Decoding new physics at 1 fb^{-1} LHC with Flavour and CP observables

Robert N. Hodgkinson

Discrete 2010 - 10th December 2010, Valencia

Based on L. Calibbi, J.Jones-Perez, RNH, A. Masiero, V. Mitsou and O. Vives
Work in Progress

Early LHC running

The Present

The LHC is operational!

- QCD spectrum πs, Ks, J/Ψs, Υs...
- Ws and Zs
- Top quarks

The Future

What to expect in the 1 year $7 \sim 8$ TeV run?

Early LHC running

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What to expect in the 1 year $7 \sim 8$ TeV run?

- Higgs boson $\times$

Early LHC running

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- QCD spectrum πs, Ks, J/Ψs, Υs $\ldots$ $\surd$
- Ws and Zs $\surd$
- Top quarks $\surd$

The Future

What to expect in the 1 year $7 \sim 8$ TeV run?

- Higgs boson $\times$
- New Physics!

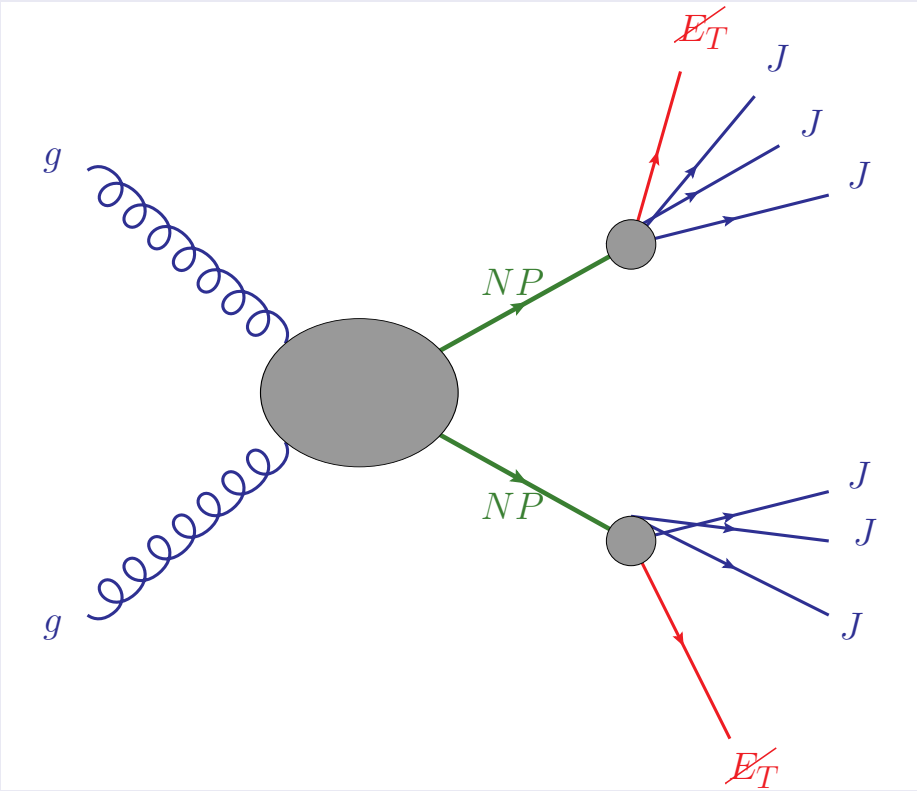
LHC can easily see new light, coloured particles

Outline

Outline

New Physics at Early LHC

New Physics Production



LHC Potential

Higher C.O.M. energy gives

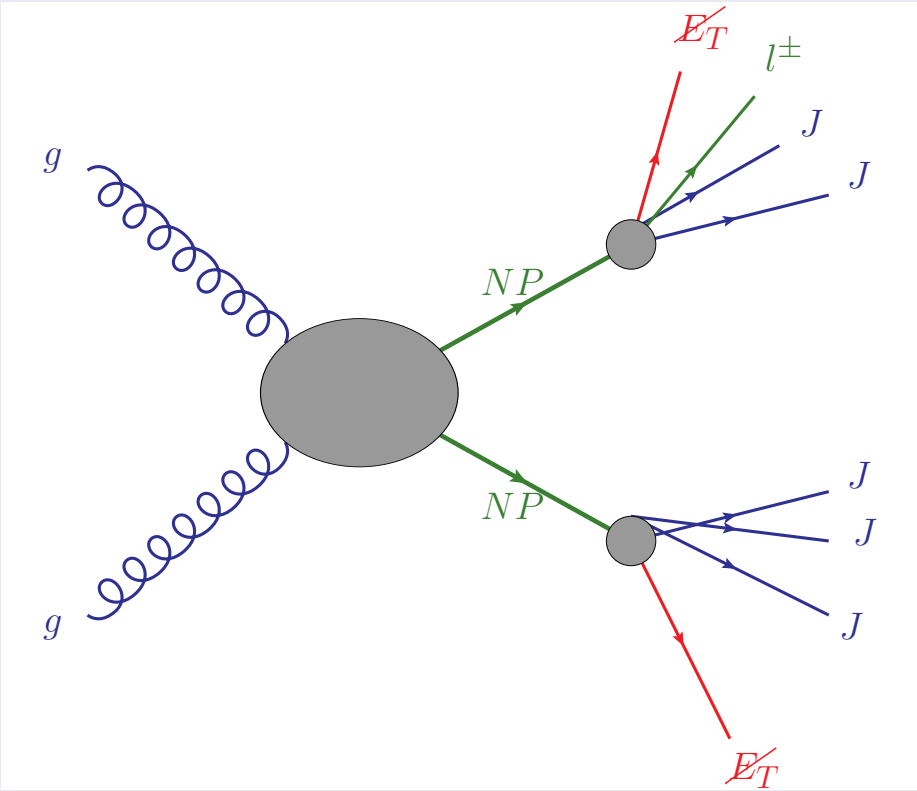
- Higher production threshold
- Increased gluino-gluino cross-section

Decay modes

- Energetic Jets
- High Multiplicity
- Missing (transverse) energy

New Physics at Early LHC

New Physics Production



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Supersymmetry

SUSY

Supersymmetry connects bosons and fermions

$$Q\Psi \to \Phi, \quad Q\Phi \to \Psi$$

It predicts

- two scalar partners for each charged fermion
- a fermionic partner for each gauge boson

New Coloured Particles

- Gluons $g \to$ Gluinos $\tilde{g}$
- Quarks $q \to$ Squarks $\tilde{q}_1,\ \tilde{q}_2$

Tevatron limits

- $m_{\tilde{g}} \gtrsim 300$ GeV
- $m_{\tilde{t}} \gtrsim 115$ GeV

Lightest Squarks- Mixing

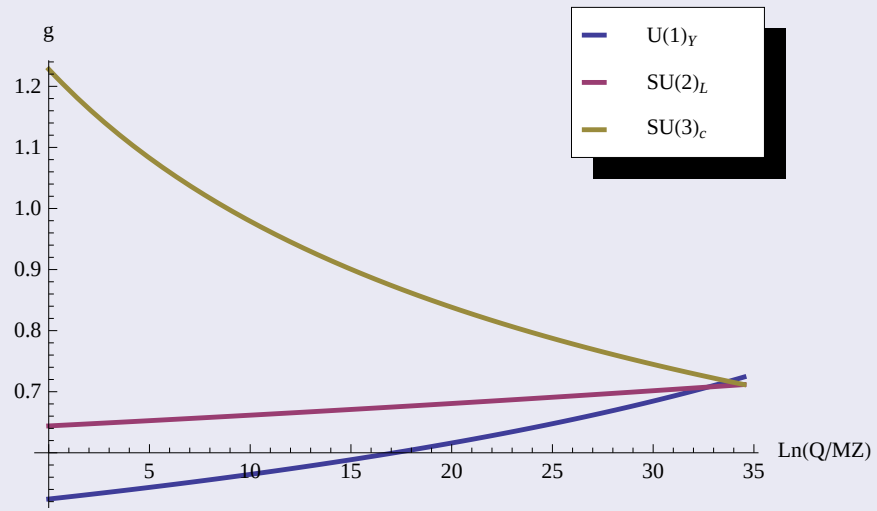
- EW doublet and singlet quarks mix
- Mass matrix (single flavour)

$$\widetilde{M}_t^2 \approx \begin{pmatrix} \widetilde{M}_Q^2 & Y_u\, v\, \mu \\ Y_u\, v\, \mu & \widetilde{M}_U^2 \end{pmatrix}$$

- Large mixing for 3rd generation $\to$ lightest $\tilde{q}$ typically a stop.

SUSY-breaking and Unification

RGE running



Parameters

Assume unification at the GUT scale

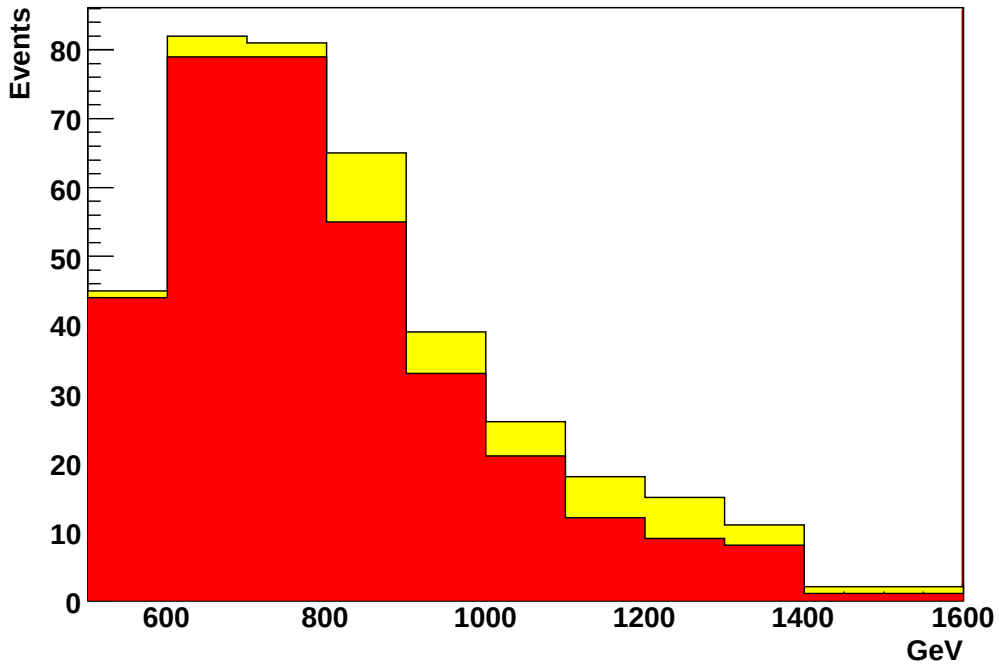
- Universal scalar mass m_0
- Universal gaugino mass $m_{1/2}$
- Universal trilinear coupling A_0
- Ratio of Higgs VEVs $\tan\beta$
- Sign of μ

Minimal Flavour Violation

- Diagonal squark mass matrices $\widetilde{\mathbf{M}}^2 = m_0^2 \mathbf{1}$
- Trilinear couplings $\mathbf{a}_{u,d,e} = A_0 \mathbf{Y}_{u,d,e}$

The Question for this Talk

What if the LHC sees a New Physics signal in 2011?



$$M_{\text{eff}} \equiv \sum p^T + \not{E}_T$$

Cuts

- $\not{E}_T \geq 100$ GeV
- $p^T_{J1} \geq 100$ GeV
- $E_{J4} \geq 50$ GeV
- $N(b) \geq 1$
- $N(l^{\pm}) \geq 1$

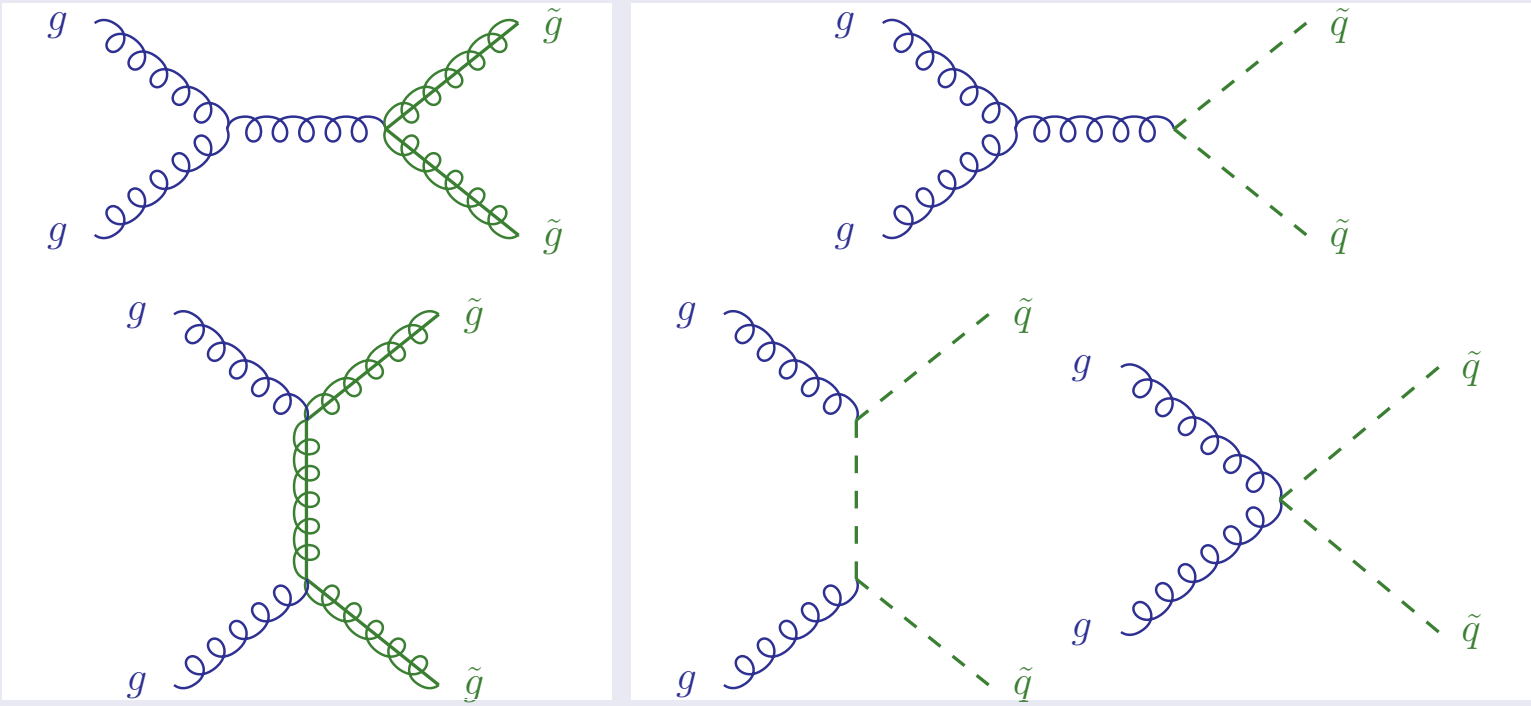
Backgrounds

- QCD
- $t\bar{t}$
- W+Jets/Z+Jets
- $WW/ZZ/WZ$

A new state with mass $535 \lesssim M \lesssim 653$ GeV

Squark/Gluino production

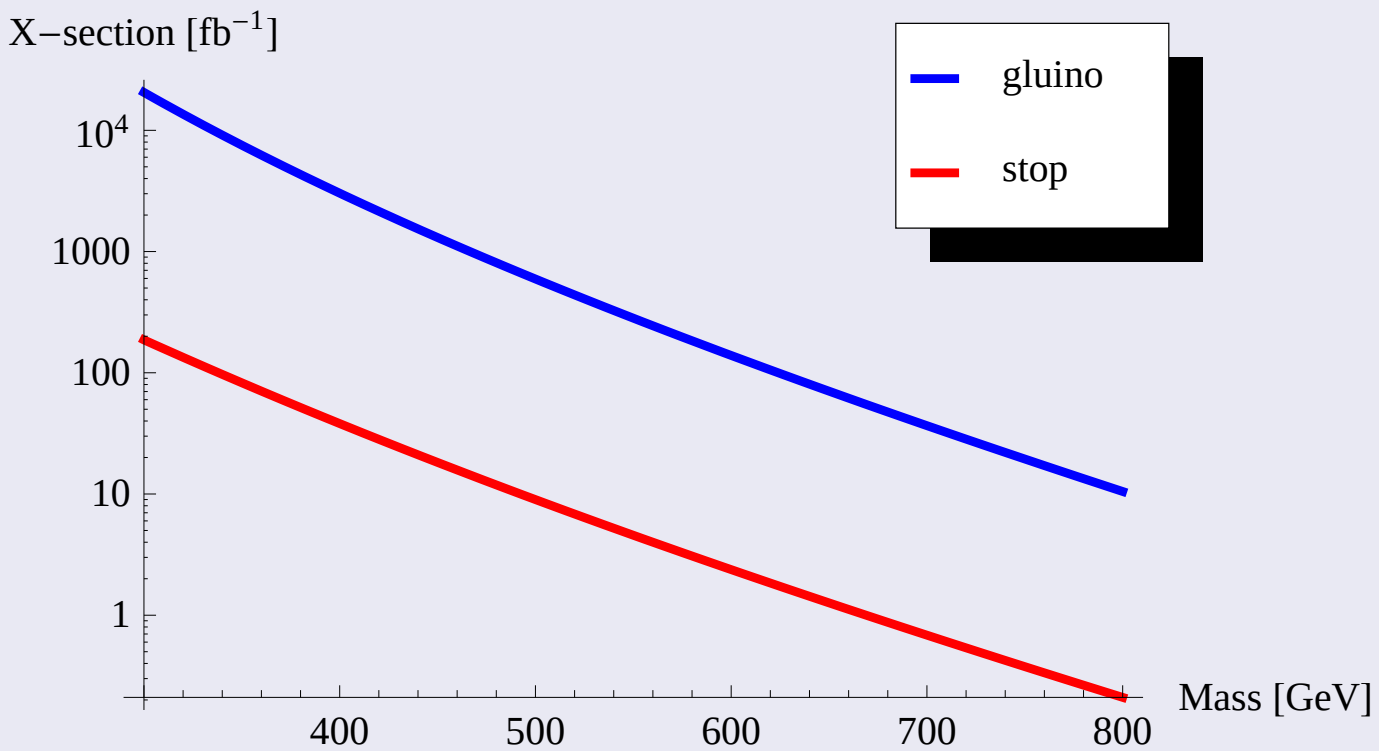
Gluon Fusion



- QCD vertices only for gluinos and top squarks
- Production X-sections insensitive to details of spectrum

Production rates

7 TeV LHC Cross Section



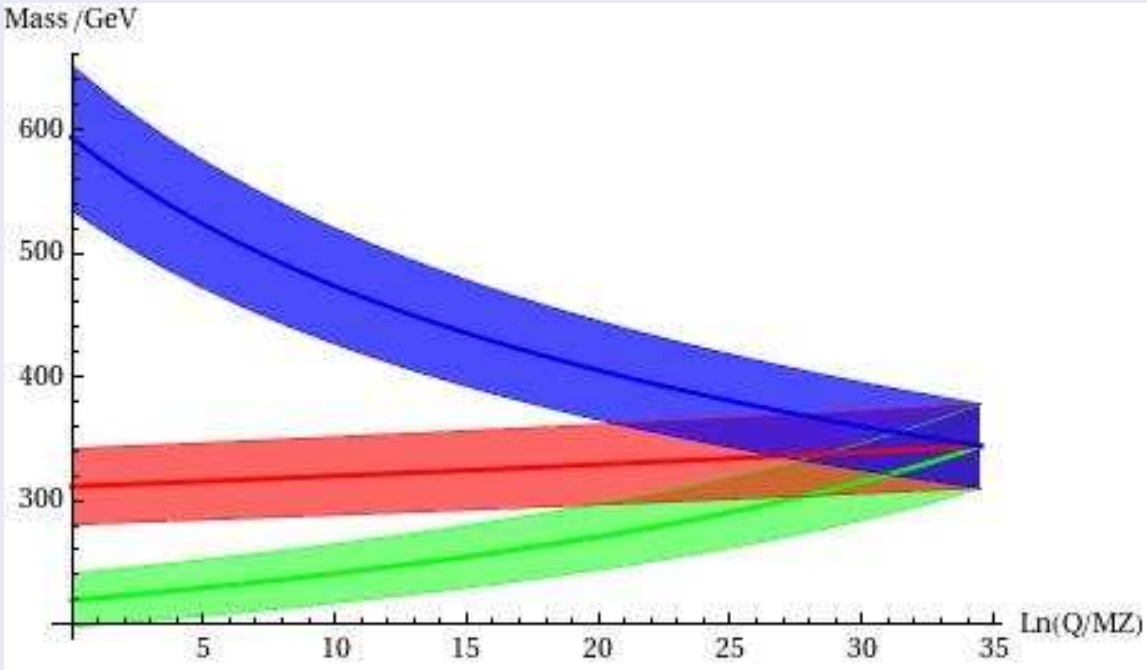
Coloured NP excess at ~ 600 GeV $\Longrightarrow$ Gluino candidate

Outline

Outline

Gaugino Masses from Running

1-loop RGEs



Full treatment including threshold corrections gives

$$535 \lesssim M_{\tilde{g}} \lesssim 653 \Longrightarrow \left\{ \begin{array}{ccccc} 138 & \lesssim & M_{\tilde{w}} & \lesssim & 206 \\ 76 & \lesssim & M_{\tilde{b}} & \lesssim & 107 \end{array} \right.$$

SUSY Flavour Contributions

Processes

SUSY partners contribute to precision observables such as

- $B_s \to \mu\bar{\mu}$
- $B \to \tau\nu$
- $K \to \pi\nu\bar{\nu}$
- $(g-2)_\mu$
- $b \to s\gamma$
- $b \to s\mu\bar{\mu}$
- $b \to s\nu\bar{\nu}$

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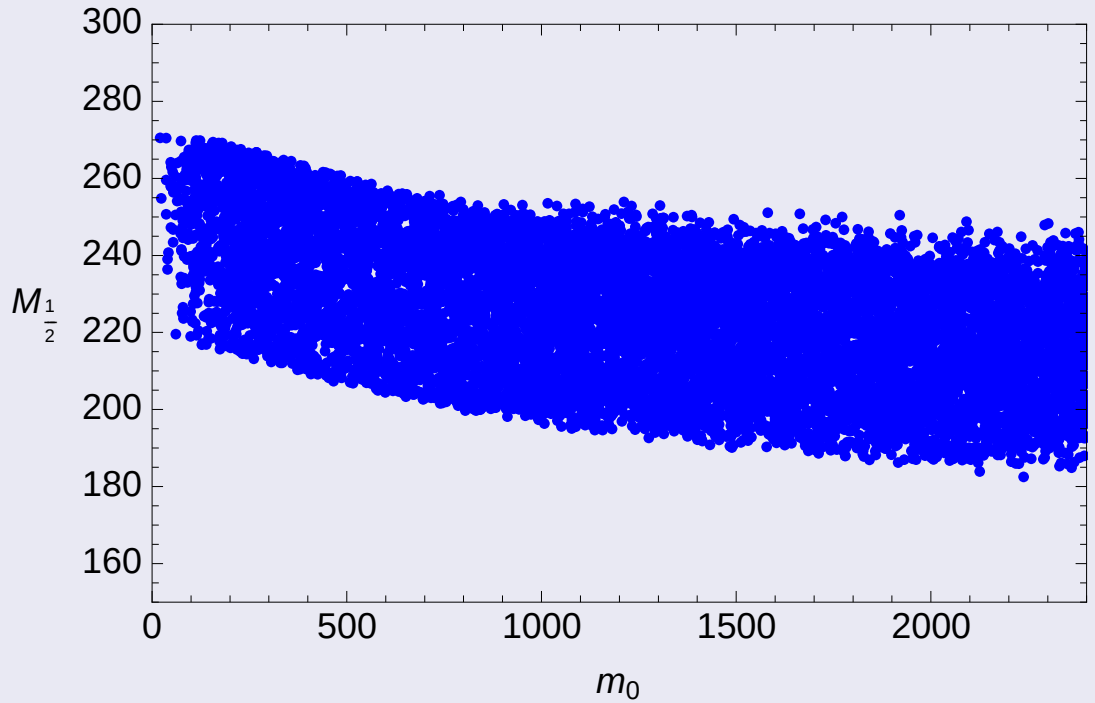
Parameter Scan I

SUSY and Higgs Constraints



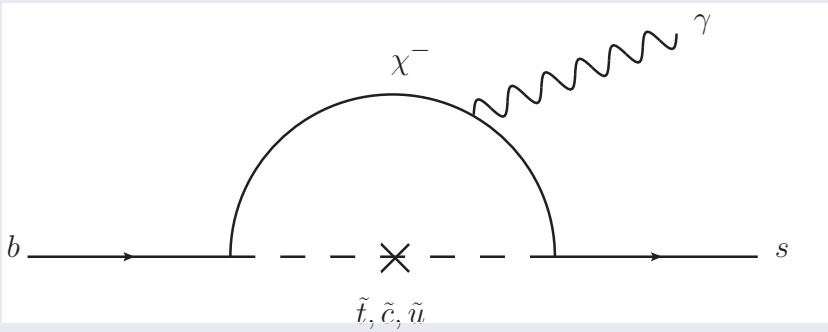
Lightest SUSY Masses

	Direct Search	
	min	max
$\tilde{g}$	535	653
$\tilde{\chi}^{\pm}$	138	206
$\tilde{\chi}^{0}$	76	107
$\tilde{t}$	131	1400
$\tilde{b}$	420	1960
$\tilde{\tau}$	86	2390

Points satisfy Direct Search exclusion and Higgs bounds

SUSY Flavour Contributions I

$b \to s\gamma$

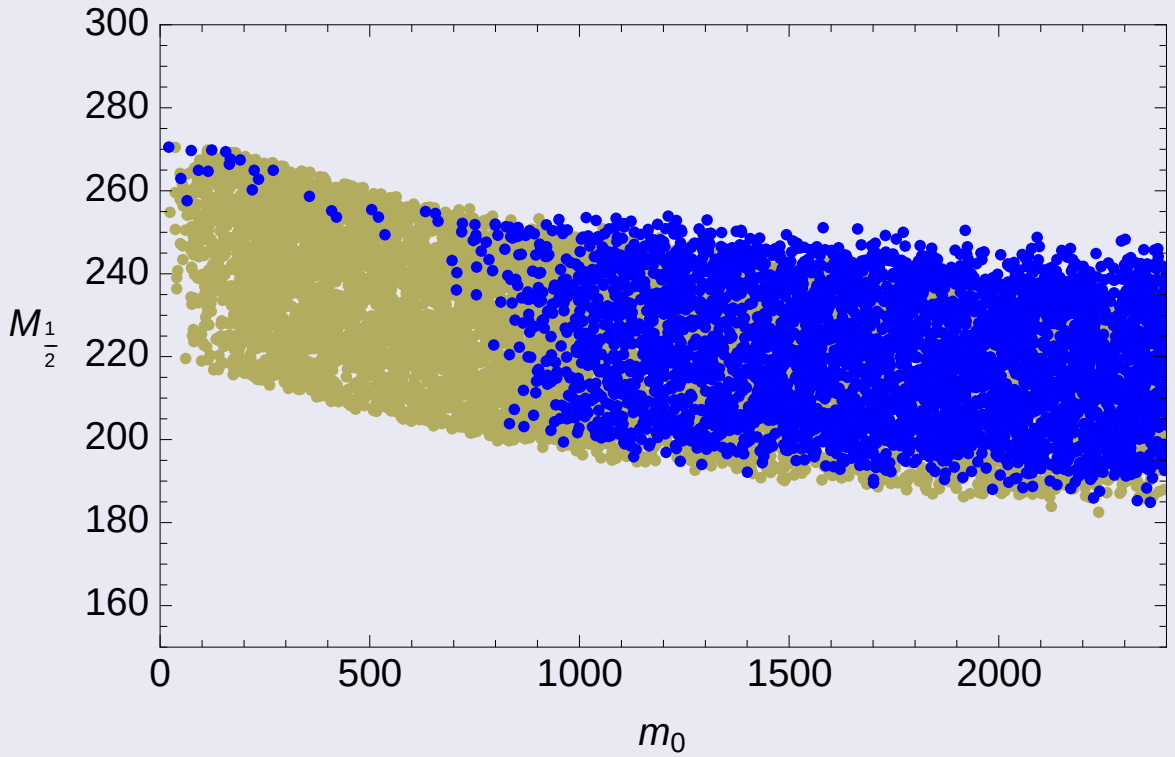


- Experiment
  $\mathcal{B}(b \to s\gamma) = (3.55 \pm 0.26) \times 10^{-4}$
  HFAG, arXiv:0704.3575
- SM prediction
  $\mathcal{B}(b \to s\gamma) = (3.12 \pm 0.21) \times 10^{-4}$
  Feroz, Hobson, Roszkowski, Ruiz de Austri, Trotta arXiv:0903.2487

- Agreement at 2σ
- Lower limit on the masses of the squarks

Parameter Scan II

$b \to s\gamma$



- Blue: Allowed
- Grey: Disallowed (3σ)

Mass Bounds II

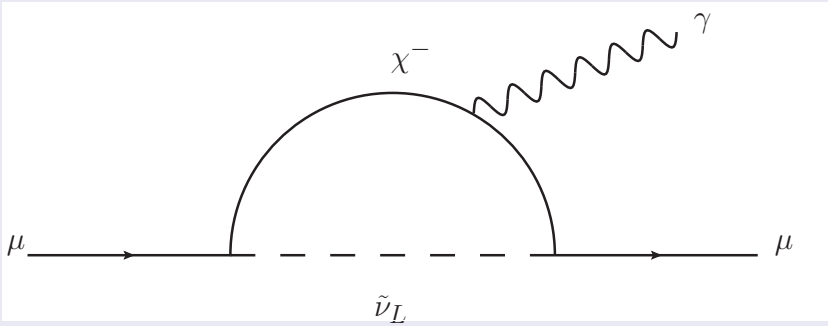
Lightest SUSY particles

	Direct Search		$+ b \to s\gamma$		$+ (g-2)_\mu$	
	min	max	min	max	min	max
$\tilde{g}$	535	653	535	653		
$\tilde{\chi}^{\pm}$	138	206	138	206		
$\tilde{\chi}^{0}$	76	107	76	107		
$\tilde{t}$	131	1400	194	1400		
$\tilde{b}$	420	1960	531	1960		
$\tilde{\tau}$	86	2390	105	2390		

- Agreement with experiment at 3σ

SUSY Flavour Contributions II

$(g-2)_\mu$

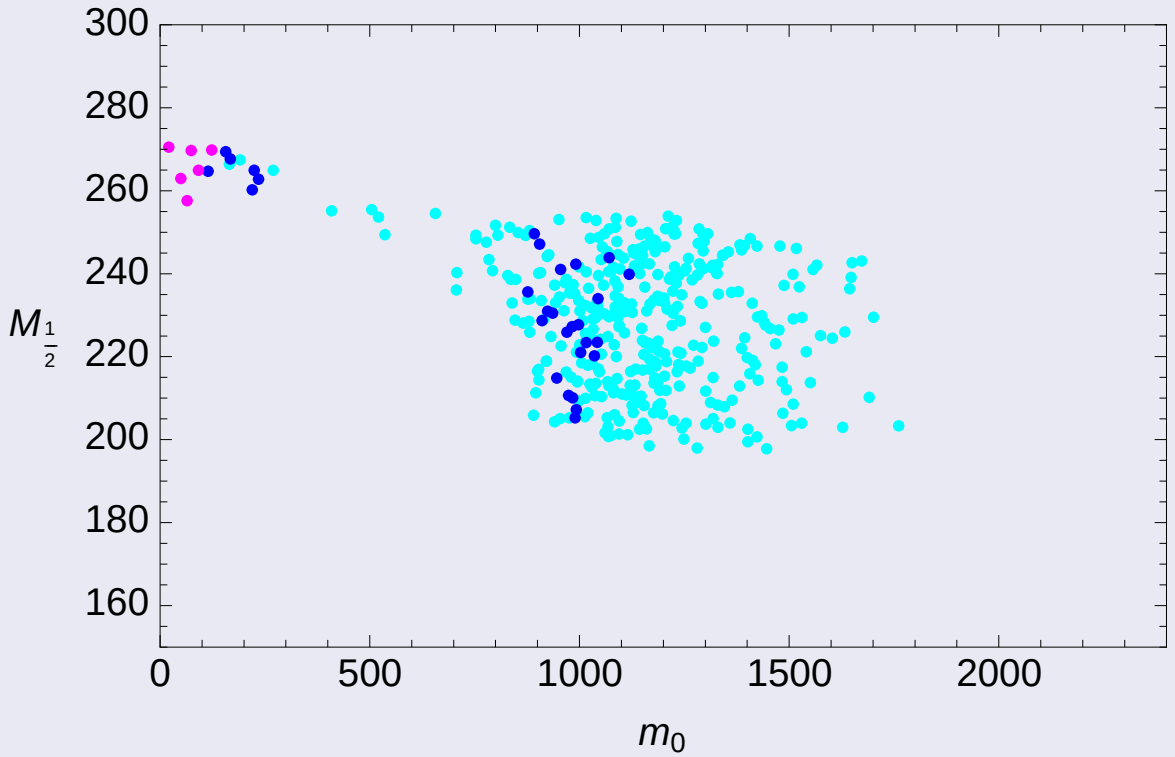


- $\Delta a_\mu \equiv a_\mu^{\text{Exp}} - a_\mu^{\text{SM}} = (316 \pm 79) \times 10^{-11}$
  Passera, Marciano, Sirlin
  arXiv:1001.4528

- **Disagreement** at $> 3\sigma$
- **Upper** limit on the masses of the sleptons

Parameter Scan III

$b \to s\gamma$



- Magenta: 1σ
- Blue: 2σ
- Cyan: 3σ

Mass Bounds III

Lightest SUSY particless

	Direct Search		$+ b \to s\gamma$		$+ (g-2)_\mu$	
	min	max	min	max	min	max
$\tilde{g}$	535	653	535	653	537	653
$\tilde{\chi}^{\pm}$	138	206	138	206	155	199
$\tilde{\chi}^{0}$	76	107	76	107	80	106
$\tilde{t}$	131	1400	194	1400	376	859
$\tilde{b}$	420	1960	531	1960	531	1040
$\tilde{\tau}$	86	2390	105	2390	105	982

- Agreement with experiment at 3σ

Mass Bounds IV

Lightest SUSY particless

	Direct Search		+Flavour Constraints	
	min	max	min	max
$\tilde{g}$	535	653	535	619
$\tilde{\chi}^{\pm}$	138	206	155	185
$\tilde{\chi}^{0}$	76	107	80	95
$\tilde{t}$	131	1400	576	681
$\tilde{b}$	420	1960	771	873
$\tilde{\tau}$	86	2390	733	835

- $(g-2)_\mu$ at 3σ
- $b \to s\gamma$ at 2σ

Outline

Mass Insertion Limits

Non-MFV

- Previously assumed Minimal Flavour Violation
- Squark Mass Matrices assumed diagonal at GUT scale $\widetilde{\mathbf{M}}^2 \sim \mathbf{1}_3$
- Flavour Models predict off-diagonal flavour-mixing elements

$$\widetilde{\mathbf{M}}^2 \sim m_0^2 \begin{pmatrix} 1 & \delta_{12} & \delta_{13} \\ \delta_{21} & 1 & \delta_{23} \\ \delta_{31} & \delta_{32} & 1 \end{pmatrix}$$

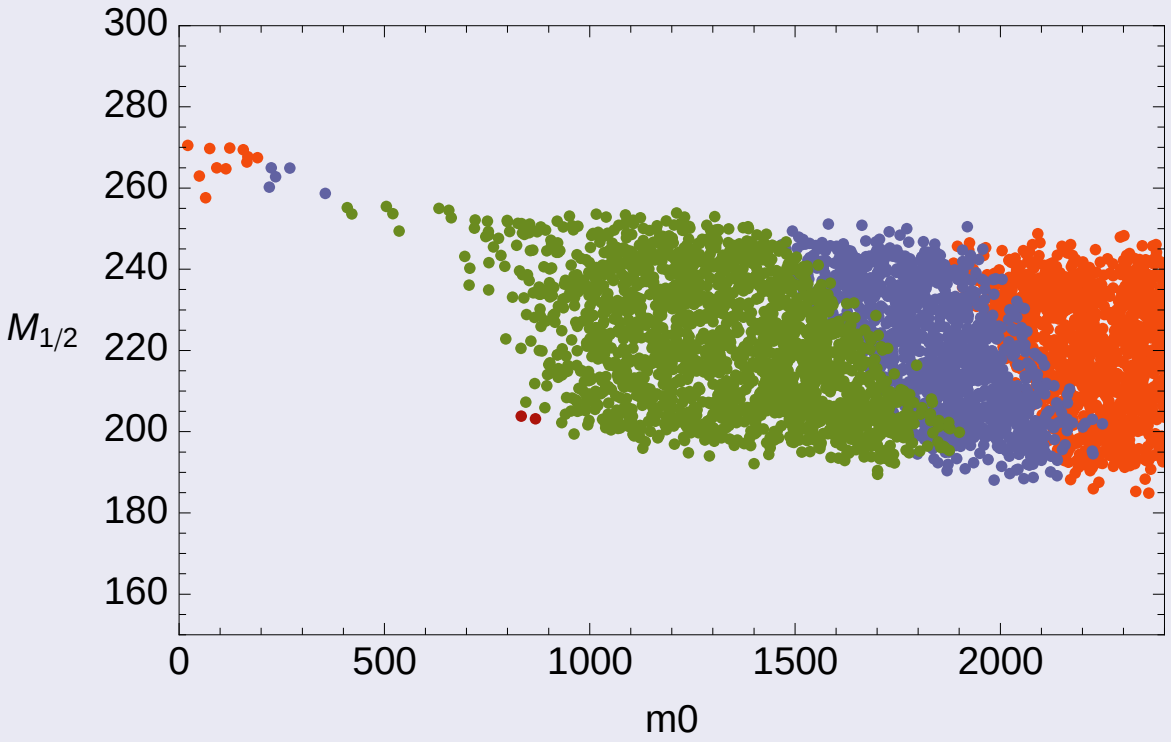
- Parametrise in terms of Mass Insertions δ_{ij}

CP Violation

- Squark mass^2 matrices are Hermitian
- δ_{ij}s generally complex- new CP-violating phases

Mass Insertion Limits I

Kaon Mixing - Real Part ΔM_K



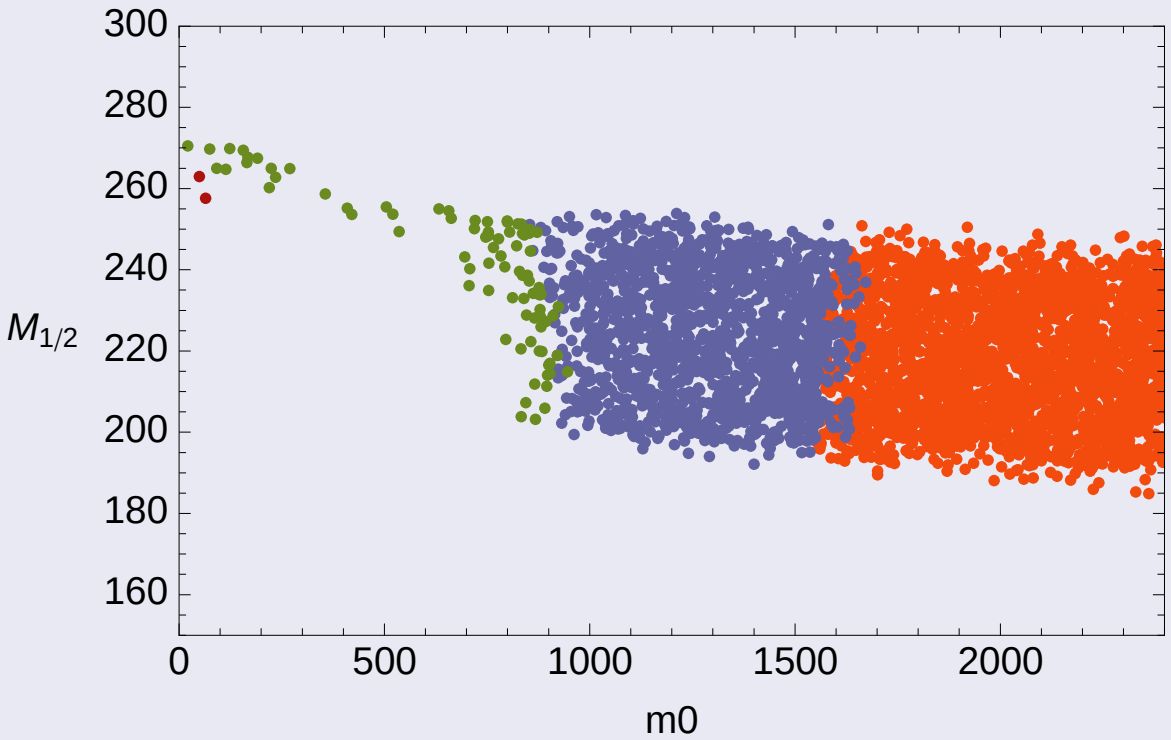
Upper bounds

- $(8.4 \sim 10) \times 10^{-}2$
- $(7.1 \sim 8.4) \times 10^{-}2$
- $(5.9 \sim 7.1) \times 10^{-}2$
- $(5.0 \sim 5.9) \times 10^{-}2$

- Bound on $\sqrt{\mathrm{Re}\left\{\left(\delta^d_{12}\right)_{LL}\left(\delta^d_{12}\right)_{LL}\right\}} = \sqrt{\mathrm{Re}\left\{\left(\delta^d_{12}\right)_{RR}\left(\delta^d_{12}\right)_{RR}\right\}}$

Mass Insertion Limits II

Kaon Mixing - Real Part ΔM_K



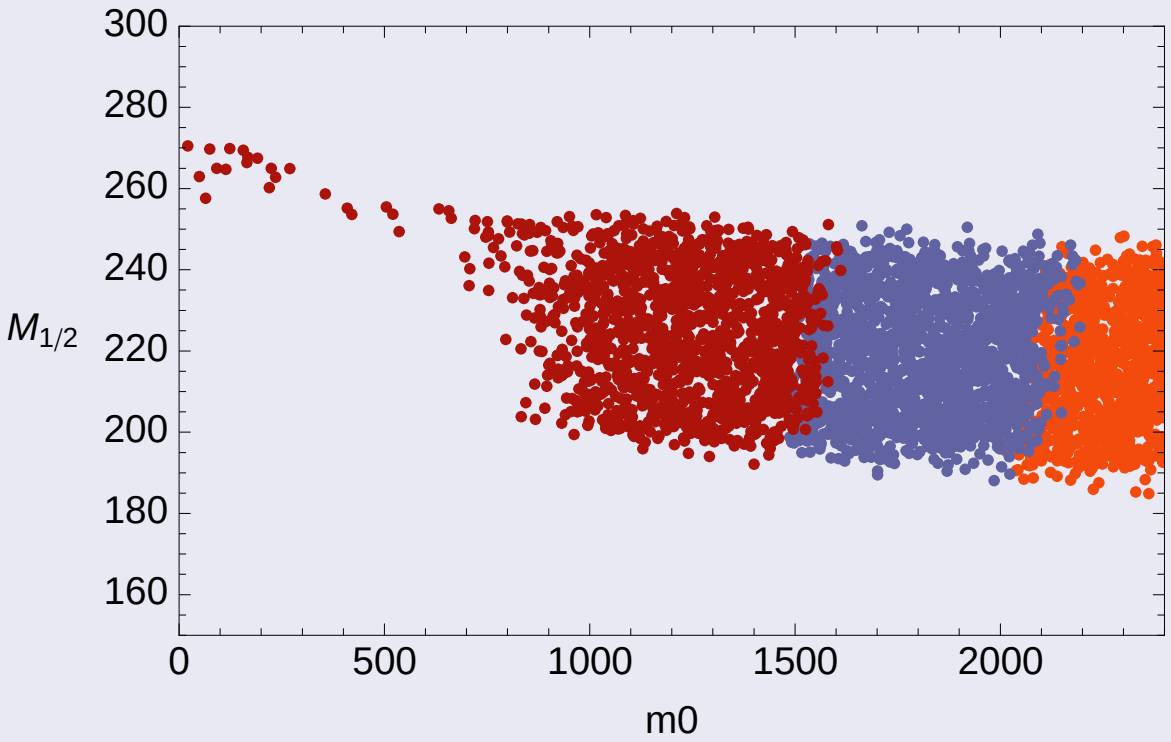
Upper bounds

- $(4.7 \sim 8.0) \times 10^{-}3$
- $(2.8 \sim 4.7) \times 10^{-}3$
- $(1.6 \sim 2.8) \times 10^{-}3$
- $(1.0 \sim 1.6) \times 10^{-}3$

- Bound on $\sqrt{\mathrm{Re}\left\{\left(\delta^d_{12}\right)_{LL}\left(\delta^d_{12}\right)_{RR}\right\}}$

Mass Insertion Limits III

Kaon Mixing - Real Part ΔM_K



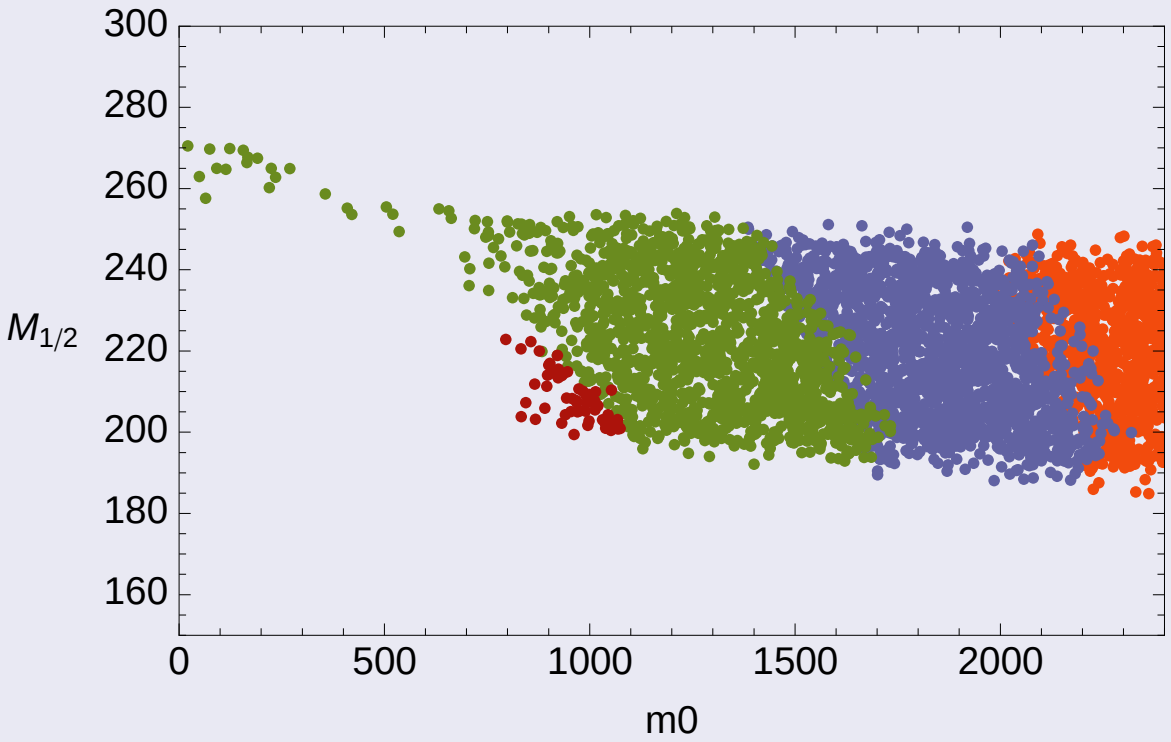
Upper bounds

- $(2.1 \sim 3.0) \times 10^{-}2$
- $(1.0 \sim 2.1) \times 10^{-}2$
- $(0.7 \sim 1.0) \times 10^{-}2$

- Bound on $\sqrt{\mathrm{Re}\left\{\left(\delta^d_{12}\right)_{LR}\left(\delta^d_{12}\right)_{LR}\right\}} = \sqrt{\mathrm{Re}\left\{\left(\delta^d_{12}\right)_{RL}\left(\delta^d_{12}\right)_{RL}\right\}}$

Mass Insertion Limits IV

Kaon Mixing - Real Part ΔM_K



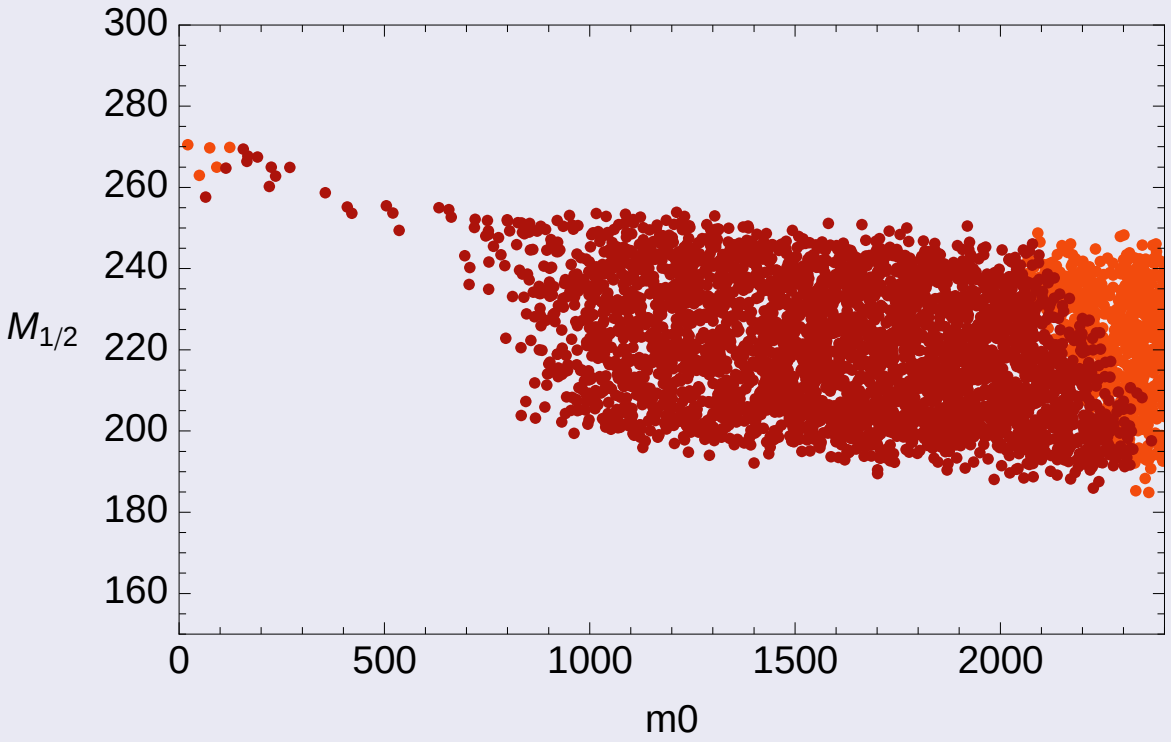
Upper bounds

- $(5.0 \sim 6.0) \times 10^{-}3$
- $(4.2 \sim 5.0) \times 10^{-}3$
- $(3.6 \sim 4.2) \times 10^{-}3$
- $(3.0 \sim 3.6) \times 10^{-}3$

- Bound on $\sqrt{\mathrm{Re}\left\{\left(\delta^d_{12}\right)_{LR}\left(\delta^d_{12}\right)_{RL}\right\}}$

Mass Insertion Limits V

Kaon Mixing - Imaginary Part ϵ_K



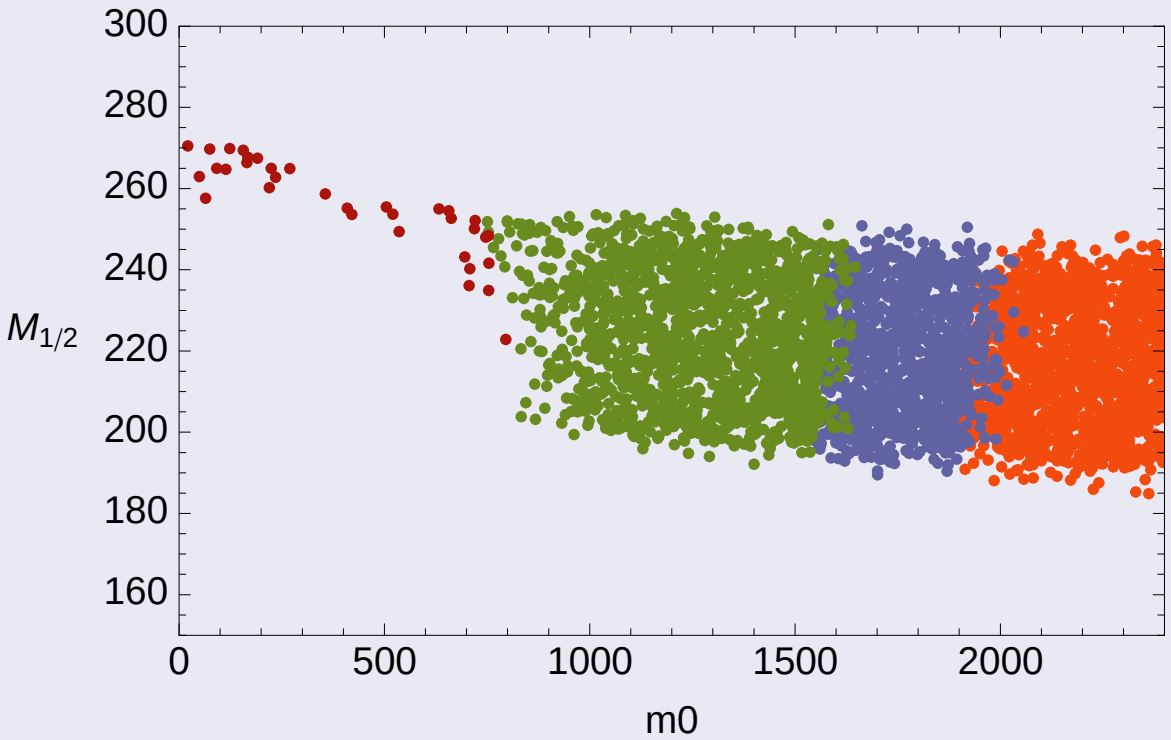
Upper bounds

- $(3.0 \sim 4.0) \times 10^{-}2$
- $\lesssim 3.0 \times 10^{-}2$

- Bound on $\sqrt{\mathrm{Im}\left\{\left(\delta^d_{12}\right)_{LL}\left(\delta^d_{12}\right)_{LL}\right\}} = \sqrt{\mathrm{Im}\left\{\left(\delta^d_{12}\right)_{RR}\left(\delta^d_{12}\right)_{RR}\right\}}$

Mass Insertion Limits VI

Kaon Mixing - Imaginary Part ϵ_K



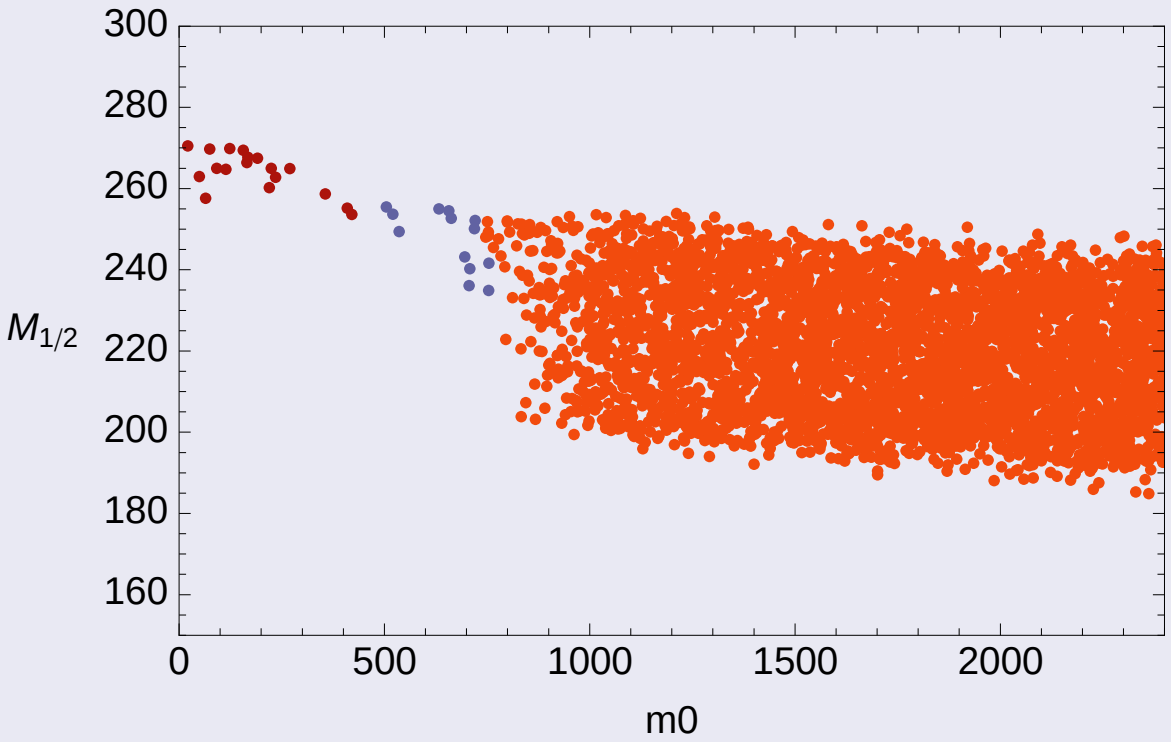
Upper bounds

- $(8.4 \sim 10) \times 10^{-}3$
- $(7.1 \sim 8.4) \times 10^{-}3$
- $(5.9 \sim 7.1) \times 10^{-}3$
- $(5.0 \sim 5.9) \times 10^{-}3$

- Bound on $\sqrt{\mathrm{Im}\left\{\left(\delta^d_{12}\right)_{LL}\left(\delta^d_{12}\right)_{RR}\right\}}$

Mass Insertion Limits VII

Kaon Mixing - Imaginary Part ϵ_K



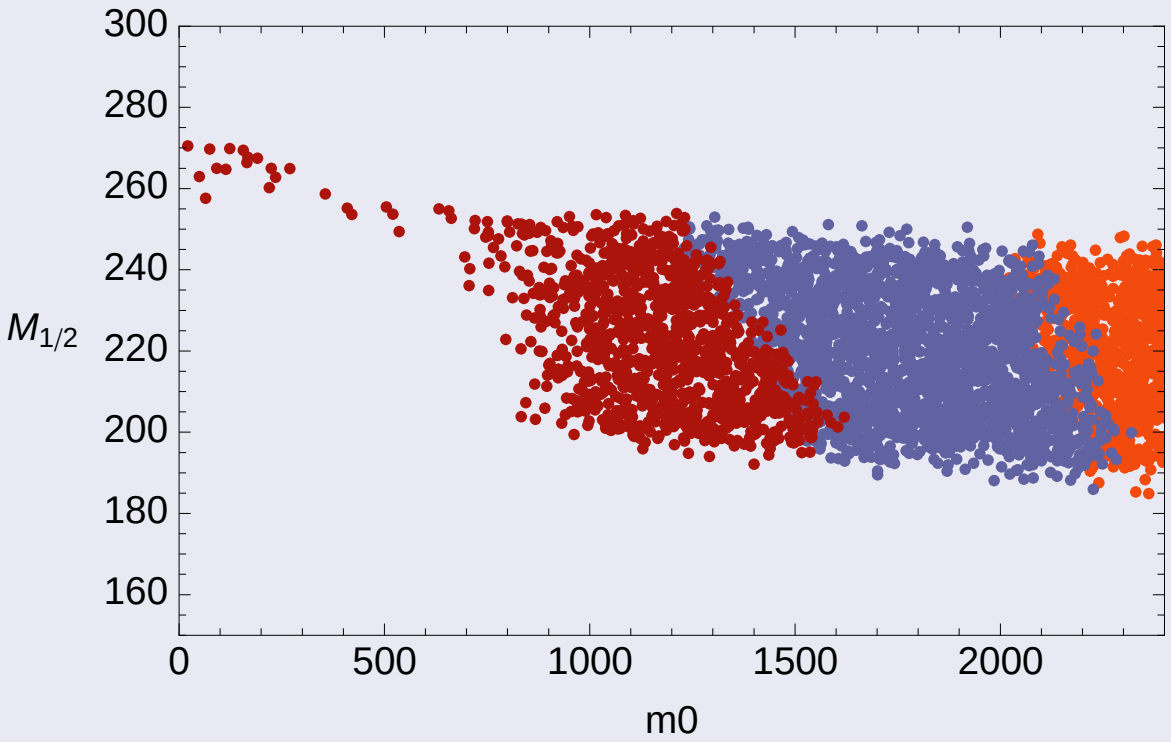
Upper bounds

- $(9.5 \sim 10) \times 10^{-}3$
- $(8.5 \sim 9.5) \times 10^{-}3$
- $(8.0 \sim 8.5) \times 10^{-}3$

- Bound on $\sqrt{\mathrm{Im}\left\{\left(\delta^d_{12}\right)_{LR}\left(\delta^d_{12}\right)_{LR}\right\}} = \sqrt{\mathrm{Im}\left\{\left(\delta^d_{12}\right)_{RL}\left(\delta^d_{12}\right)_{RL}\right\}}$

Mass Insertion Limits VIII

Kaon Mixing - Imaginary Part ϵ_K



Upper bounds

- $(8.5 \sim 9.0) \times 10^{-}3$
- $(7.9 \sim 8.5) \times 10^{-}3$
- $(7.5 \sim 7.9) \times 10^{-}3$
- $(7.0 \sim 7.5) \times 10^{-}3$

- Bound on $\sqrt{\mathrm{Im}\left\{\left(\delta^d_{12}\right)_{LR}\left(\delta^d_{12}\right)_{RL}\right\}}$

Outline

Summary

SUSY Spectrum

- LHC may see evidence of New Physics by the end of 2011
- This will be interpreted as a SUSY signal! (Rightly or wrongly)
- Precision observables already set tight limits on the spectrum in constrained models
- $\mathcal{B}(b \to s\gamma)$ and $(g-2)_\mu$ particularly useful
- The better we can measure the masses, the more useful the flavour limits become!

Flavour Limits

- Can also place limits on the squark Mass Insertions
- Crucial information for Flavour Model-builders