# Fitting MMAMSB at the LHC

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# Outline



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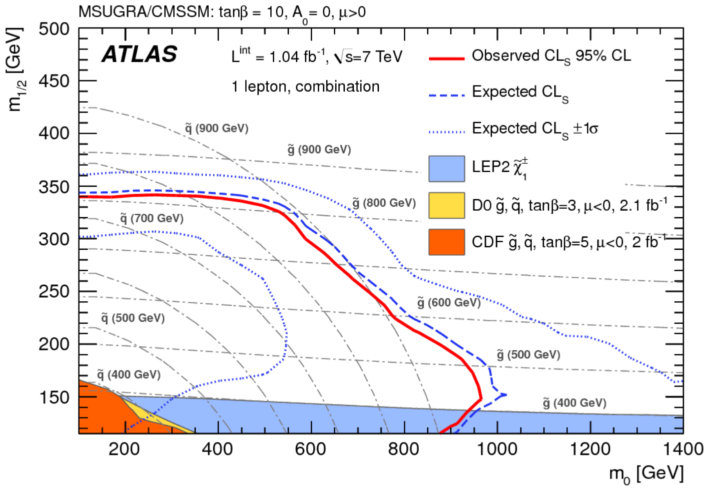
# SUSY at the LHC




The LHC has taken a big bite out of SUSY parameter space.

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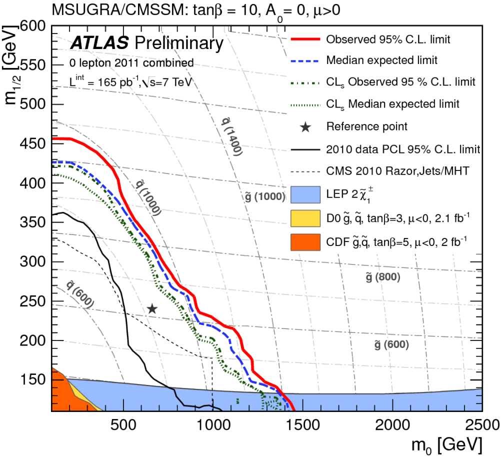
# SUSY at the LHC

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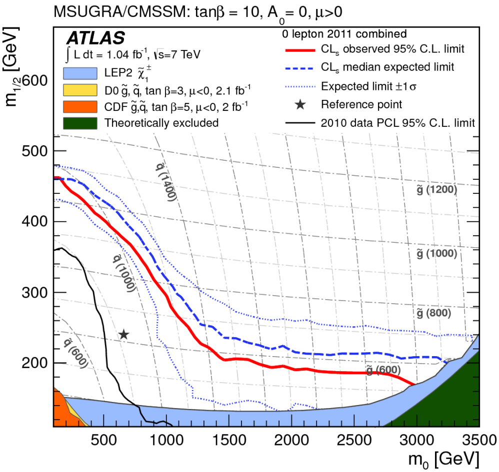
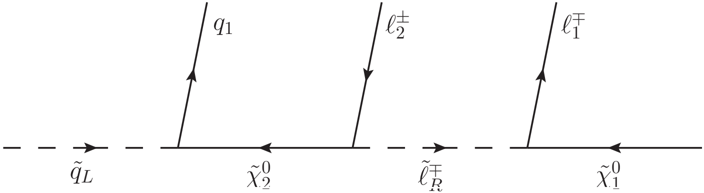
# SUSY at the LHC



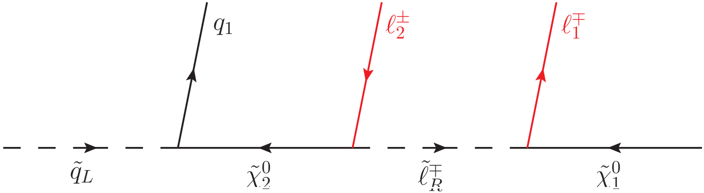

The LHC has taken a big bite out of SUSY parameter space.

# Jets (and/or leptons) + $E_T^{\text{miss}}$




The strongest constraints come from multi-jet (perhaps with leptons) and missing energy events, which come from squark and gluino production followed by (possibly long) decay chains.

# Jets (and/or leptons) + $E_T^{\text{miss}}$

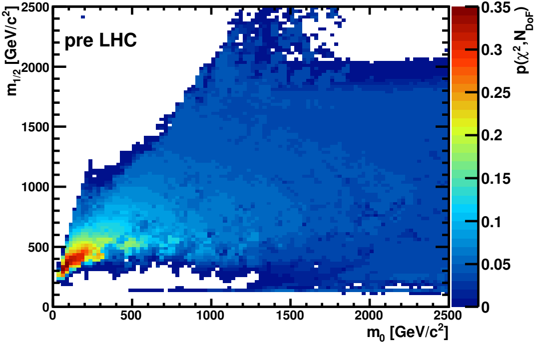



These events also provide mass measurements via kinematical endpoints like:

$$\left(m_{\ell\ell}{}^2\right)^{\text{edge}} = \frac{\left(m^2_{\tilde{\chi}_2^0} - m^2_{\tilde{\ell}_R}\right)\left(m^2_{\tilde{\ell}_R} - m^2_{\tilde{\chi}_1^0}\right)}{m^2_{\tilde{\ell}_R}}$$

# SUSY Fits

These measurements (and others) can be used as inputs into a parameter fit.




[Buchmueller, Cavanaugh, De Roeck, Dolan, Ellis, Flacher, Heinemeyer, Isidori, Martinez Santos, Olive, Rogerson, Ronga & Weiglein 1110.3568]

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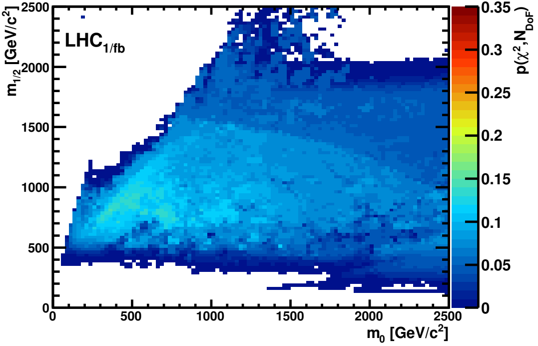


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# SUSY Fits

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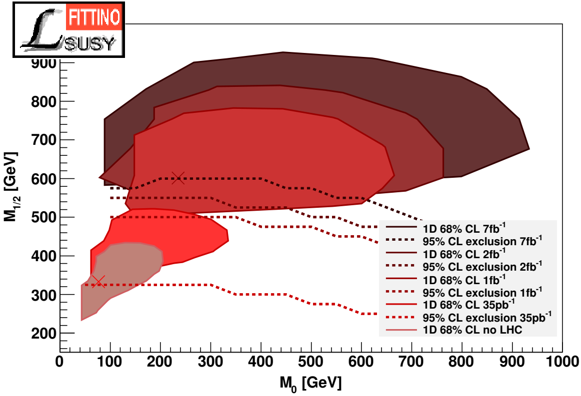


[Bechtle, Desch, Dreiner, Kramer, O'Leary, Robens, Sarrazin & Wienemann 1105.5398]

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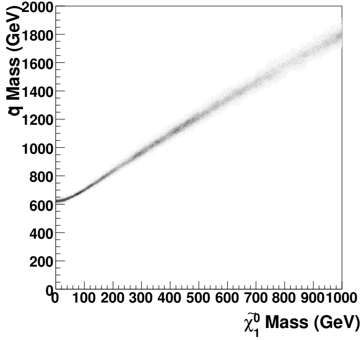
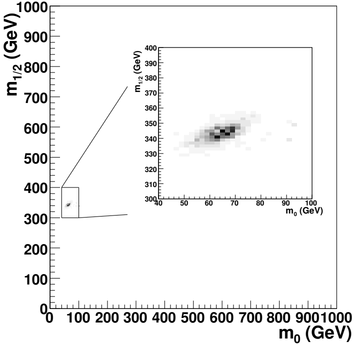
# Including cross sections with standard Monte Carlo

Kinematical edges only:




[Lester, Parker & White hep-ph/0508143]

Including cross sections:

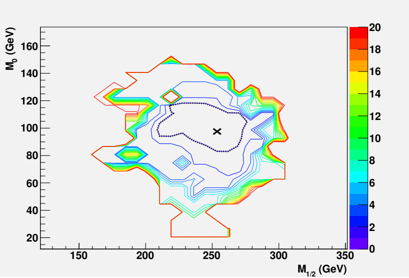



Cross sections can drastically improve fit results. Unfortunately, when estimated by generating events with standard tools, cross sections are very costly to compute.

# Including cross sections in fits the fast way

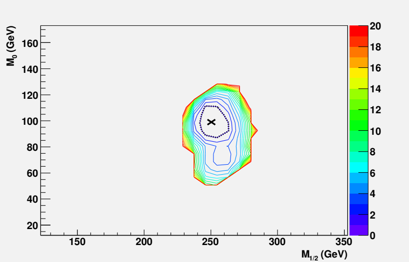
Recently, a technique was developed to estimate cross sections as quickly as kinematical endpoints.

Kinematical edges only:




[Dreiner, Krämer, Lindert & O'Leary 1003.2648]

Including cross sections:



# Which high scale model do we fit to?

There are many common SUSY breaking scenarios. Which one should we fit? Can fit tell us if we've chosen the wrong one?

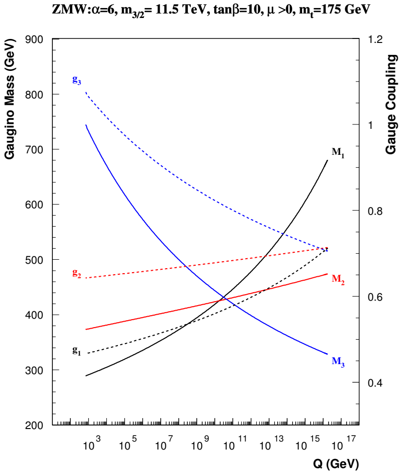
| Model | parameters | $\chi^2$/d.o.f | $p-$value |
|---|---|---|---|
| CMSSM | $m_0 = 92.1$ GeV, $m_{1/2} = 300.6$ GeV<br>$A_0 = 984$ GeV, $\tan\beta = 12.3$ | $0.22/1$ | 0.64 |
| mAMSB | $m_{aux} = 28.46$ TeV, $m_0 = 255.5$ GeV<br>$\tan\beta = 22.4$ | $52/2$ | $< 10^{-10}$ |
| mGMSB | $M_{mess} = 1.0\ 10^{14}$ GeV, $\Lambda = 1.78\ 10^4$ GeV<br>$N_5 = 5$, $\tan\beta = 22.2$ | 0.36/2 | 0.83 |
| LVS | $m_0 = 359$ GeV, $\tan\beta = 4.75$ | 44.2/3 | $1.4 \times 10^{-9}$ |

[Allanach & Dolan 1107.2856 — SUSY with prejudice]

Maybe, maybe not.

# Mixed modulus-anomaly mediated SUSY breaking (MMAMSB)

- Significant gravity (modulus) and anomaly mediation contributions
- Gaugino masses appear to unify at intermediate scale ("mirage" mediation)
- Can be realized in KKLT-type string models [Kachru, Kallosh, Linde & Trivedi hep-th/0301240]
- Alleviates gravitino and moduli decay problems




[Baer, Park, Tata, & Wang hep-ph/0604253]

# Fitting MMAMSB at the LHC

Our goal here is to see if we can use prospective LHC measurements to perform a fit to MMAMSB and measure the parameters of the model. We would like to answer:

- How well can the MMAMSB parameters be determined using LHC measurements?
- Can the MMAMSB be distinguished from other SUSY breaking scenarios?
- Does including cross sections help address these questions?

# Outline

# MMAMSB: parameters and soft SUSY breaking terms

$$
\begin{aligned}
M_a &= \frac{m_{3/2}}{16\pi^2}[\alpha + b_a g_a^2], \\
A_{ijk} &= \frac{m_{3/2}}{16\pi^2}[(n_i + n_j + n_k - 3)\alpha + (\gamma_i + \gamma_j + \gamma_k)], \\
m_i^2 &= \left(\frac{m_{3/2}}{16\pi^2}\right)^2 [(1 - n_i)\alpha^2 + 4\alpha\xi_i - \dot{\gamma}_i].
\end{aligned}
$$

[Choi, Falkowski, Nilles, Olechowski & Pokorski hep-th/0411066; Choi, Jeong & Okumura hep-ph/0504037; Falkowski, Lebedev & Mambrini hep-ph/0507110]

Parameters:

- $\alpha$: interpolates between pure modulus ($\alpha \to \infty$) and pure anomaly ($\alpha \to 0$, with $\alpha m_{3/2}$ const.) breaking
- $n_i$: modular weight = 0, 1, 1/2 if $i^{\text{th}}$ matter field located on $D3$, $D7$, $D3$-$D7$ brane intersection
- $m_{3/2}$: gravitino mass
- $\tan\beta$

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# MMAMSB: parameters and soft SUSY breaking terms

$$M_a = \frac{m_{3/2}}{16\pi^2}[\alpha + b_a g_a^2],$$
$$A_{ijk} = \frac{m_{3/2}}{16\pi^2}[(n_i + n_j + n_k - 3)\alpha + (\gamma_i + \gamma_j + \gamma_k)],$$
$$m_i^2 = \left(\frac{m_{3/2}}{16\pi^2}\right)^2 [(1 - n_i)\alpha^2 + 4\alpha\xi_i - \dot{\gamma}_i].$$

[Choi, Falkowski, Nilles, Olechowski & Pokorski hep-th/0411066; Choi, Jeong & Okumura hep-ph/0504037; Falkowski, Lebedev & Mambrini hep-ph/0507110]

Constants:

- $g_a$ is the gauge coupling and $b_a$ the 1-loop beta function coefficient for the gauge group $a$
- $\gamma_i$ is the anomalous dimension, and $\dot{\gamma}_i$ the logarithmic derivative of the anomalous dimension of the $i^{\text{th}}$ matter field
- $\xi_i$ are mixed anomaly-modulus contributions

# Gaugino mass pattern

The gaugino mass pattern provides a hallmark signature of many SUSY breaking scenarios [Choi & Nilles hep-ph/0702146]

**Gravity: $M_1 : M_2 : M_3 \simeq 1 : 2 : 6$**

Also characteristic of many GMSB models as well as gaugino mediation and large volume type IIB string compactifications.

**Anomaly: $M_1 : M_2 : M_3 \simeq 3.3 : 1 : 9$**

Requires that SUSY-breaking sector is sequestered from the visible sector.

**MMAMSB: $M_1 : M_2 : M_3 \simeq (\alpha + 3.3) : (2\alpha + 1) : (6\alpha - 9)$**

Requires $\alpha$ large enough to avoid tachyonic sleptons typical of AMSB (which are solved in mAMSB with ad hoc $m_0$). KKLT predicts $\alpha = 5$.

# MMAMSB benchmark model selection

## Existing contraints must be satisfied

Dark matter density and direct detection, flavor and precision measurements, collider (LEP and early LHC) searches

## $\alpha$ in interesting range

Not too close to gravity or anomaly limits, close to KKLT-preferred value

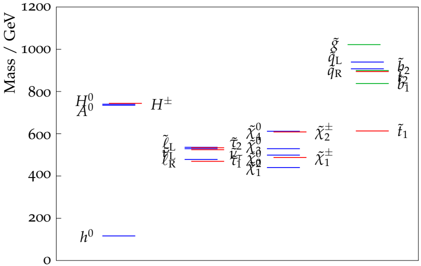
## LHC measurements must be feasible

$\tilde{q} \to q\tilde{\chi}_2^0 \to q\ell^{\pm}\tilde{\ell}_R^{\pm} \to q\ell^+\ell^-\tilde{\chi}_1^0$ decay chain must be present with sufficiently large branching ratio, mass splittings, and production cross section

# MMAMSB benchmark model parameters

- If $n_i$ same for all matter fields, then constraints require $n_i \equiv n = 1/2$.
- We choose $\tan\beta = 10$ and $\text{sign}(\mu) = +1$.
- Relic density then requires $\alpha \simeq 4.8$, $m_{3/2} \gtrsim 15$ TeV.

| Parameter | Value |
|---|---|
| $\alpha$ | 4.8 |
| $m_{3/2}$ | 21 TeV |
| $\tan\beta$ | 10 |
| $\text{sign}(\mu)$ | +1 |
| $n$ | 0.5 |




In this model, $M_1 : M_2 : M_3 \simeq 1 : 1.2 : 2.2$

# Outline

1. Introduction
2. MMAMSB
3. Fit procedure
4. Fit results

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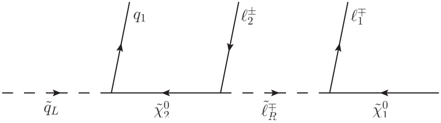
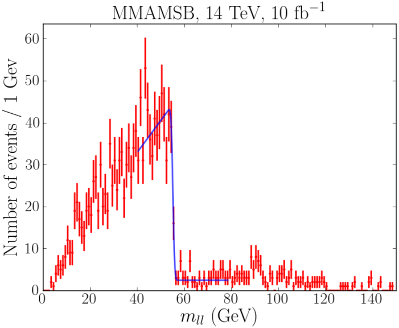
# Kinematical observables

Conventionally, the primary inputs to SUSY parameter fits have been the edges and endpoints of kinematical distributions.




$$(m_{\ell\ell}^2)^{\mathrm{edge}} = \frac{\left(m_{\tilde{\chi}_2^0}^2 - m_{\tilde{\ell}_R}^2\right)\left(m_{\tilde{\ell}_R}^2 - m_{\tilde{\chi}_1^0}^2\right)}{m_{\tilde{\ell}_R}^2}$$




In order to perform a fit using these observables, we implement MMAMSB in the fitting program `Fittino`, which efficiently samples the parameter space using Markov chain Monte Carlo.

[Bechtle, Desch, Uhlenbrock, Wienemann 0907.2589], `http://www-flc.desy.de/fittino/`

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# Our fit: "Group I" observables

This group includes standard kinematical edges built from the "golden" decay chain shown previously. These are observable already at 7 TeV and/or lower luminosity.

- $m_{\ell\ell}^{\rm max}$, the dilepton invariant mass edge
- $m_{q\ell\ell}^{\rm max}$, the jet dilepton invariant mass edge
- $m_{q\ell}^{\rm low}$, the jet-lepton low invariant mass edge
- $m_{q\ell}^{\rm high}$, the jet-lepton high invariant mass edge

[Gjelsten, Miller & Osland hep-ph/0410303]

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# Our fit: "Group II" observables

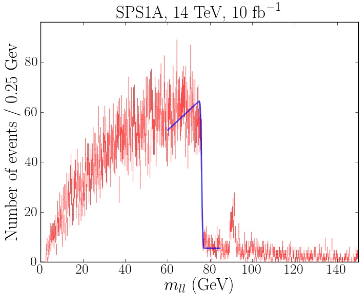
These provide additional information, e.g. on 3rd generation sparticle properties, but require 14 TeV and at least 10 $\mathrm{fb}^{-1}$.

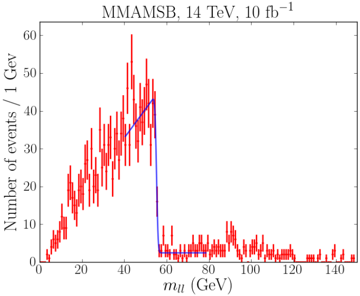
- $m_{q\ell\ell}^{\mathrm{thr}}$, the jet-dilepton threshold invariant mass edge [Gjelsten, Miller & Osland hep-ph/0410303]
- $m_{\tilde{q}}^{T2}$, the squark stransverse mass [Lester & Summers hep-ph/9906349; Barr, Lester & Stephens hep-ph/0304226]
- $m_{\tau\tau}^{\mathrm{max}}$, the di-tau invariant mass edge[a,b]
- $m_{tb}^{w}$, the weighted top-bottom invariant mass edge[b]
- $\Delta m_{\tilde{g}\tilde{\chi}_1^0}$, the mass difference between the gluino and the LSP[a,b]
- $m_{(\tilde{\chi}_4^0)\ell\ell}^{\mathrm{max}}$, the dilepton invariant mass edge from the decay of a $\tilde{\chi}_4^0$[a,b]
- $r_{\tilde{\ell}\tilde{\tau}}^{\mathrm{BR}}$, the ratio of selectron (smuon) to stau mediated $\tilde{\chi}_2^0$ decays[b]

[[a]LHC/ILC Study Group hep-ph/0410364; [b]Bechtle, Desch, Uhlenbrock, Wienemann 0907.2589]

# Estimating uncertainties

One of the most important ingredients in a fit is the uncertainty on each observable.

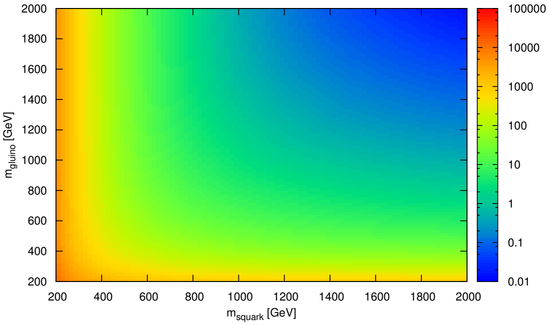



- We extrapolate the uncertainties from the thorough study of SPS1a [LHC/ILC Study Group hep-ph/0410364] to our MMAMSB model
- We checked that this is reasonable for $(m_{\ell\ell})^{\text{edge}}$ by generating events and explicitly fitting this endpoint for MMAMSB

# Rate observables

Rates are extremely sensitive to the SUSY mass scale.




[Dreiner, Krämer, Lindert & O'Leary 1003.2648]

- Including rates in the fit should improve parameter determination and model discrimination—by how much?
- We need a clever way to estimate rates quickly enough to use them in the fit.

# Observable values and uncertainties

| Observable | Nominal value | Uncertainty | | | | | |
|---|---|---|---|---|---|---|---|
| | | $10\ fb^{-1}$ 7 TeV | $1\ fb^{-1}$ 14 TeV | $10\ fb^{-1}$ 14 TeV | $100\ fb^{-1}$ 14 TeV | LES | JES |
| **Group I** | | | | | | | |
| $m_{\ell\ell}^{\max}$ | 55.45 | 6.01 | 4.25 | 1.34 | 0.43 | 0.05 | - |
| $m_{q\ell\ell}^{\max}$ | 373.4 | 70.2 | 49.6 | 15.7 | 4.96 | - | 3.7 |
| $m_{q\ell}^{\mathrm{low}}$ | 223.3 | 38.0 | 26.8 | 8.5 | 4.40 | - | 2.2 |
| $m_{q\ell}^{\mathrm{high}}$ | 311.9 | 26.0 | 18.4 | 5.8 | 4.70 | - | 3.1 |
| **Group II** | | | | | | | |
| $m_{q\ell\ell}^{\mathrm{thr}}$ | 145.5 | - | - | 29.6 | 9.37 | - | 1.5 |
| $m_{\tilde{q}}^{T2}$ | 662.0 | - | - | 28.2 | 8.91 | - | 7.0 |
| $m_{\tau\tau}^{\max}$ | 58.94 | - | - | 15.9 | 5.04 | - | 0.6 |
| $m_{tb}^{w}$ | 494.1 | - | - | 43.0 | 13.6 | - | 4.9 |
| $\Delta m_{\tilde{g}\tilde{\chi}_1^0}$ | 582.0 | - | - | 48.5 | 15.3 | - | 5.8 |
| $m_{(\tilde{\chi}_4^0)\ell\ell}^{\max}$ | 168.6 | - | - | 9.96 | 3.15 | 0.17 | - |
| $r_{\tilde{\ell}\tilde{\tau}}^{\mathrm{BR}}$ | 0.457 | - | - | 0.0114 | 0.0036 | - | - |

- Group I observables reasonably measured at 7 TeV and/or low luminosity.
- At high luminosity and 14 TeV, Group I observables are extremely accurately determined.
- Group II observables can be fairly well measured at high luminosity and 14 TeV.

# Rates: implementation

[Dreiner, Krämer, Lindert & O'Leary 1003.2648], https://github.com/b4lrog/dev_LHC-FASER

## Included channels

- $R_{jj\not{E}_T}$: two hard jets and missing energy
- $R_{\ell\ell jj\not{E}_T}$: two hard jets and missing energy with a pair of opposite sign, same flavor leptons

## Method for fast calculation of rates

- The NLO cross section for squark/gluino production is interpolated from a stored grid, generated using Prospino.

  [http://www.thphys.uni-heidelberg.de/~plehn/index.php?show=prospino&visible=tools]
- The decay table computed by a spectrum calculator is used to determine the branching ratios of the relevant decay chains.
- The acceptance–the fraction of events that passes cuts–is calculated using a novel semi-analytical technique.

# Rate observable values and uncertainties

| Observable | 7 TeV Value (fb) | 7 TeV Uncertainty | 14 TeV Value (fb) | 14 TeV Uncertainty |
|---|---|---|---|---|
| $R_{jj\not{E}_T}$ | 113 | 23 | 2780 | 556 |
| $R_{\ell\ell jj\not{E}_T}$ | 11.8 | 3.5 | 245 | 49 |

- Conservative 20% systematic uncertainty is assigned to rate estimation.
- To validate the rate estimation for MMAMSB we compare with a full simulation including parton shower and hadronization using `Herwig++` [Bahr et al. 0803.0883].

# Fit details

## MMAMSB fits

- We fit MMAMSB to our benchmark model using LHC observables (only) for 10 $fb^{-1}$ at 7 TeV and 1 $fb^{-1}$, 10 $fb^{-1}$, and 100 $fb^{-1}$ at 14 TeV.
- We start with Group I observables, and show the effect of adding Group II observables, and of adding rates.

## CMSSM and mAMSB fits

- We also try fitting two other SUSY breaking scenarios to our MMAMSB benchmark point:
  - The constrained MSSM (CMSSM)
  - Minimal anomaly mediated SUSY breaking (mAMSB)
- From these fits, we can see how well MMAMSB can be distinguished from other models.
- We will also look at the impact of the different observables, especially rates, in these fits.

# Outline



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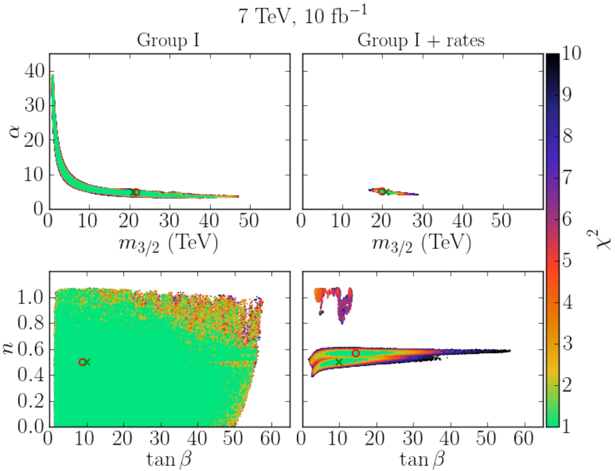
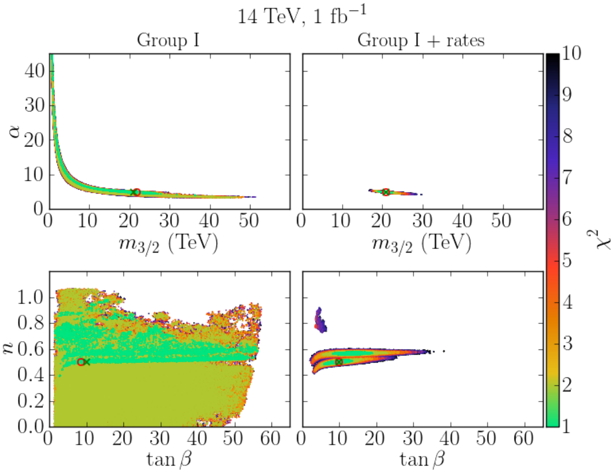
# MMAMSB: 7 TeV, 10 $fb^{-1}$, Group I observables



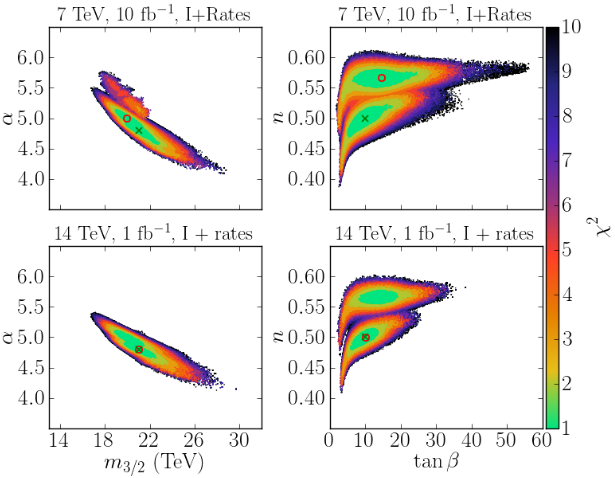

At 7 TeV, rate information necessary to have any constraint on parameter space.

# MMAMSB: 14 TeV, 1 $fb^{-1}$, Group I observables




At 14 TeV but with low luminosity, can also begin to measure parameters only if rates are included.

# Closer look at fits with rates

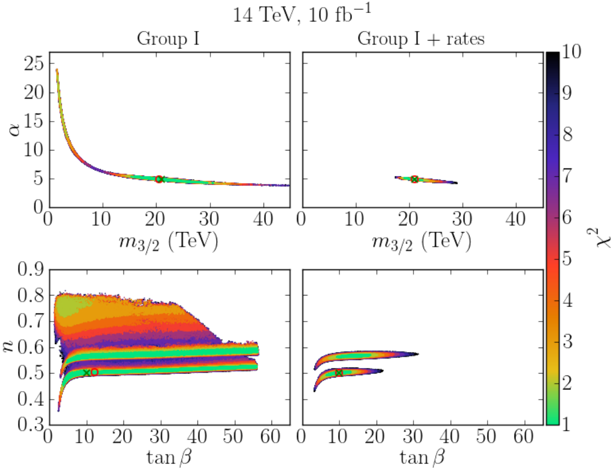



With rates, $\alpha$ and $m_{3/2}$ can be measured to within 10-15%.

# Why rates are so important

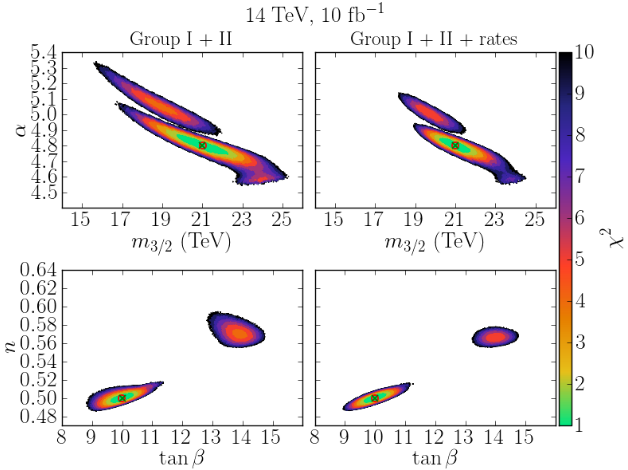
- The soft breaking terms all have leading pieces proportional to $m_{3/2}\alpha$.
- Since rates are sensitive to the absolute SUSY mass scale (unlike kinematic edges, which are sensitive to mass differences), they constrain this combination effectively.
- $n$ is also fairly well constrained, because of its contribution to the soft breaking terms.
- A measurement of $\tan\beta$, on the other hand, requires observables sensitive to third generation particles (as we will see).

# MMAMSB: 14 TeV, 10 $fb^{-1}$, Group I observables




Again, rates necessary to have a decent measurement of parameters, though some degeneracy remains. $\tan\beta$ remains especially poorly constrained.

# MMAMSB: 14 TeV, 10 fb$^{-1}$, Group I & II observables




- In Group II, $r^{\rm BR}_{\tilde{\ell}\tilde{\tau}}$ and $m_{\tau\tau}$ can measure $\tan\beta$.
- With high luminosity, Group II (esp. $m^{T2}_{\tilde{q}}$ and $m^{thr}_{qll}$) can constrain $\alpha$ and $m_{3/2}$, but rates do better.

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# Double minimum

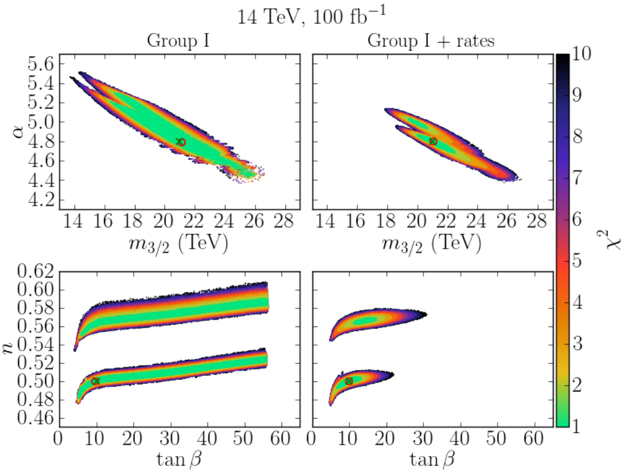
## Why a double minimum in the tan $\beta$–$n$ plane?

- Functional forms for $m_{qll}^{\max}$, $m_{ql}^{\rm low}$ and $m_{ql}^{\rm high}$ depend on mass ordering of sparticles in cascade
- In the correct minimum we have $2m_{\tilde{\ell}}^2 > m_{\tilde{\chi}_1^0}^2 + m_{\tilde{\chi}_2^0}^2 > 2m_{\tilde{\chi}_1^0}m_{\tilde{\chi}_2^0}$
- In the second minimum, order switches to $m_{\tilde{\chi}_1^0}^2 + m_{\tilde{\chi}_2^0}^2 > 2m_{\tilde{\chi}_1^0}m_{\tilde{\chi}_2^0} > 2m_{\tilde{\ell}}^2$, the functional forms change, and so different spectrum can lead to similar values of the observables.

## How to break the degeneracy?

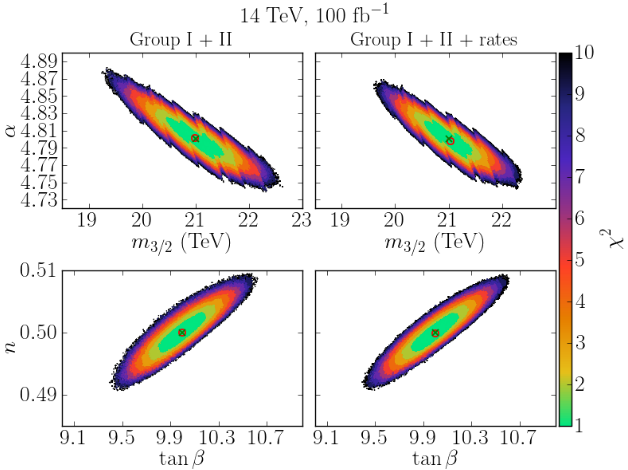
- Measure the $\tilde{\chi}_1^0$ mass accurately at a linear collider [Martyn hep-ph/0406123; Gjelsten, Miller & Osland hep-ph/0507232; JC, Dreiner & Wienemann 1110.1287]
- Measure the shape of the invariant mass distributions [Miller, Osland & Raklev hep-ph/0510356; Gjelsten, Miller, Osland & Raklev hep-ph/0611080]

# MMAMSB: 14 TeV, 100 fb$^{-1}$, Group I



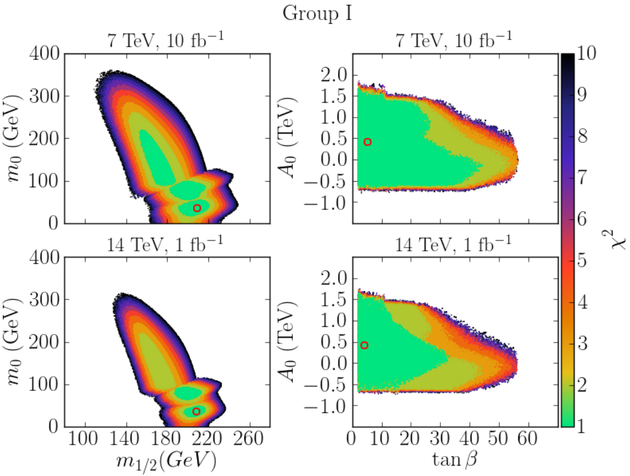

- Mass edges alone can now constrain most parameters.
- Adding rates significantly improves measurements.

# MMAMSB: 14 TeV, 100 fb$^{-1}$, Group I & II




All parameters measured to within 5%, and degeneracy broken (by $m_{\tau\tau}^{\max}$).

# CMSSM: 7 TeV, 10 fb$^{-1}$, Group I

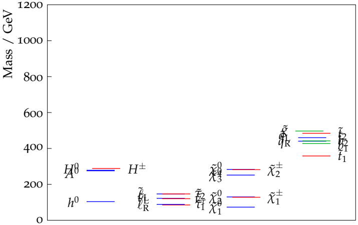



At 7 TeV, with no rate information, the CMSSM can fit our MMAMSB model well.

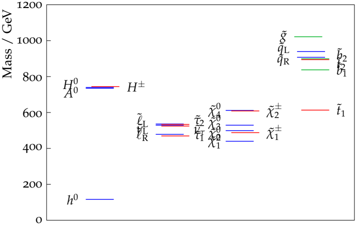
# CMSSM: 7 TeV, 10 $\text{fb}^{-1}$, adding rates

At 7 TeV, 10 $\text{fb}^{-1}$ with only Group I, CMSSM best-fit spectrum is light.

CMSSM best-fit, Group I




MMAMSB benchmark




## Adding rates leads to exclusion

- When we add rates, they try to pull mass scale up.
- Mass edges continue to prefer low mass scale.
- Tension between them yields new best-fit point with $\chi^2/\text{d.o.f.} = 216/2$!
- At best-fit point, $m_{ql}^{\text{high}}$ is 13 $\sigma$ high, while $R_{jjE_T^{\text{miss}}}$ is 5.3 $\sigma$ high.

# CMSSM: 14 TeV, 10 fb$^{-1}$

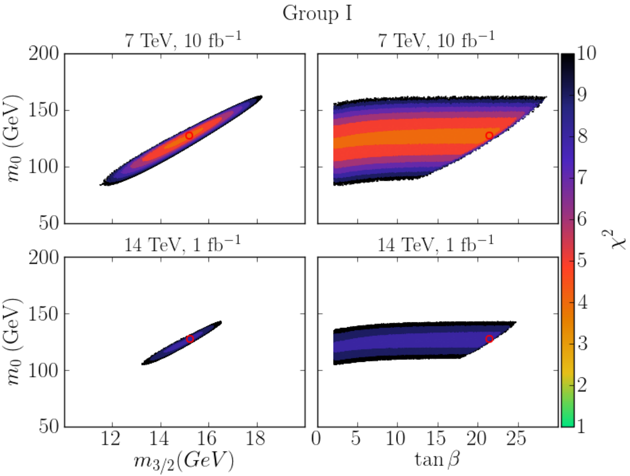
## Adding Group II excludes CMSSM

- With only Group I, best-fit has $\chi^2 = 2.1$
- With Group II included, best-fit is excluded at $\chi^2/\text{d.o.f.} = 122/7$
- Exclusion dominated by $m_{\tilde{q}}^{T2}$ wich is 8.9 $\sigma$ away from the measured value
- $m_{\tilde{q}}^{T2} \propto \sqrt{m_{\tilde{q}}^2 - 2m_{\tilde{\chi}_1^0}^2}$, so sensitive to squark mass and tries to pull mass scale up

## Rates give far more convincing exclusion

- At best-fit point from Group I fit, $R_{jjE_T^{\text{miss}}}$ is 218 $\sigma$ from the measured value!
- The fit done at 7 TeV and 10 fb$^{-1}$ with only Group I excludes the CMSSM at greater significance ($\chi^2/\text{d.o.f.} = 216/2$) than the fit done at 14 TeV and 10 fb$^{-1}$ using Group I and II ($\chi^2/\text{d.o.f.} = 122/7$).

# mAMSB: 7 TeV, 10 fb$^{-1}$, Group I




- Mass edges alone can disfavor mAMSB, because gaugino mass splitting is larger than in MMAMSB or the CMSSM.
- Adding rates can exclude mAMSB with $\chi^2/\text{d.o.f.} = 238/3$.

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# mAMSB: comparing rates with Group II

## Group II at 14 TeV and 10 fb$^{-1}$

- Best-fit point is excluded with $\chi^2/\text{d.o.f.} = 330/8$
- Exclusion dominated by $m_{\tilde{q}}^{T2}$ wich is 12 $\sigma$ away from the measured value
- Again, $m_{\tilde{q}}^{T2}$ tries to pull mass scale up, while edges try to pull it down

## Effectiveness of rates

- At best-fit point from Group I + II fit, $R_{jjE_T^{\text{miss}}}$ is 953 $\sigma$ from the measured value!
- Rates, again, are far more sensitive to the mass scale than stransverse mass.

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# Conclusions

- The MMAMSB is a theoretically and phenomenologically interesting fusion of gravity and anomaly mediation.
- Fits using LHC observables can determine the MMAMSB parameters accurately.
- Using rate observables, especially at lower energies and luminosities, is crucial to the success of the fit.
- The MMAMSB can be distinguished from the CMSSM and mAMSB, especially if rate information is used.

For future work, this type of analysis can be extended to more general models to see if their parameters can be determined using fits with rates.

# MMAMSB: summary of fits

| MMAMSB | $\alpha$ 4.8 | $m_{3/2}$ (TeV) 21 | $\tan\beta$ 10 | n 0.5 |
|---|---|---|---|---|
| **7 TeV and 10 fb$^{-1}$** | | | | |
| I | $4.8^{+33.5}_{-1.4}$ | $22^{+19}_{-21}$ | $9^{+48}_{-8}$ | $0.5^{+0.5}_{-0.5}$ |
| I + rates | $4.99^{+0.15}_{-0.42}$ | $20.0^{+2.9}_{-1.0}$ | $15^{+10}_{-10}$ | $0.56^{+0.02}_{-0.10}$ |
| **14 TeV and 1 fb$^{-1}$** | | | | |
| I | $4.8^{+41.0}_{-0.8}$ | $22^{+15}_{-21}$ | $9^{+48}_{-7}$ | $0.5^{+0.5}_{-0.1}$ |
| I + rates | $4.80^{+0.31}_{-0.13}$ | $21.0^{+1.5}_{-2.1}$ | $10^{+9}_{-4}$ | $0.50^{+0.08}_{-0.02}$ |
| **14 TeV and 10 fb$^{-1}$** | | | | |
| I | $4.8^{+0.5}_{-0.6}$ | $21^{+10}_{-5}$ | $12^{+44}_{-9}$ | $0.50^{+0.09}_{-0.05}$ |
| I + rates | $4.80^{+0.26}_{-0.12}$ | $21.0^{+1.5}_{-1.9}$ | $10^{+9}_{-3}$ | $0.50^{+0.07}_{-0.01}$ |
| I + II | $4.80^{+0.07}_{-0.05}$ | $21.0^{+1.2}_{-1.3}$ | $10.0^{+0.4}_{-0.3}$ | $0.500^{+0.005}_{-0.004}$ |
| I + II + rates | $4.80^{+0.04}_{-0.04}$ | $21.0^{+0.7}_{-0.7}$ | $10.0^{+0.4}_{-0.3}$ | $0.500^{+0.005}_{-0.004}$ |
| **14 TeV and 100 fb$^{-1}$** | | | | |
| I | $4.8^{+0.3}_{-0.4}$ | $21^{+5}_{-4}$ | $10^{+47}_{-4}$ | $0.50^{+0.09}_{-0.02}$ |
| I + rates | $4.80^{+0.24}_{-0.12}$ | $21.0^{+1.5}_{-1.6}$ | $10^{+7}_{-3}$ | $0.500^{+0.069}_{-0.008}$ |
| I + II | $4.801^{+0.024}_{-0.023}$ | $21.0^{+0.5}_{-0.5}$ | $9.99^{+0.19}_{-0.19}$ | $0.500^{+0.003}_{-0.003}$ |
| I + II + rates | $4.798^{+0.023}_{-0.019}$ | $21.0^{+0.4}_{-0.5}$ | $10.00^{+0.19}_{-0.19}$ | $0.500^{+0.003}_{-0.003}$ |

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# CMSSM: summary of fits

| CMSSM | $m_0$ (GeV) | $m_{1/2}$ (GeV) | $\tan\beta$ | $A_0$ (GeV) | $\chi^2$/d.o.f. |
|---|---|---|---|---|---|
| **7 TeV and 10 fb$^{-1}$** | | | | | |
| I | $36^{+189}_{-21}$ | $210^{+12}_{-58}$ | $5^{+40}_{-3}$ | $405^{+1256}_{-1056}$ | 0.12/0 |
| I + rates | 78 | 413 | 7.8 | 649 | 216/2 |
| **14 TeV and 1 fb$^{-1}$** | | | | | |
| I | $35^{+59}_{-12}$ | $208^{+10}_{-21}$ | $4^{+29}_{-1.0}$ | $409^{+1237}_{-1038}$ | 0.23/0 |
| I + rates | 69 | 379 | 7.6 | 580 | 334/2 |
| **14 TeV and 10 fb$^{-1}$** | | | | | |
| I | $35.3^{+47.8}_{-4.8}$ | $208.4^{+3.2}_{-10.1}$ | $5^{+27}_{-2}$ | $373^{+801}_{-742}$ | 2.1/0 |
| I + rates | 59 | 331 | 9.4 | 538 | 1643/2 |
| I + II | 39 | 210 | 8.0 | 364 | 122/7 |
| I + II + rates | 57 | 328 | 6.5 | 531 | 1806/9 |
| **14 TeV and 100 fb$^{-1}$** | | | | | |
| I | $33.6^{+2.5}_{-2.1}$ | $207.3^{+2.1}_{-2.4}$ | $4.7^{+2.2}_{-1.2}$ | $365^{+112}_{-105}$ | 11.8/0 |
| I + rates | 51 | 319 | 8.0 | 542 | 2533/2 |
| I + II | 38 | 203 | 8.1 | 354 | 907/7 |
| I + II + rates | 173 | 311 | 5.8 | 502 | 4043/9 |

# mAMSB: summary of fits

| mAMSB | $m_0$ (GeV) | $m_{3/2}$ (TeV) | $\tan\beta$ | $\chi^2$/d.o.f. |
|---|---|---|---|---|
| **7 TeV and 10 fb$^{-1}$** | | | | |
| I | $127^{+14}_{-21}$ | $15.2^{+1.2}_{-1.8}$ | $21^{+2}_{-19}$ | 3.8/1 |
| I + rates | 317 | 32 | 33 | 238/3 |
| **14 TeV and 1 fb$^{-1}$** | | | | |
| I | $127^{+10}_{-16}$ | $15.2^{+0.8}_{-1.4}$ | $21^{+2}_{-10}$ | 7.6/1 |
| I + rates | 316 | 32 | 4.7 | 397/3 |
| **14 TeV and 10 fb$^{-1}$** | | | | |
| I | 124 | 15 | 21 | 72/1 |
| I + rates | 316 | 32 | 25 | 3084/3 |
| I + II | 116 | 14 | 16 | 330/8 |
| I + II + rates | 316 | 32 | 9 | 4135/10 |
| **14 TeV and 100 fb$^{-1}$** | | | | |
| I | 126 | 15 | 21 | 275/1 |
| I + rates | 292 | 30 | 11 | 4591/3 |
| I + II | 100 | 13 | 16 | 1886/8 |
| I + II + rates | 292 | 30 | 9 | 13678/10 |