+L+2s} = \begin{cases} +1 \text{ for SM particles} \\ -1 \text{ for SUSY particles} \end{cases}$$

- Lepton and/or baryon number violation constrained by previous experiments but not forbidden.

**bilinear terms**

$$W_{\cancel{RP}} = \overbrace{\sum_i \varepsilon_i \hat{L}_i \hat{H}_u + \sum_{i,j,k} \lambda_{ijk} \hat{L}_i \hat{L}_j \hat{E}_k + \sum_{i,j,k} \lambda'_{ijk} \hat{L}_i \hat{Q}_j \hat{D}_k}^{\text{L-number violating terms}} + \underbrace{\sum_{i,j,k} \lambda''_{ijk} \hat{U}^c_i \hat{D}^c_j \hat{D}^c_k}_{\text{B-number violating terms}}$$

$i,j,k$ = quark and lepton generations

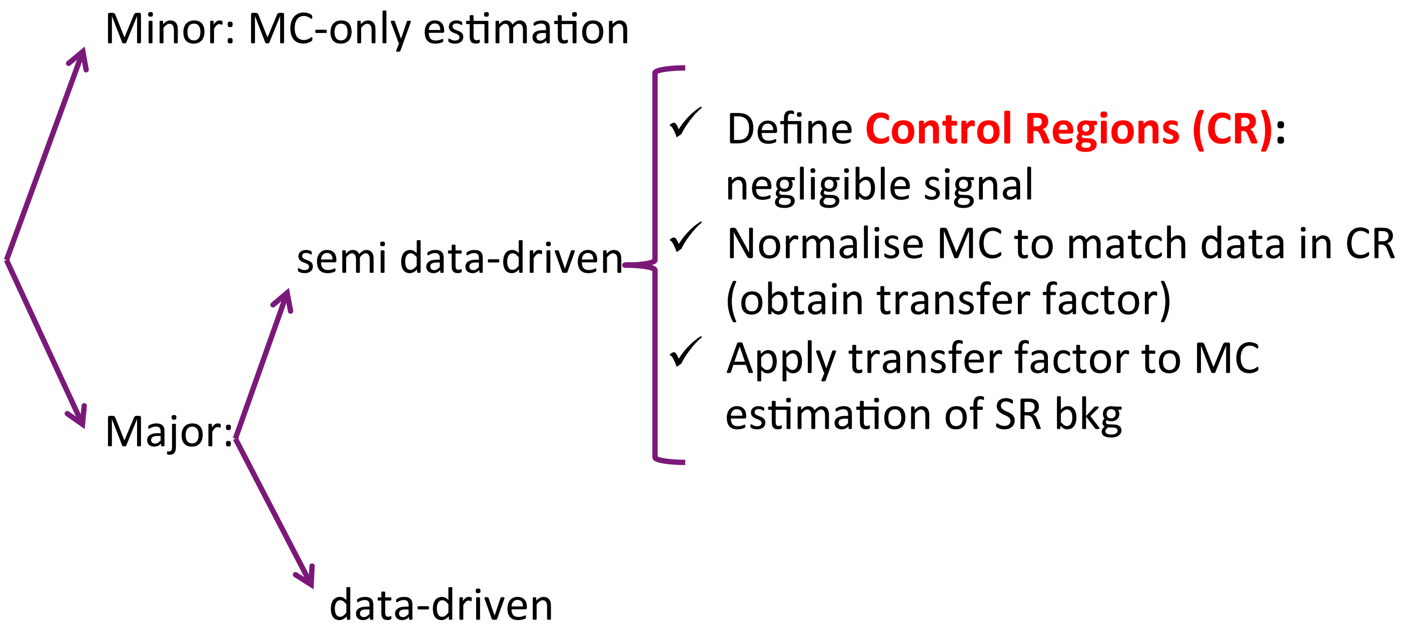
| RPConserving SUSY models: | RPViolating SUSY models: |
|---|---|
| - Neutral Stable LSP | - LSP: no need to be neutral nor stable. |
| | - LSP decay: possibility to explore new signals, exploit LSP invariant mass and decay properties |
| - Sparticles produced in pairs | - Single Sparticles production is possible |
| - Large $E_T^{miss}$ | - Not so large $E_T^{miss}$ |

# ATLAS SUSY Search Strategy

## SUSY events in our data?

- **Define Signal Region(s) (SR):** set of cuts (on EtMiss, jet multiplicity, etc) that favour signal over background

- **Background events in our SR?**



Minor: MC-only estimation

Major:

semi data-driven

- ✓ Define **Control Regions (CR)**: negligible signal
- ✓ Normalise MC to match data in CR (obtain transfer factor)
- ✓ Apply transfer factor to MC estimation of SR bkg

data-driven

- **Discovery/Exclusion fit:**
  - CLs exclusion limits or discovery

# The Analysis

# Overview

- **Search for SUSY in events with a leptonically decaying Z, jets and $E_T^{miss}$**
- **Use 20 $fb^{-1}$ of 8 TeV ATLAS data**
- Update of Conf. note ATLAS-CONF-2012-152 (5.8 $fb^{-1}$ @ 8TeV)

- Target models:
  - General Gauge Mediation (GGM)
  - bilinear RPV SUSY (bRPV)

- Three Signal Regions defined:
  - one for high μ values in GGM
  - one for low μ values in GGM
  - one for bRPV

- Background estimation:
  - Main background: Lepton flavour-symmetric backgrounds (dileptonic ttbar, dileptonic WW, Z(ττ), st in dileptonic Wt channel)

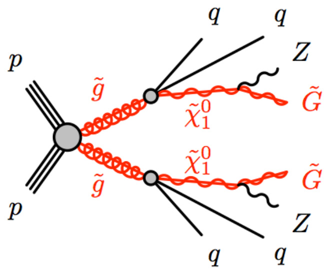
    Data-driven. Use eμ sample to estimate contribution in ee, μμ regions
  - Z + jets (fake $E_T^{miss}$)

    Use data-driven jet-smearing method to estimate fake $E_T^{miss}$ contribution
  - Minor bkgs estimated using MC
  - Fake leptons estimated with matrix method

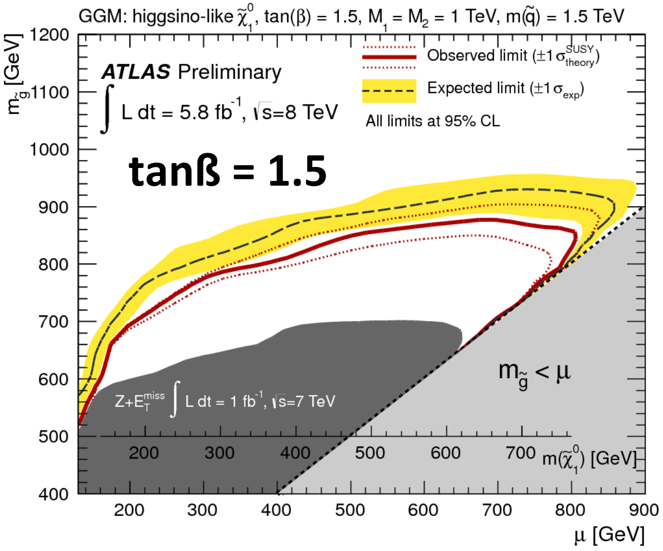
# Target models

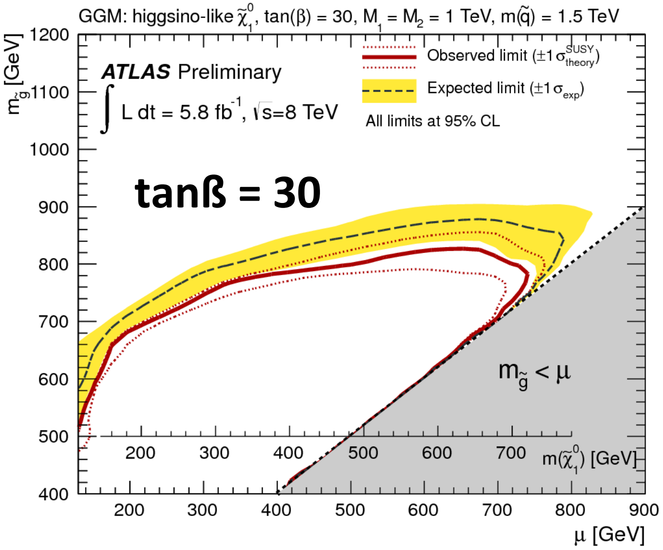
ATLAS-CONF-2012-152

- **General Gauge Mediation (GGM)**
  - RPC model
  - LSP always the gravitino (escapes detection => $E_T^{miss}$)
  - Phenomenology depends on NLSP (next to lightest SUSY particle): $\tilde{\chi}_1^0$ for most of the parameter space
  - **This analysis:**
    - $\tilde{\chi}_1^0$ higgsino-like
    - Parameters:
      - **$m_{gluino}$ and μ: free parameters**
      - $M_1 = M_2 = 1$TeV, $c\tau_{NLSP} < 0.1$ mm
      - all other sparticle masses ≈ 1.5
      - **Two grids studied:**
        - **tanß = 1.5**
        - **tanß = 30**



**Previous GGM Results**

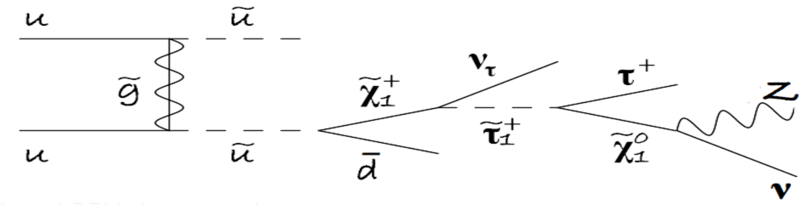




# Target models

- **bilinear R-parity violating (bRPV) SUSY**
  - R-parity violated through bilinear terms: $W_{\not{R}\not{P}} = \sum_i \varepsilon_i \hat{L}_i \hat{H}_u$
  - couplings can be embedded in any RPC scenario: MSSM, SUGRA, …
  - connected to neutrino physics (bRPV parameters unambiguously determined after fitting to neutrino physics data)

  - **This analysis:**
    - **"Higgs-aware" mSUGRA/cMSSM (predicts Higgs mass compatible with 125 GeV)**
    - Same decay chain as in RPC except for LSP ($\tilde{\chi}_1^0$) decay



  - Parameters: **$A_0$ = -2$m_0$; tanß = 30; µ > 0; $m_0$ and $m_{1/2}$: free parameters**
  - BR( $\tilde{\chi}_1^0 \rightarrow \nu + Z$ ) ≈ 30%

# Target models

## Previous bRPV Results

different parameters choice

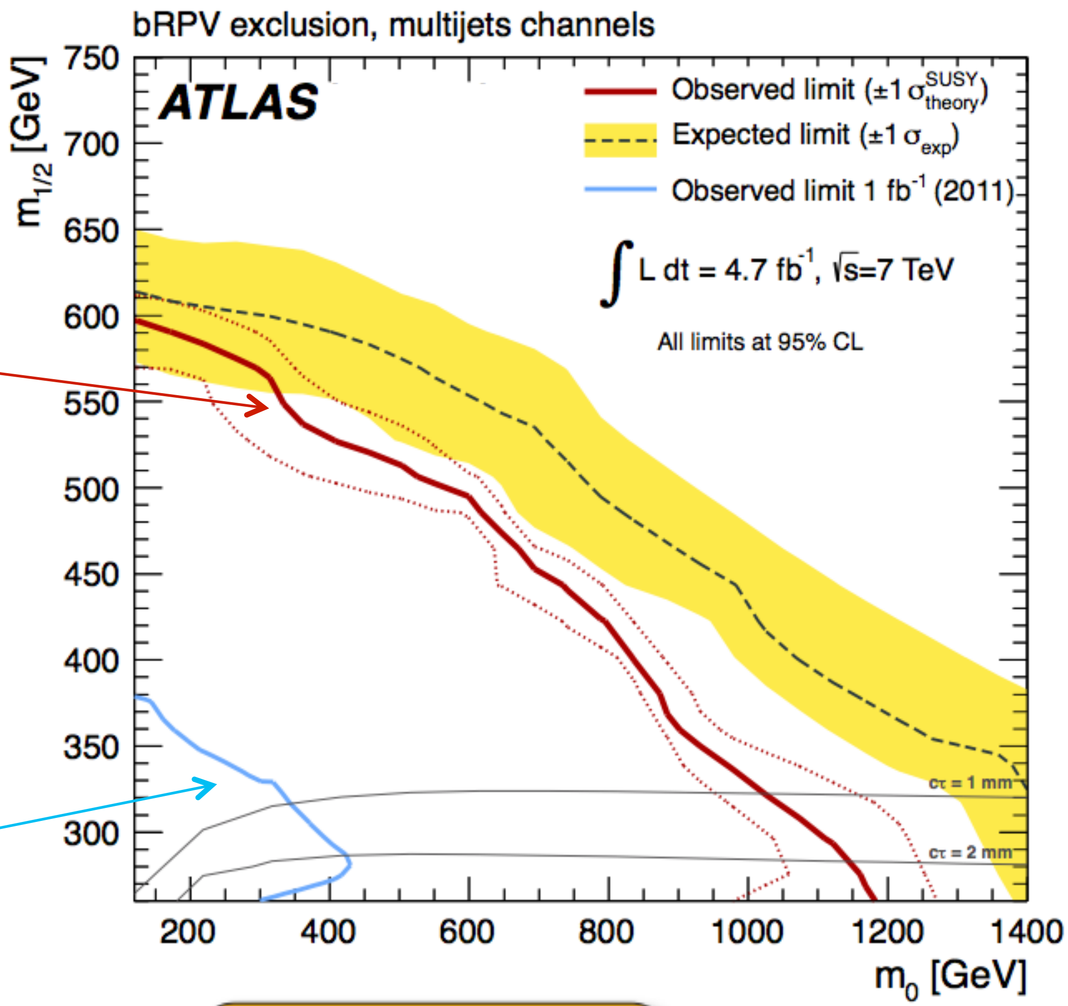
- $A_0$=0, tanβ =10, sign (μ)=+1
- Prompt decays (cτ < 5 mm)
- Production of ALL SUSY strong and electroweak processes

### Selection (multi-jets):

- 1 lepton and > 6 jets
- $p_T$>25 (20) GeV electrons (muons)
- Jets $p_T$>80 (25) GeV
- $m_T$ >120 GeV
- $E_T^{miss}$ >180 GeV
- $m^{inc}_{eff}$ >750 GeV

### Previous limits:

- ATLAS: 1 lepton + 3 (4) jets
- Low-energy processes / neutrino parameters
- Tevatron or CMS: No results



**ATLAS-CONF-2012-140**

# Event Selection

- **Preselection:**
  - Dilepton triggers ORed with single lepton triggers to recover inefficiencies
  - 2 OS SF leptons (electrons or muons)
    - Leading lepton $p_T > 25$ GeV
    - Subleading lepton $p_T > 10$ GeV
    - Invariant mass close to m(Z): $81 < m_{ll} < 101$ GeV
- **Signal Regions** (SRs) **definition**:

| **Signal Region** | **SR1** | **SR2** | **SR3** |
|---|---|---|---|
| **Number of jets >** | 1 | 3 | 4 |
| **$E_T^{miss}$ [GeV] >** | 225 | 150 | 100 |
| **$H_T$ [GeV] >** | 600 | 900 | 900 |
| ***Optimal for*** | *GGM* | *GGM* | *bRPV* |

- SRs not orthogonal:
  - will take the best selection among the three of them for interpretation

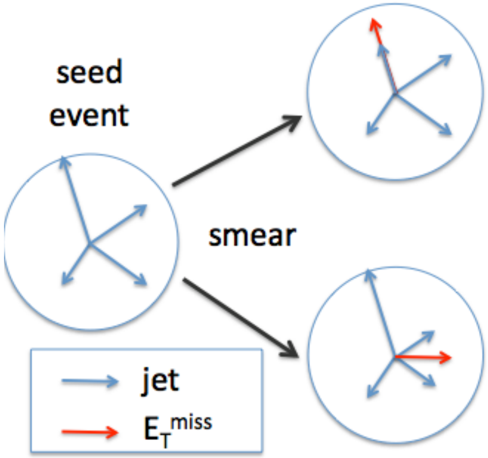
Scalar sum: $H_T = \sum_i p_T^{lepton_i} + \sum_{i=1,2} p_T^{jet_i}$

# Background Estimation

## Z (ee, μμ) + jets background    Jet smearing method:

- Goal: estimate instrumental background from mismeasured jets which lead to high fake $E_T^{miss}$

- Its contribution in the SRs is estimated from data using the "jet -smearing" method: use well reconstructed jets in low-$E_T^{miss}$ Z events to estimate acceptance in SR of poorly measured jets.



1. Select seed events: low $E_T^{miss}$ significance and high jet multiplicity.
2. With the seed sample, generate fake $E_T^{miss}$ events ("pseudo-data") by using the calorimeter response function.
   Generate 5000 smeared events per seed event.
3. Normalize pseudo-data $E_T^{miss}$ distribution to data in region $0 \text{ GeV} < E_T^{miss} < 40 \text{ GeV}$
4. Validate the smeared data in VRs

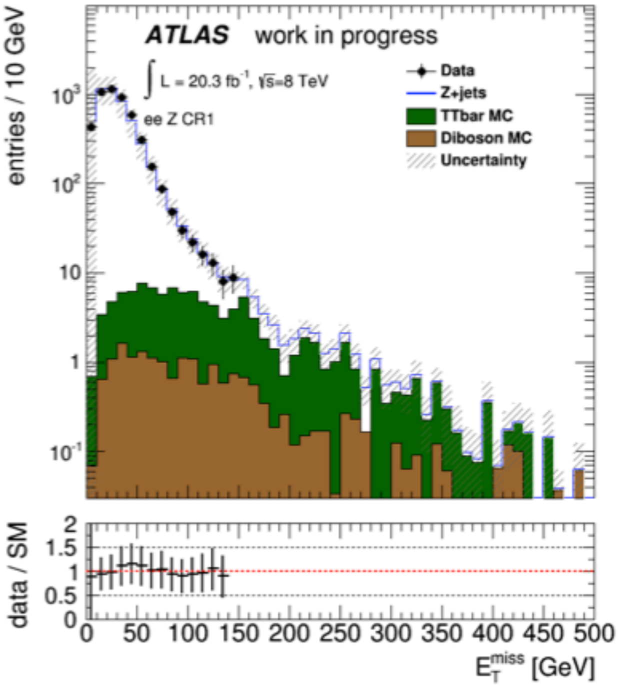
# Background Estimation

## Z (ee, μμ) + jets background

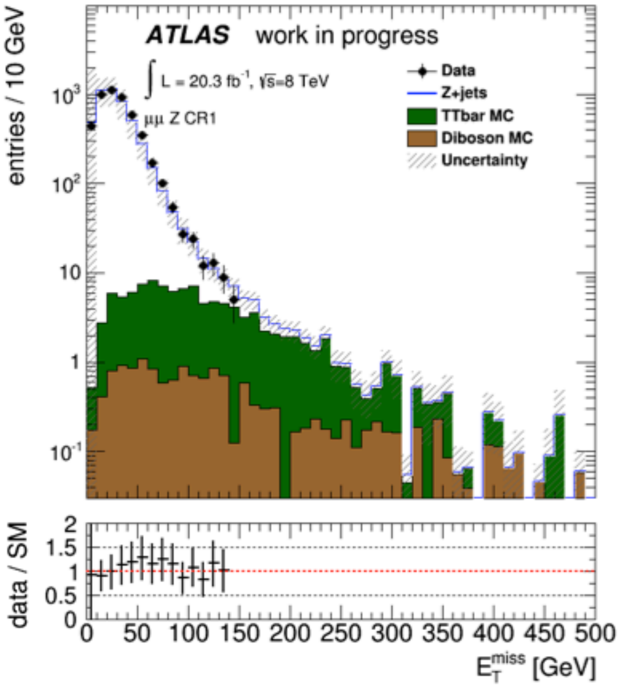
## Jet smearing method:

- **Validation Region 1: $N_{jets} > 1$, $H_T > 600$, $E_T^{miss} < 150$:**
    - Background estimation agrees with data

electron channel



muon channel



### Estimation in SRs

| **Signal Region** | **No. Smeared Events** |
|---|---|
| SR1ee | 1.08 ± 0.40 |
| SR1μμ | 0.54 ± 0.19 |
| SR2ee | 1.46 ± 0.45 |
| SR2μμ | 1.23 ± 0.29 |
| SR3ee | 3.88 ± 1.28 |
| SR3μμ | 3.80 ± 0.75 |

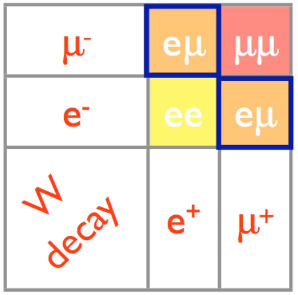
# Background Estimation

## WW, ttbar, Wt, Z(ττ) background

## Flavour-Symmetric method:

- Basic idea of method: flavor symmetric background ($t\bar{t}$, WW, Wt, $\tau\tau$) fulfill the relation

$$\text{ee} : \mu\mu : \text{e}\mu = 1 : 1 : 2$$



| | | |
|---|---|---|
| $\mu^-$ | e$\mu$ | $\mu\mu$ |
| $e^-$ | ee | e$\mu$ |
| W decay | $e^+$ | $\mu^+$ |

- Use e-$\mu$ events to get estimate for ee and $\mu\mu$ regions:

$$N_{ee}^{\text{est.}} = \frac{1}{2} N_{e\mu}\, k_{ee}\, \alpha$$

$$N_{\mu\mu}^{\text{est.}} = \frac{1}{2} N_{e\mu}\, k_{\mu\mu}\, \alpha$$

- $k_{ee}, k_{\mu\mu}$ account for different reconstruction efficiencies for electron and muons and are calulated in control regions:

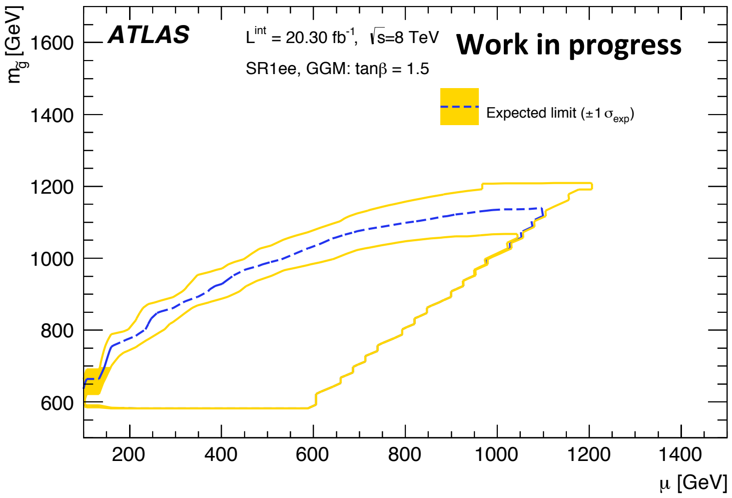
$$k_{ee} = \sqrt{\frac{N_{ee}^{\text{CR}}}{N_{\mu\mu}^{\text{CR}}}}, \qquad k_{\mu\mu} = \sqrt{\frac{N_{\mu\mu}^{\text{CR}}}{N_{ee}^{\text{CR}}}}$$

- New: additional factor $\alpha$ necessary to account for efficiency of dilepton triggers:

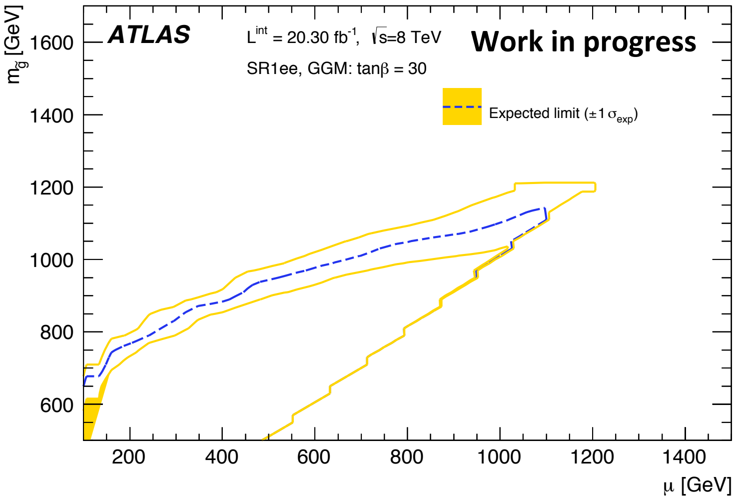
$$\alpha = \frac{\sqrt{\epsilon_{ee}^{\text{trig}} \epsilon_{\mu\mu}^{\text{trig}}}}{\epsilon_{e\mu}^{\text{trig}}}$$

# Expected Reach

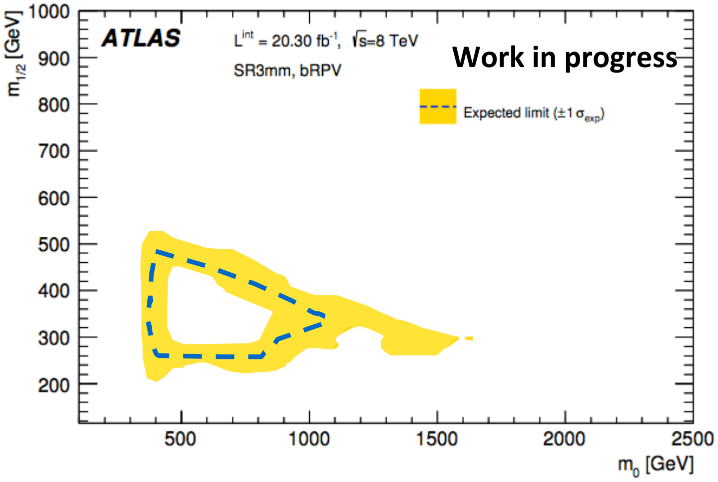
## GGM tanß = 1.5 ee channel



## GGM tanß = 30 ee channel



## bRPV μμ channel



# Summary

- Z(ll) + jets + EtMiss analysis ongoing
- Update, including the whole 2012 dataset, of previous analysis ATLAS-CONF-2012-152
- Good sensitivity for two very different SUSY models:
  - GGM
  - bRPV

- The main backgrounds in the SRs are estimated with data-driven methods. Preliminary results show good agreement between data and estimates in CRs and VRs.

- The analysis is currently in its final states

- Results are expected very soon:

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

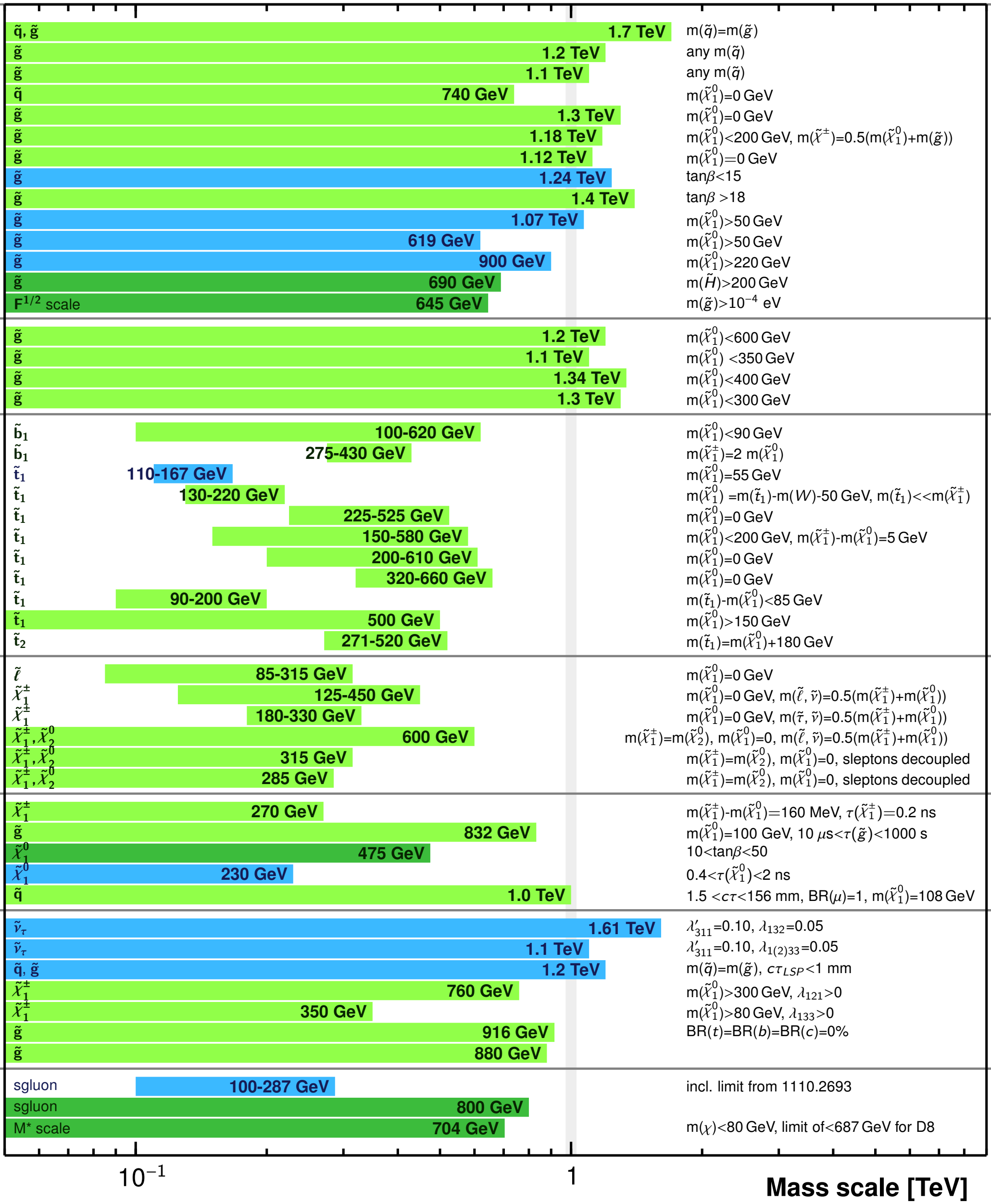
# BACKUP

# ATLAS SUSY Searches* - 95% CL Lower Limits

*Status: SUSY 2013*

***ATLAS*** Preliminary

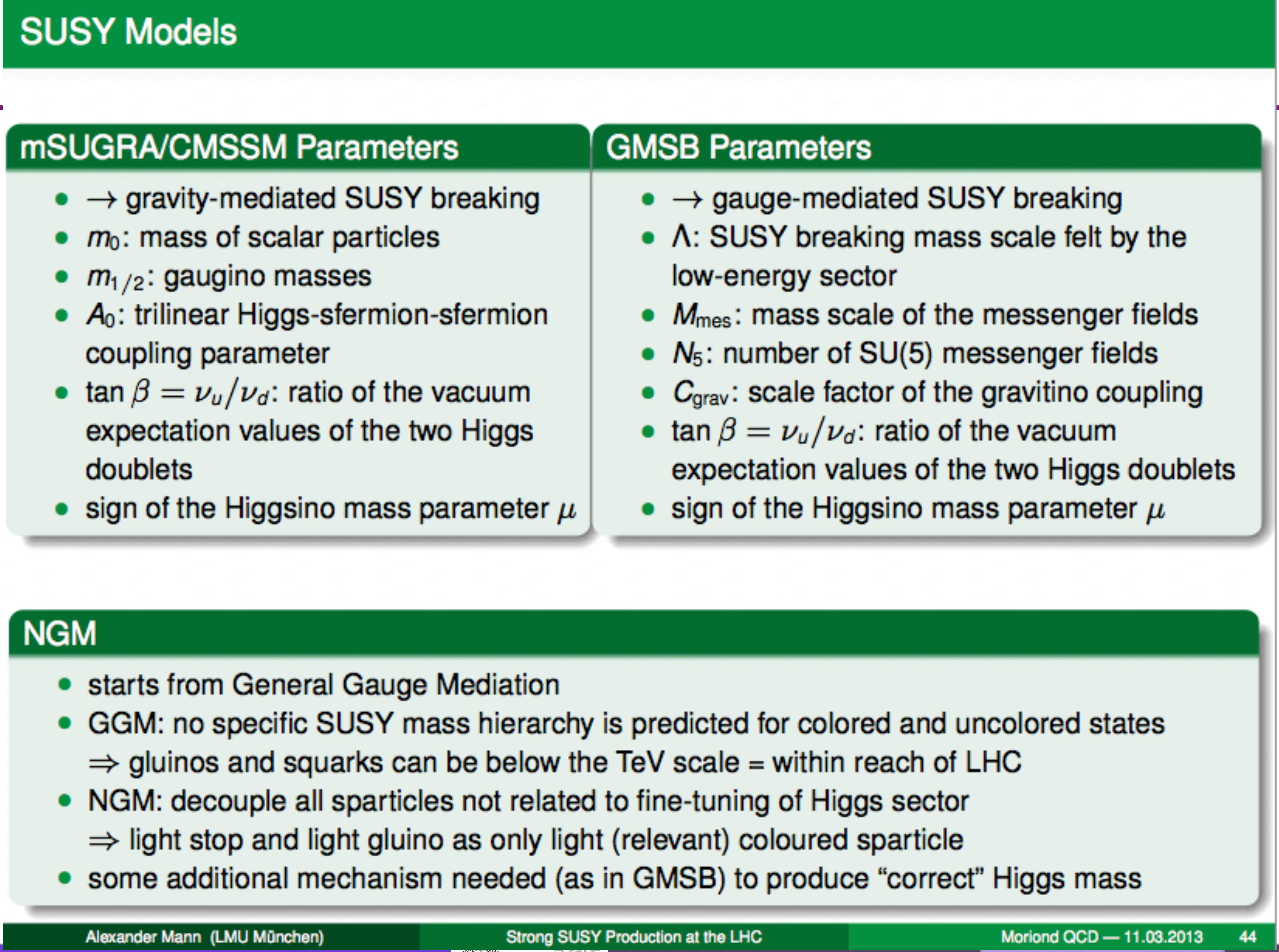
$\int \mathcal{L}\, dt = (4.6 - 22.9)\ \mathrm{fb}^{-1}$  $\sqrt{s} = 7,\ 8$ TeV



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

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

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



# SUSY Models

## mSUGRA/CMSSM Parameters

- → gravity-mediated SUSY breaking
- $m_0$: mass of scalar particles
- $m_{1/2}$: gaugino masses
- $A_0$: trilinear Higgs-sfermion-sfermion coupling parameter
- $\tan\beta = \nu_u/\nu_d$: ratio of the vacuum expectation values of the two Higgs doublets
- sign of the Higgsino mass parameter $\mu$

## GMSB Parameters

- → gauge-mediated SUSY breaking
- Λ: SUSY breaking mass scale felt by the low-energy sector
- $M_{\text{mes}}$: mass scale of the messenger fields
- $N_5$: number of SU(5) messenger fields
- $C_{\text{grav}}$: scale factor of the gravitino coupling
- $\tan\beta = \nu_u/\nu_d$: ratio of the vacuum expectation values of the two Higgs doublets
- sign of the Higgsino mass parameter $\mu$

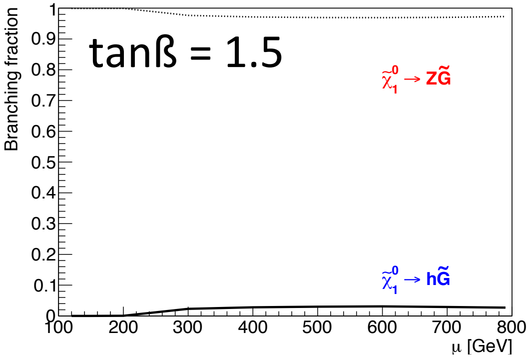
## NGM

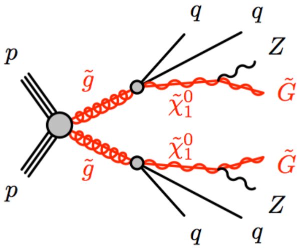
- starts from General Gauge Mediation
- GGM: no specific SUSY mass hierarchy is predicted for colored and uncolored states
  ⇒ gluinos and squarks can be below the TeV scale = within reach of LHC
- NGM: decouple all sparticles not related to fine-tuning of Higgs sector
  ⇒ light stop and light gluino as only light (relevant) coloured sparticle
- some additional mechanism needed (as in GMSB) to produce "correct" Higgs mass

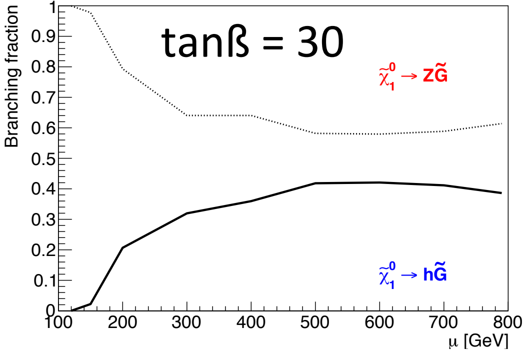
Alexander Mann (LMU München) | Strong SUSY Production at the LHC | Moriond QCD — 11.03.2013 | 44

# Target models

- **General Gauge Mediation (GGM)**
  - RPC model
  - LSP always the gravitino (escapes detection => $E_T^{miss}$)
  - Phenomenology depends on NLSP (next to lightest SUSY particle): $\tilde{\chi}_1^0$ for most of the parameter space
  - **This analysis:**
    - $\tilde{\chi}_1^0$ higgsino-like
    - Parameters: $M_1 = M_2 =$ 1TeV, $c\tau_{NLSP} <$ 0.1 mm; **$m_{gluino}$ and μ: free parameters**; all other sparticle masses ≈ 1.5
    - Two grids studied:
      - tanß = 1.5: $\tilde{\chi}_1^0 \rightarrow Z\tilde{G}$
      - tanß = 30 : $\left\{ \begin{array}{l} \tilde{\chi}_1^0 \rightarrow Z\tilde{G} \\ \tilde{\chi}_1^0 \rightarrow h\tilde{G} \end{array} \right.$







# Results

**GGM**

## Z(ll) + jets + EtMiss

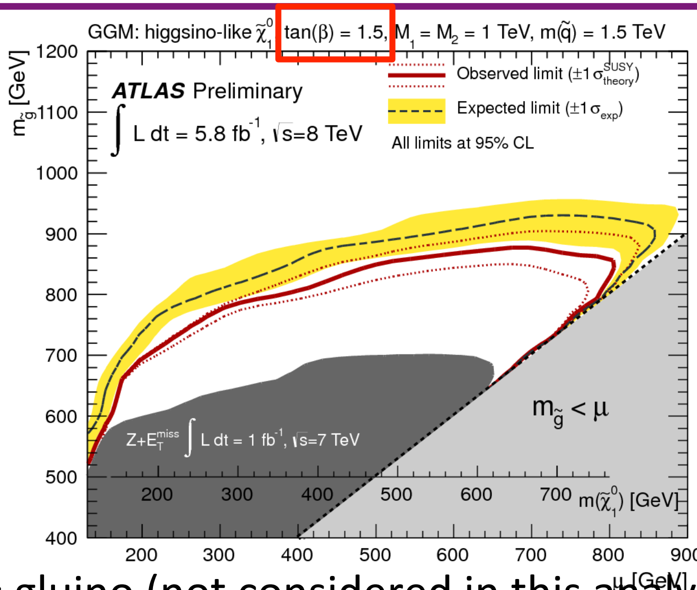
**GGM** (General Gauge Mediation)

M1 and M2 ➔ bino mass and wino mass

m(gluino) ➔ gluino mass

μ ➔ higgsino mass

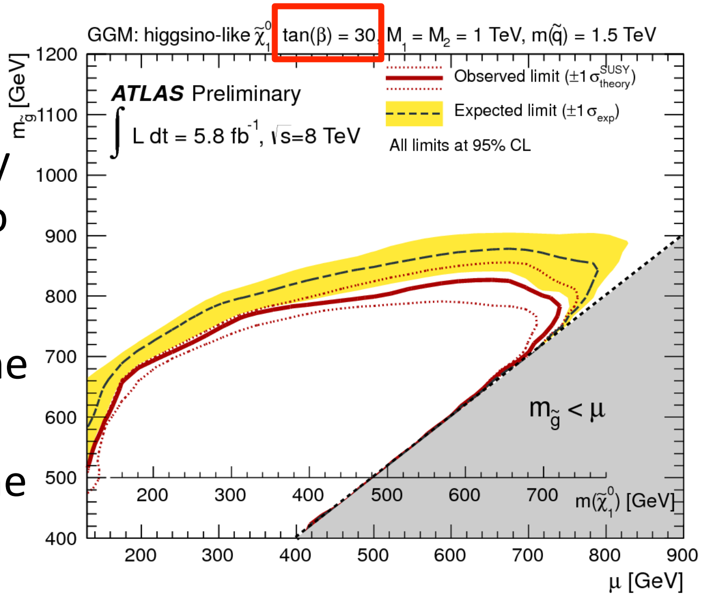
tanß ➔ ratio of the vacuum expectation values of the two Higgs doublets



▨ NLSP = gluino (not considered in this analysis)

Choice of parameters for this analysis implies:

- **LSP = gravitino**
- **NLSP = Higgsino-like lightest neutralino**
- NLSP decay length $c\tau_{NLSP}$ = 0.1 mm
- 2 different GGM grids
  - tanß=1.5 => NLSP -> Z + Gravitino dominant decay
  - tanß=30 => NLSP-> h + Gravitino and Z + Gravitino



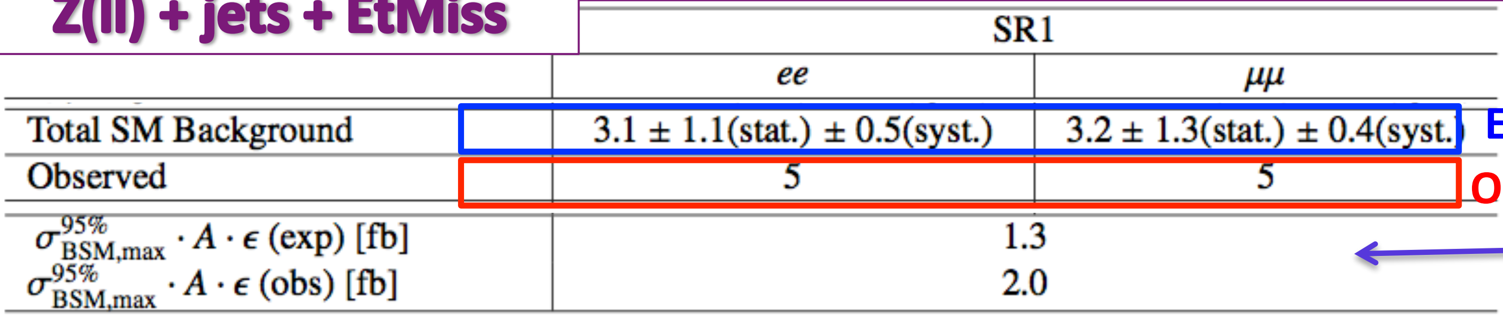
**Exclusion limits:**

- tanß = 1.5 => m(gluino) up to 680 – 880 GeV for μ in the range 180-800 GeV
- tanß = 30 => m(gluino) up to 680 – 820 GeV for μ in the range 180-740 GeV

√s = 8 TeV
L = 5.8 fb$^{-1}$

# Results

## Z(ll) + jets + EtMiss

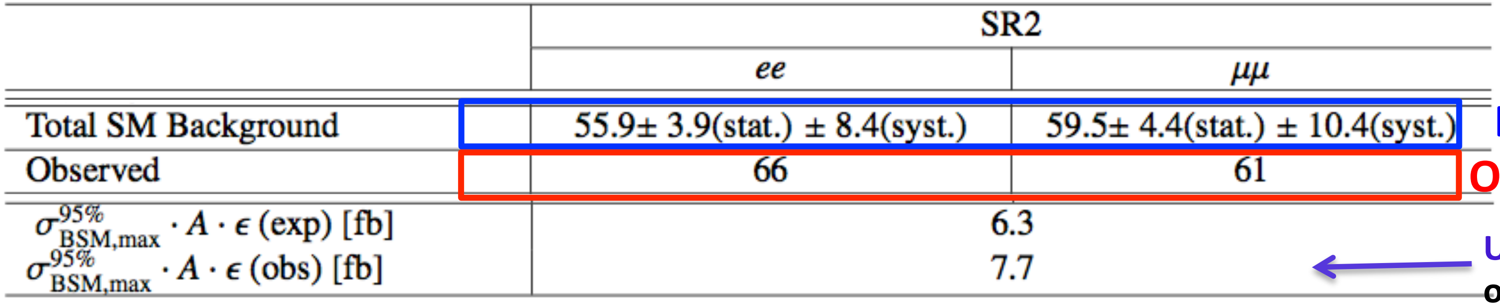


| | SR1 | |
|---|---|---|
| | *ee* | $\mu\mu$ |
| Total SM Background | 3.1 ± 1.1(stat.) ± 0.5(syst.) | 3.2 ± 1.3(stat.) ± 0.4(syst.) |
| Observed | 5 | 5 |
| $\sigma^{95\%}_{\mathrm{BSM,max}} \cdot A \cdot \epsilon$ (exp) [fb] | 1.3 | |
| $\sigma^{95\%}_{\mathrm{BSM,max}} \cdot A \cdot \epsilon$ (obs) [fb] | 2.0 | |

**Expected bkg events**

**Observed data events**

**Upper limits on visible cross sections from models of physics beyond the SM**

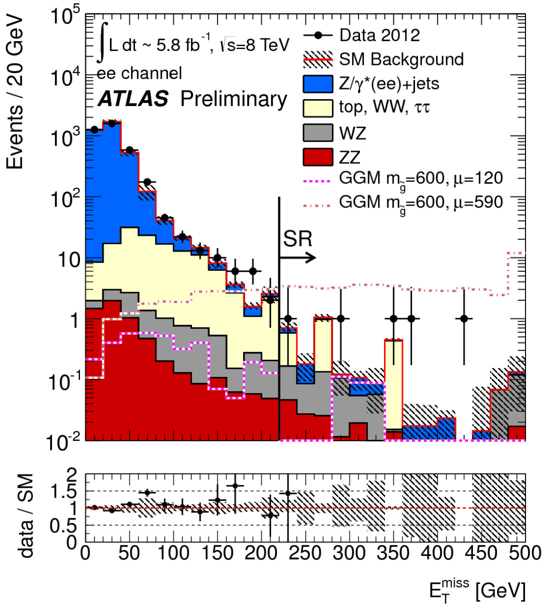


| | SR2 | |
|---|---|---|
| | *ee* | $\mu\mu$ |
| Total SM Background | 55.9± 3.9(stat.) ± 8.4(syst.) | 59.5± 4.4(stat.) ± 10.4(syst.) |
| Observed | 66 | 61 |
| $\sigma^{95\%}_{\mathrm{BSM,max}} \cdot A \cdot \epsilon$ (exp) [fb] | 6.3 | |
| $\sigma^{95\%}_{\mathrm{BSM,max}} \cdot A \cdot \epsilon$ (obs) [fb] | 7.7 | |

**Expected bkg events**

**Observed data events**

**Upper limits on visible cross sections from models of physics beyond the SM**

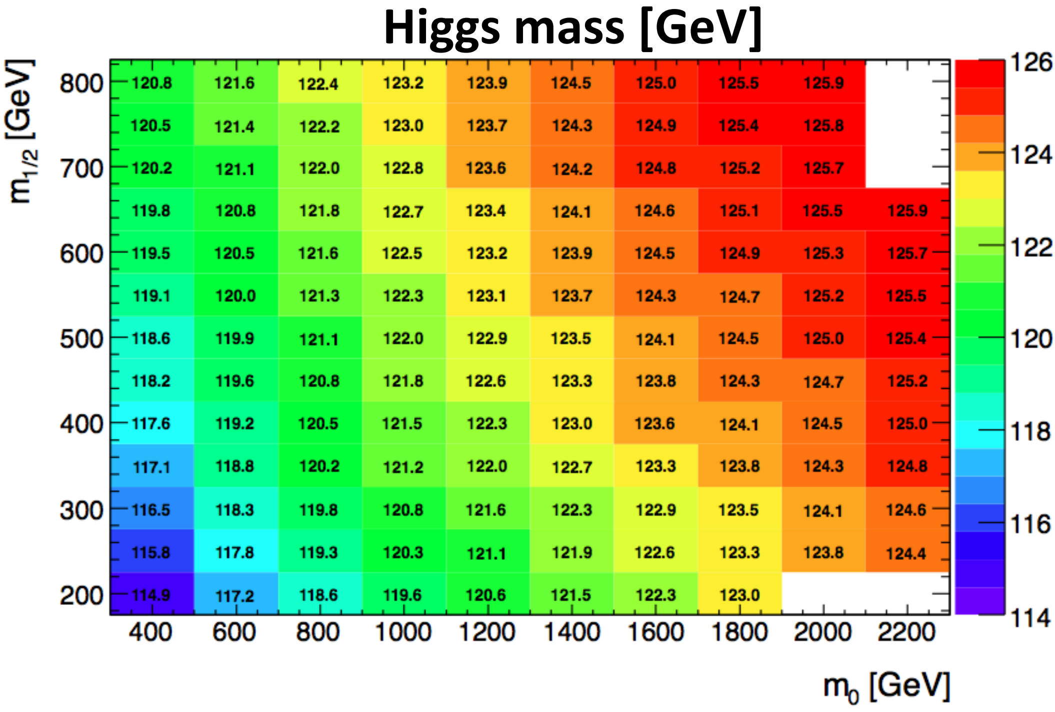


**SR1 ee**

**NO SIGNIFICANT EXCESS IN ANY OF THE SIGNAL REGIONS**

# Theoretical Model to Probe

- **mSUGRA (minimal Supergravity) with bRPV, 5 free parameters:**
  - $m_0$ and $m_{1/2}$: scalar and gaugino masses at GUT scale
  - $A_0$: trilinear scalar coupling
  - tanβ: the ratio of the Higgs vacuum expectation values
  - sign(μ): sign of the higgsino mass parameter
- Parameter choice: **$\tan\beta = 30$, $A_0 = -2m_0$ GeV, sign( $\mu$ ) = 1**
  - LSP is the lightest neutralino
  - allows compatibility with the recent Higgs boson discovery



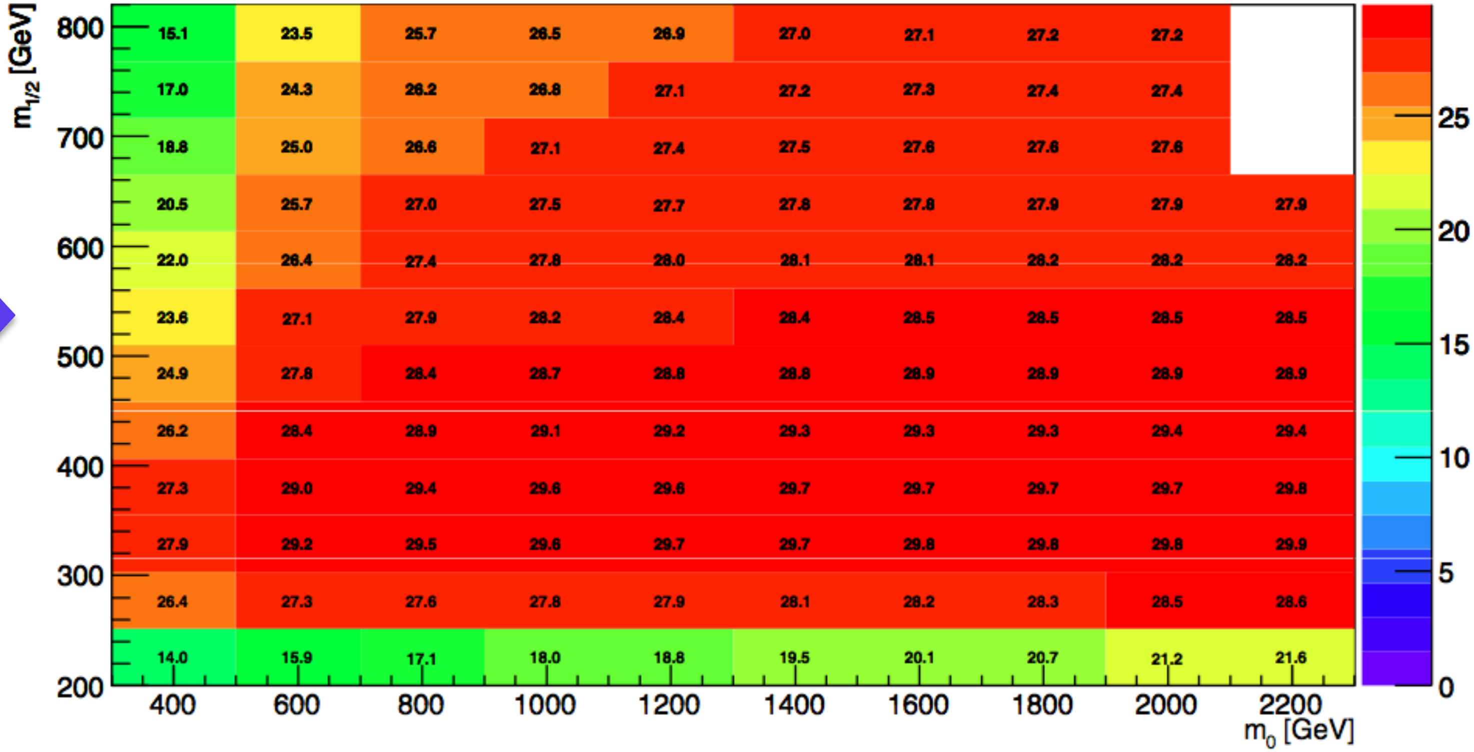
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 800 | 120.8 | 121.6 | 122.4 | 123.2 | 123.9 | 124.5 | 125.0 | 125.5 | 125.9 | |
| | 120.5 | 121.4 | 122.2 | 123.0 | 123.7 | 124.3 | 124.9 | 125.4 | 125.8 | |
| 700 | 120.2 | 121.1 | 122.0 | 122.8 | 123.6 | 124.2 | 124.8 | 125.2 | 125.7 | |
| | 119.8 | 120.8 | 121.8 | 122.7 | 123.4 | 124.1 | 124.6 | 125.1 | 125.5 | 125.9 |
| 600 | 119.5 | 120.5 | 121.6 | 122.5 | 123.2 | 123.9 | 124.5 | 124.9 | 125.3 | 125.7 |
| | 119.1 | 120.0 | 121.3 | 122.3 | 123.1 | 123.7 | 124.3 | 124.7 | 125.2 | 125.5 |
| 500 | 118.6 | 119.9 | 121.1 | 122.0 | 122.9 | 123.5 | 124.1 | 124.5 | 125.0 | 125.4 |
| | 118.2 | 119.6 | 120.8 | 121.8 | 122.6 | 123.3 | 123.8 | 124.3 | 124.7 | 125.2 |
| 400 | 117.6 | 119.2 | 120.5 | 121.5 | 122.3 | 123.0 | 123.6 | 124.1 | 124.5 | 125.0 |
| | 117.1 | 118.8 | 120.2 | 121.2 | 122.0 | 122.7 | 123.3 | 123.8 | 124.3 | 124.8 |
| 300 | 116.5 | 118.3 | 119.8 | 120.8 | 121.6 | 122.3 | 122.9 | 123.5 | 124.1 | 124.6 |
| | 115.8 | 117.8 | 119.3 | 120.3 | 121.1 | 121.9 | 122.6 | 123.3 | 123.8 | 124.4 |
| 200 | 114.9 | 117.2 | 118.6 | 119.6 | 120.6 | 121.5 | 122.3 | 123.0 | | |
| | 400 | 600 | 800 | 1000 | 1200 | 1400 | 1600 | 1800 | 2000 | 2200 |

# Z(ll) + jets + EtMiss

On-going analysis:

- using 20.7 $fb^{-1}$ (full 2012 data set) of LHC data with √s = 8 TeV
- looking for final states with a Z boson decaying to two leptons
- interpretation in the context of:
    - GGM (General Gauge Mediation)
    - mSUGRA-bRPV

BR(Neutralino_1 -> Z + nu)



| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 15.1 | 23.5 | 25.7 | 26.5 | 26.9 | 27.0 | 27.1 | 27.2 | 27.2 | |
| 17.0 | 24.3 | 26.2 | 26.8 | 27.1 | 27.2 | 27.3 | 27.4 | 27.4 | |
| 18.8 | 25.0 | 26.6 | 27.1 | 27.4 | 27.5 | 27.6 | 27.6 | 27.6 | |
| 20.5 | 25.7 | 27.0 | 27.5 | 27.7 | 27.8 | 27.8 | 27.9 | 27.9 | 27.9 |
| 22.0 | 26.4 | 27.4 | 27.8 | 28.0 | 28.1 | 28.1 | 28.2 | 28.2 | 28.2 |
| 23.6 | 27.1 | 27.9 | 28.2 | 28.4 | 28.4 | 28.5 | 28.5 | 28.5 | 28.5 |
| 24.9 | 27.8 | 28.4 | 28.7 | 28.8 | 28.8 | 28.9 | 28.9 | 28.9 | 28.9 |
| 26.2 | 28.4 | 28.9 | 29.1 | 29.2 | 29.3 | 29.3 | 29.3 | 29.4 | 29.4 |
| 27.3 | 29.0 | 29.4 | 29.6 | 29.6 | 29.7 | 29.7 | 29.7 | 29.7 | 29.8 |
| 27.9 | 29.2 | 29.5 | 29.6 | 29.7 | 29.7 | 29.8 | 29.8 | 29.8 | 29.9 |
| 26.4 | 27.3 | 27.6 | 27.8 | 27.9 | 28.1 | 28.2 | 28.3 | 28.5 | 28.6 |
| 14.0 | 15.9 | 17.1 | 18.0 | 18.8 | 19.5 | 20.1 | 20.7 | 21.2 | 21.6 |

# Overview of the Method

$N_{ee}^{est}, N_{\mu\mu}^{est} \equiv$ estimated number of events in the **ee** and **μμ** channels **from** the **WW, ttbar, Wt and tautau** processes **in the SRs**

New names in the note: **CR-DF = same cuts than in SR but for eμ channel**

$$N_{e\mu}^{data,corr} = N_{e\mu}^{data} - N_{e\mu}^{MC,sub}$$

$N_{e\mu}^{data} \equiv$ number of eμ events observed in the CR-DFs

$N_{e\mu}^{MC,sub} \equiv$ number of events from WZ, ZZ, W+jets and Z+jets estimated from MC

$$N_{ee}^{\text{est}} = \frac{1}{2} N_{e\mu}^{\text{data,corr}} \times k_{ee} \qquad k_{ee} = \sqrt{\frac{N_{ee}^{\text{data}}}{N_{\mu\mu}^{\text{data}}}}$$

$$N_{\mu\mu}^{\text{est}} = \frac{1}{2} N_{e\mu}^{\text{data,corr}} \times k_{\mu\mu} \qquad k_{\mu\mu} = \sqrt{\frac{N_{\mu\mu}^{\text{data}}}{N_{ee}^{\text{data}}}}$$

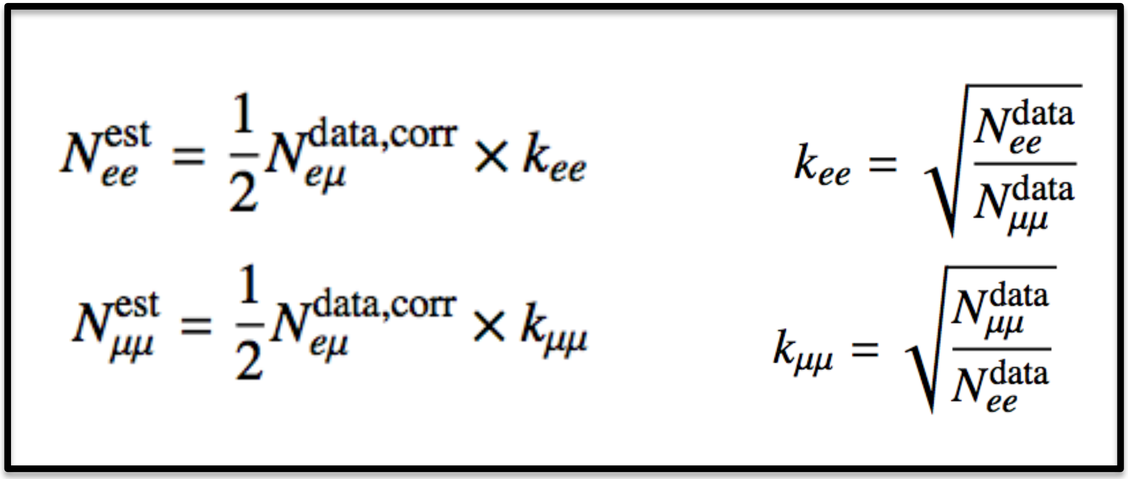
# Overview of the Method

$$k_{ee} = \sqrt{\frac{N_{ee}^{data}}{N_{\mu\mu}^{data}}}\,, \quad k_{\mu\mu} = \sqrt{\frac{N_{\mu\mu}^{data}}{N_{ee}^{data}}}$$

→ these factors take into account the differences between the electron and muon reconstruction efficiencies

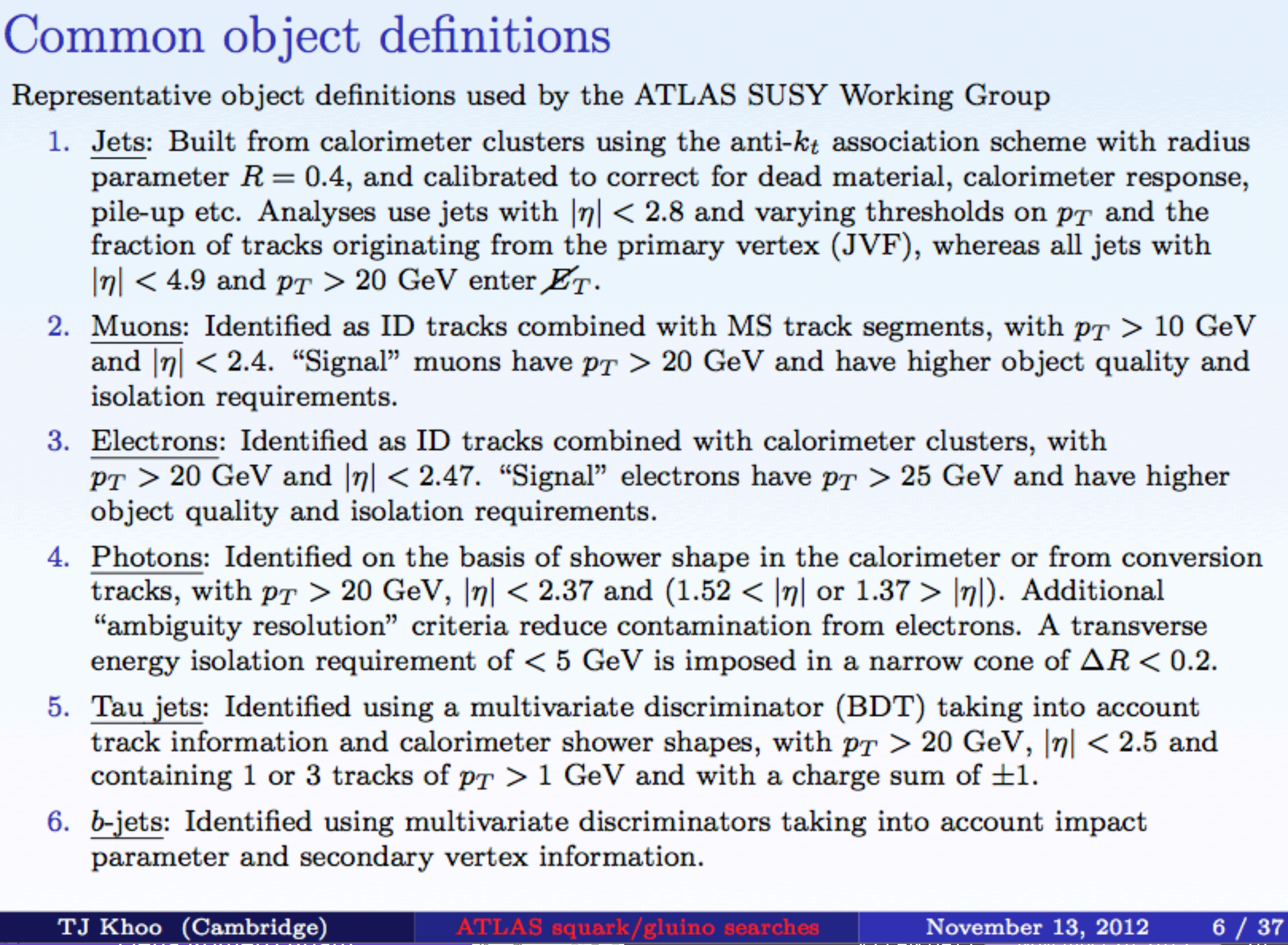
$N_{ee}^{data}, N_{\mu\mu}^{data} \equiv$ numbers of ee and μμ events from data in each of the CRs

**CRs = SRs after inverting the $E_T^{miss}$ cut**



$$N_{ee}^{\text{est}} = \frac{1}{2} N_{e\mu}^{\text{data,corr}} \times k_{ee} \qquad k_{ee} = \sqrt{\frac{N_{ee}^{\text{data}}}{N_{\mu\mu}^{\text{data}}}}$$

$$N_{\mu\mu}^{\text{est}} = \frac{1}{2} N_{e\mu}^{\text{data,corr}} \times k_{\mu\mu} \qquad k_{\mu\mu} = \sqrt{\frac{N_{\mu\mu}^{\text{data}}}{N_{ee}^{\text{data}}}}$$



# Common object definitions

Representative object definitions used by the ATLAS SUSY Working Group

1. **Jets:** Built from calorimeter clusters using the anti-$k_t$ association scheme with radius parameter $R = 0.4$, and calibrated to correct for dead material, calorimeter response, pile-up etc. Analyses use jets with $|\eta| < 2.8$ and varying thresholds on $p_T$ and the fraction of tracks originating from the primary vertex (JVF), whereas all jets with $|\eta| < 4.9$ and $p_T > 20$ GeV enter $\not{E}_T$.
2. **Muons:** Identified as ID tracks combined with MS track segments, with $p_T > 10$ GeV and $|\eta| < 2.4$. "Signal" muons have $p_T > 20$ GeV and have higher object quality and isolation requirements.
3. **Electrons:** Identified as ID tracks combined with calorimeter clusters, with $p_T > 20$ GeV and $|\eta| < 2.47$. "Signal" electrons have $p_T > 25$ GeV and have higher object quality and isolation requirements.
4. **Photons:** Identified on the basis of shower shape in the calorimeter or from conversion tracks, with $p_T > 20$ GeV, $|\eta| < 2.37$ and $(1.52 < |\eta|$ or $1.37 > |\eta|)$. Additional "ambiguity resolution" criteria reduce contamination from electrons. A transverse energy isolation requirement of $< 5$ GeV is imposed in a narrow cone of $\Delta R < 0.2$.
5. **Tau jets:** Identified using a multivariate discriminator (BDT) taking into account track information and calorimeter shower shapes, with $p_T > 20$ GeV, $|\eta| < 2.5$ and containing 1 or 3 tracks of $p_T > 1$ GeV and with a charge sum of $\pm 1$.
6. ***b*-jets:** Identified using multivariate discriminators taking into account impact parameter and secondary vertex information.

# Background Estimation

## Z + jets background

**Jet smearing method:**

**SM backgrounds:**
- QCD and inclusive W+jets
- WZ, ZZ
- top, WW, Z(ττ); top = ttbar + Wt
- **Z + jets**

**Signal: Z + jets + EtMiss** → from LSP

**(Instrumental) bkg: Z + jets + fake Etmiss** → from mis-measurement of jets

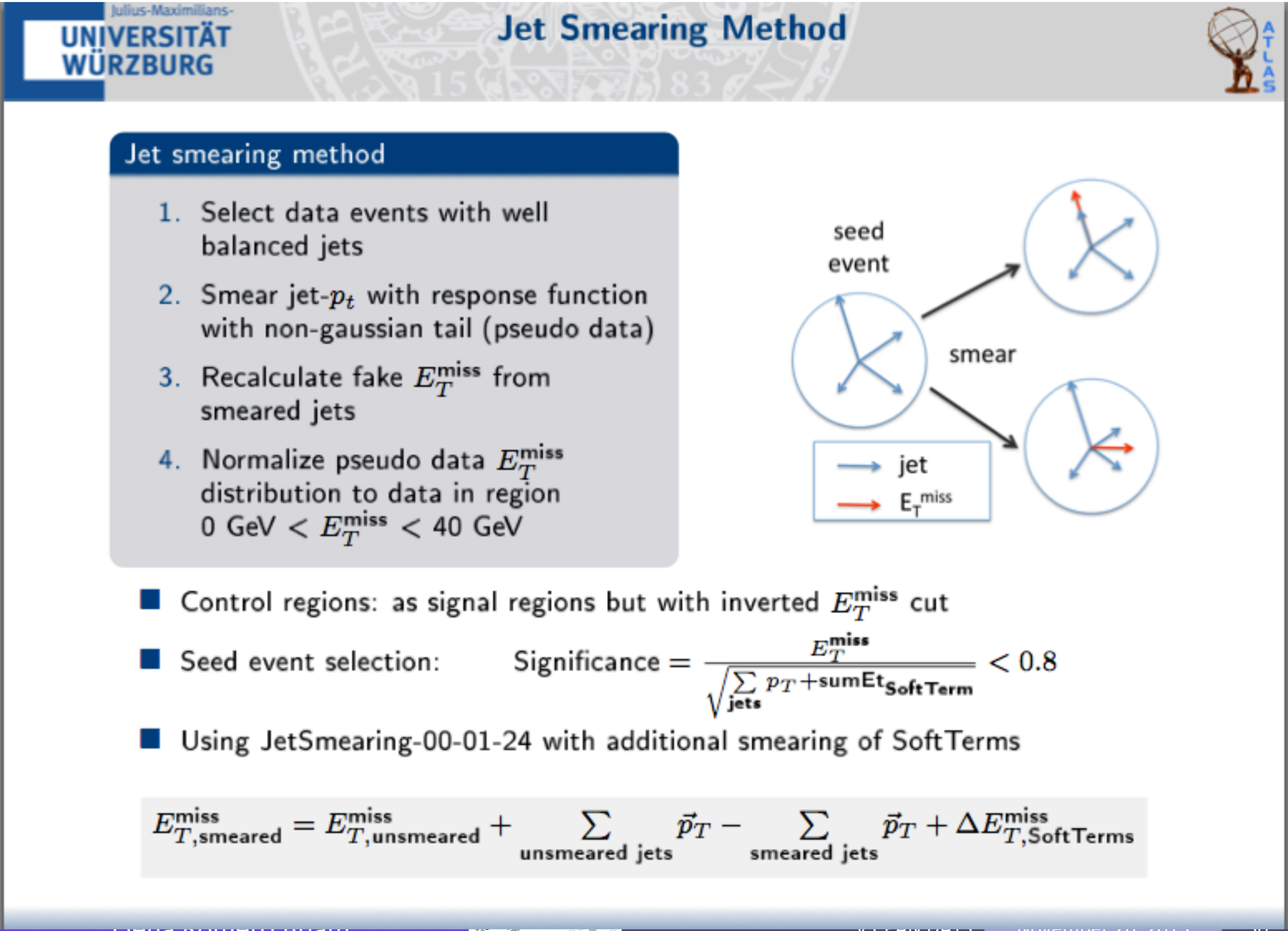
Estimating number of events in SR with high fake Etmiss ⇨ Estimating of number of Z + jets bkg events in SR

**How** do we estimate the number of events with high fake EtMiss?

**SEED REGION** × **RESPONSE FUNCTION** = **PSEUDO-DATA**

| **SEED REGION** | × | **RESPONSE FUNCTION** | = | **PSEUDO-DATA** |
|---|---|---|---|---|
| region with well measured jets => low EtMiss region | | modeling the response of the calorimeters | | simulation of events with no real EtMiss after passing throught the calorimeter |

Applying SR cuts to pseudo-data => Estimation of number of Z + jets bkg events in SR



# Jet Smearing Method

**Jet smearing method**

1. Select data events with well balanced jets
2. Smear jet-$p_t$ with response function with non-gaussian tail (pseudo data)
3. Recalculate fake $E_T^{\text{miss}}$ from smeared jets
4. Normalize pseudo data $E_T^{\text{miss}}$ distribution to data in region 0 GeV $< E_T^{\text{miss}} <$ 40 GeV

- Control regions: as signal regions but with inverted $E_T^{\text{miss}}$ cut
- Seed event selection: Significance $= \frac{E_T^{\text{miss}}}{\sqrt{\sum_{\text{jets}} p_T + \text{sumEt}_{\text{SoftTerm}}}} < 0.8$
- Using JetSmearing-00-01-24 with additional smearing of SoftTerms

$$E^{\text{miss}}_{T,\text{smeared}} = E^{\text{miss}}_{T,\text{unsmeared}} + \sum_{\text{unsmeared jets}} \vec{p}_T - \sum_{\text{smeared jets}} \vec{p}_T + \Delta E^{\text{miss}}_{T,\text{SoftTerms}}$$

# bRPV Phenomenology

- Model that we consider:
  - LSP = lightest neutralino
  - minimal Supergravity (mSUGRA): 5 parameters
    - m0, m1/2: scalar and gaugino masses at GUT scale
    - A0: trilinear scalar coupling
    - tanβ: ratio of Higgs vacuum expectation values
    - sign(μ): sign of the higgsino mass parameter

# bRPV

- R-Parity is violated through bilinear terms in the superpotential:

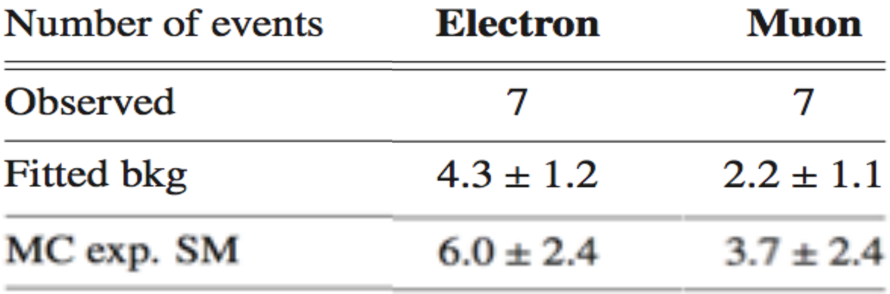
- The new terms in $W_{\text{bRPV}} = W_{\text{MSSM}} + \epsilon_i L_i H_u$ trinos and neutralinos:
  - Explanation for neutrino masses and mixings
  - Connection between neutrino parameters and neutralino decays:

- Hence, bRPV $\tan^2\theta_{23} \approx \frac{\text{BR}(\tilde{\chi}_1^0 \to \mu^\pm + W^\mp)}{\text{BR}(\tilde{\chi}_1^0 \to \tau^\pm + W^\mp)}$ to be consistent with constraints from neutrino experiments

# 1 lepton + ≥ 7 jets + EtMiss

- Analysis performed using **4.7 fb$^{-1}$** of 2011 collision data at **√s = 7 TeV**
- **Signal Region:** Exactly one isolated electron or muon + ≥ 7 jets + missing transverse energy

## RESULTS



| Number of events | **Electron** | **Muon** |
|---|---|---|
| Observed | 7 | 7 |
| Fitted bkg | 4.3 ± 1.2 | 2.2 ± 1.1 |
| MC exp. SM | 6.0 ± 2.4 | 3.7 ± 2.4 |

- Observed excess compatible with SM with ~ 2 σ

Muon: $p_0 = 0.0186$ sigma = 2.083
Electron: $p_0 = 0.132$ sigma = 1.12
Combined: $p_0 = 0.0189$ sigma = 2.077

# Results

**mSUGRA/cMSSM**

1τ analysis

**yellow band** ➔ 1σ statistical and systematic uncertainties on the expected background

**dashed red lines** ➔ influence of the theoretical uncertainties on the signal cross section on the limit