



## Killing constrained supersymmetry softly...

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## Thanks for the invitation to UC Irvine!



- Physics beyond the Standard Model at the LHC?
- Great expectations: the pre-LHC gold rush
- Global fits of supersymmetric models
- Beyond supersymmetry: simplified models
- Conclusions

## Why new physics at the LHC?

• The naturalness problem: why is  $M_{\rm Higgs} \ll M_{\rm Planck}$ ?



 $\rightarrow$  new colored (top) partners with mass below about 500 GeV?

#### Dark matter



weakly interacting massive particle with mass below about 1 TeV?

#### ► Naturalness & dark matter

- ightarrow new particles at the TeV-scale including a stable WIMP
- $\rightarrow$  generic LHC new physics signature: cascade decays with  ${\it E}_{\rm T,miss}$



Supersymmetry is a prime example for this class of models.

Symmetry between fermions and bosons:  $Q|\text{boson}\rangle = |\text{fermion}\rangle$  $Q|\text{fermion}\rangle = |\text{boson}\rangle$ with algebra  $\{Q_{\alpha}, Q_{\beta}^{\dagger}\} = (\sigma^{\mu})_{\alpha\beta}P_{\mu}$ 

 $\rightarrow$  SUSY is the unique maximal external symmetry in nature.

 $\rightarrow$  One needs to introduce superpartners to the Standard Model particles.

 $\sqrt{\text{SUSY}}$  protects the Higgs mass from large radiative corrections:

$$\frac{1}{11} \bigoplus_{II} \overline{W} + \frac{1}{11} \longrightarrow \delta m_H^2 \sim -\frac{\alpha}{\pi} (\Lambda^2 + \widetilde{m}_F^2)$$

 $\delta m_H^2 \sim rac{lpha}{\pi} (m_F^2 - \widetilde{m}_F^2) 
ightarrow$  no fine-tuning if  $\widetilde{m} \lesssim \mathcal{O}(1~{
m TeV})$ 

✓ SUSY allows for coupling unification, radiative EWSB, dark matter (assuming R-parity), ...

## The Minimal Supersymmetric extension of the SM

- external symmetries: Poincaré symmetry & supersymmetry
- ▶ internal symmetries: SU(3)⊗SU(2)⊗U(1) gauge symmetries

${\rm Gauge \ Bosons}\ S=1$	Gauginos $S=1/2$		
gluon, $W^{\pm}, Z, \gamma$	gluino, $\widetilde{W}, \widetilde{Z}, \widetilde{\gamma}$		
Fermions $S = 1/2$	Sfermions $S = 0$		
$egin{pmatrix} u_L\ d_L\end{pmatrix}inom{ u_L\ e_L}\ u_R, d_R, e_R \end{pmatrix}$	$egin{pmatrix} \widetilde{u}_L \ \widetilde{d}_L \end{pmatrix} egin{pmatrix} \widetilde{ u}_L^e \ \widetilde{e}_L \end{pmatrix} \ \widetilde{u}_R, \widetilde{d}_R, \widetilde{e}_R \end{pmatrix}$		
Higgs	Higgsinos		
$\binom{H_2^{\mathrm{o}}}{H_2^-}\binom{H_1^+}{H_1^0}$	$igg( rac{H_2^o}{\widetilde{H}_2^-} igg) igg( rac{H_1^+}{\widetilde{H}_1^0} igg)$		

• SUSY breaking  $\rightarrow$  sparticle masses?

The SUSY parameter space is strongly constrained by

► SM precision observables:

 ${
m BR}(b o s\gamma)$ ,  ${
m BR}(B_s o \mu\mu)$ ,  ${
m BR}(b o au
u)$ ,  $\Delta m_{B_s}$ ,  $(g-2)_{\mu}$ ,  $m_W$ ,  $\sin^2 heta_{
m eff}$ 

astrophysical observations:

 $\Omega_{\rm DM},$  direct and indirect DM detection limits

- ► direct sparticle and Higgs boson search limits from colliders:  $m_{\tilde{\chi}^{\pm}}$ , LEP limits on MSSM Higgs bosons
- ► LHC SUSY exclusions from jets+*E*<sub>Tmiss</sub> searches
- ► the LHC Higgs signal
- $\rightarrow$  test supersymmetric models through global fits

[see e.g. SFitter, Mastercode, SuperBayes and Fittino]

• the anomalous magnetic moment of the muon  $(g-2)_{\mu}$ :



 $\rightarrow$  SUSY loops:  $a_{\mu}^{\text{SUSY}} \sim \text{sgn}(\mu) \tan\beta M_{\text{SUSY}}^{-2}$ 

## Indirect SUSY searches

• the anomalous magnetic moment of the muon  $(g-2)_{\mu}$ :



 $\rightarrow$  SUSY loops:  $a_{\mu}^{\text{SUSY}} \sim \text{sgn}(\mu) \tan\beta M_{\text{SUSY}}^{-2}$ 

## Indirect SUSY searches

•  $\Omega_{\rm DM}$  is too large for large parts of the MSSM parameter space, special annihilation mechanisms are needed:



## The constrained Minimal SuperSymmetric Model

#### Current data cannot constrain general SUSY models

 $\rightarrow$  Consider the constrained MSSM: a model with universal scalar and fermion sparticle masses  $M_0$  and  $M_{1/2}$  at the GUT scale

## The constrained Minimal SuperSymmetric Model

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cMSSM fit to B, K and EWK observables,  $(g - 2)_{\mu}$  and  $\Omega_{\rm DM}$ :



 $\rightarrow$  SUSY is just around the corner...



## SUSY! SUSY! SUSY from the LHC!



## Summary of BSM searches at the LHC: limits, limits and more limits...



## Summary of SUSY searches at the LHC

#### ATLAS SUSY Searches\* - 95% CL Lower Limits

ATLAS Preliminary  $\sqrt{s} = 7, 8 \text{ TeV}$ 

Status: ICHEP 2014

010	103.101121 2014							V3 = 1, 0 10 V
	Model	$e, \mu, \tau, \gamma$	Jets	$E_{T}^{miss}$	∫£ dt[fb	-1] Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM MSUGRA/CMSSM MSUGRA/CMSSM 49, 3-49 <sup>2</sup> 1, 42, 3-49 <sup>2</sup> 1, 43, 3-49 <sup>2</sup> 1, 44, 44, 44, 44, 44, 44, 44, 44, 44, 44,	$\begin{matrix} 0 \\ 1 \ e, \mu \\ 0 \\ 0 \\ 1 \ e, \mu \\ 2 \ e, \mu \\ 2 \ e, \mu \\ 1 \ e, \tau + 0 \ 1 \ \ell \\ 2 \ \gamma \\ 1 \ e, \mu + \gamma \\ 2 \ e, \mu (Z) \\ 0 \end{matrix}$	2-6 jets 3-6 jets 7-10 jets 2-6 jets 2-6 jets 3-6 jets 0-3 jets 0-3 jets mono-jet	20 20 20 20 20 20 20 20 20 20 20 20 20 2	20.3 20.3 20.3 20.3 20.3 20.3 20.3 20.3	11 121 2 1115 2	3.770 (中国)     4.9947(1)     4.9947(1)     4.994(	1405.7875 ATLAB.CONF-2013-082 1308.1841 1405.7875 1405.7875 ATLAB.CONF-2013-089 1407.0903 ATLAB.CONF-2013-049 1407.0903 ATLAB.CONF-2012-141 211.1167 ATLAB.CONF-2012-142 ATLAB.CONF-2012-142
3 <sup>rd</sup> gen. § med.	$\hat{\vec{s}} \rightarrow b \hat{\vec{s}} \hat{\vec{t}}_{1}^{0}$ $\hat{\vec{s}} \rightarrow a \hat{\vec{t}}_{1}^{0}$ $\hat{\vec{s}} \rightarrow a \hat{\vec{t}}_{1}^{0}$ $\hat{\vec{s}} \rightarrow b \hat{\vec{t}}_{1}^{0}$	0 0 0-1 e, µ 0-1 e, µ	3 b 7-10 jets 3 b 3 b	Yes Yes Yes	20.1 20.3 20.1 20.1	2 125 2 1.1 TeV 2 1.3 2 1.3	TeV         m(k_1^0)<400 GeV           V         m(k_1^0)<4350 GeV	1407.0600 1308.1841 1407.0600 1407.0600
3 <sup>rd</sup> gen. squarks direct production	$ \begin{split} & \tilde{b}_1 \tilde{b}_1 \cdot \tilde{b}_1 \rightarrow \delta \tilde{t}_1^{(0)} \\ & \tilde{b}_1 \tilde{b}_1 \cdot \tilde{b}_1 \rightarrow \delta \tilde{t}_1^{(0)} \\ & \tilde{b}_1 \tilde{b}_1 \cdot \tilde{b}_1 \rightarrow \delta \tilde{t}_1^{(0)} \\ & \tilde{t}_1 \tilde{t}_1^{(0)} (\theta h)_1 \cdot J_1 \rightarrow \delta \tilde{t}_1^{(0)} \\ & \tilde{t}_1 \tilde{t}_1^{(0)} (\theta m d m )_1 \tilde{t}_1 \rightarrow \delta \tilde{t}_1^{(0)} \\ & \tilde{t}_1 \tilde{t}_1^{(0)} (\theta m a v)_1 \tilde{t}_1 \rightarrow \delta \tilde{t}_1^{(0)} \\ & \tilde{t}_1 \tilde{t}_1^{(0)} (\theta m a v)_1 \tilde{t}_1 \rightarrow \delta \tilde{t}_1^{(0)} \\ & \tilde{t}_1 \tilde{t}_1^{(0)} (\theta m a v)_1 \tilde{t}_1 \rightarrow \delta \tilde{t}_1^{(0)} \\ & \tilde{t}_1 \tilde{t}_1^{(0)} (\theta m a v)_1 \tilde{t}_1 \rightarrow \delta \tilde{t}_1^{(0)} \\ & \tilde{t}_1 \tilde{t}_1^{(0)} (\theta m a v)_1 \tilde{t}_1 \rightarrow \delta \tilde{t}_1^{(0)} \\ & \tilde{t}_1 \tilde{t}_1^{(0)} (\theta m a v)_1 \tilde{t}_1 \rightarrow \delta \tilde{t}_1^{(0)} \\ & \tilde{t}_1 \tilde{t}_1 (\theta m a v)_1 \tilde{t}_1 \rightarrow \delta \tilde{t}_1^{(0)} \\ & \tilde{t}_1 \tilde{t}_1 (\theta m a v)_1 \tilde{t}_1 \rightarrow \delta \tilde{t}_1^{(0)} \\ & \tilde{t}_1 \tilde{t}_1 (\theta m a v)_1 \tilde{t}_1 \rightarrow \delta \tilde{t}_1^{(0)} \\ & \tilde{t}_1 \tilde{t}_1 (\theta m a v)_1 \tilde{t}_1 \rightarrow \delta \tilde{t}_1^{(0)} \\ & \tilde{t}_1 \tilde{t}_1 (\theta m a v)_1 \tilde{t}_1 \rightarrow \delta \tilde{t}_1^{(0)} \\ & \tilde{t}_1 \tilde{t}_1 (\theta m a v)_1 \tilde{t}_1 \rightarrow \delta \tilde{t}_1^{(0)} \\ & \tilde{t}_1 \tilde{t}_1 (\theta m a v)_1 \tilde{t}_1 \rightarrow \delta \tilde{t}_1^{(0)} \\ & \tilde{t}_1 \tilde{t}_1 (\theta m a v)_1 \tilde{t}_1 \rightarrow \delta \tilde{t}_1^{(0)} \\ & \tilde{t}_1 \tilde{t}_1 (\theta m a v)_1 \tilde{t}_1 \rightarrow \delta \tilde{t}_1^{(0)} \\ & \tilde{t}_1 $	$\begin{array}{c} 0 \\ 2 \ e, \mu \ (SS) \\ 1.2 \ e, \mu \\ 2 \ e, \mu \\ 2 \ e, \mu \\ 0 \\ 1 \ e, \mu \\ 0 \\ 3 \ e, \mu \ (Z) \end{array}$	2 b 0-3 b 1-2 b 0-2 jets 2 jets 2 b 1 b 2 b 1 b 2 b 1 b 1 b 1 b 1 b 1 b 1 b	en en en en en en en en en en en en en e	20.1 20.3 4.7 20.3 20.3 20.1 20.1 20.3 20.3 20.3 20.3	J.         100-850 Gay           J.         100/810 Gay           J.         100/810 Gay           J.         100/810 Gay           J.         100/810 Gay           J.         100/80 Gay           J.         100/80 Gay           J.         100/80 Gay           J.         100/80 Gay           J.         500/80 Gay	(ແຖ້)-350 GaV (ແຖ້)-355 GaV (ແຖ້)-355 GaV (ແຖ້)-355 GaV (ແຖ້)-355 GaV (ແຖ້)-350 GaV (ແຖ້)-350 GaV (ແຖ້)-350 GaV (ແຖ້)-350 GaV (ແຖ້)-350 GaV (ແຖ້)-350 GaV (ແຖ້)-350 GaV	1308.2831 1404.2500 1208.4305,1209.2102 1403.4853 1308.2631 1407.0583 1406.1122 1407.0608 1403.5222 1403.5222
EW dîrect	$ \begin{array}{c} l_{1,\mathbf{R}} l_{1,\mathbf{R}}, l \rightarrow l \tilde{k}_{1}^{0} \\ \tilde{k}_{1}^{*} \tilde{k}_{1}^{*}, \tilde{k}_{1}^{*} \rightarrow l n (\tilde{r}) \\ \tilde{k}_{1}^{*} \tilde{k}_{1}^{*}, \tilde{k}_{1}^{*} \rightarrow l n (\tilde{r}) \\ \tilde{k}_{1}^{*} \tilde{k}_{2}^{*} \rightarrow l n (\tilde{r}) \\ \tilde{k}_{1}^{*} \tilde{k}_{2}^{*} \rightarrow l n (\tilde{r}) \\ \tilde{k}_{1}^{*} \tilde{k}_{2}^{*} \rightarrow l n (\tilde{k}) \\ \tilde{k}_{1}^{*} \tilde{k}_{2}^{*} \rightarrow l n (\tilde{k}) \\ \tilde{k}_{2}^{*} \tilde{k}_{2}^{*} \rightarrow W \tilde{k}_{1}^{*} \tilde{k}_{1}^{*} \\ \tilde{k}_{2}^{*} \tilde{k}_{2}^{*} \rightarrow W \tilde{k}_{1}^{*} \tilde{k}_{1}^{*} \\ \tilde{k}_{2}^{*} \tilde{k}_{2}^{*} \rightarrow d \tilde{k} \\ \tilde{k}_{2}^{*} \tilde{k}_{1}^{*} \rightarrow d \tilde{k} \\ \tilde{k}_{2}^{*} \tilde{k}_{1}^{*} \rightarrow d \tilde{k} \\ \end{array} $	2 e, µ 2 e, µ 2 τ 3 e, µ 2 · 3 e, µ 1 e, µ 4 e, µ	0 0 - 0 2 b 0	22 22 22 22 22 22 22 22 22 22 22 22 22	20.3 20.3 20.3 20.3 20.3 20.3 20.3 20.3	2 90-325 GeV 2 140-465 GeV 4 160-300 GeV 4 140-465 GeV 4 140-465 GeV 700 GeV 700 GeV 700 GeV 700 GeV 700 GeV 700 GeV 700 GeV 700 GeV	$\begin{split} m(\xi_1^2) &= 0 \; \text{GeV} \\ m(\xi_1^2) &= 0 \; \text{GeV} \\ m(\xi_1^2) &= 0 \; \text{GeV} (m(\xi_1^2) &= 0 \; \text{GeV}(\xi_1^2) \\ m(\xi_1^2) &= 0 \; \text{GeV} (m(\xi_1^2) &= 0 \; \text{GeV}(\xi_1^2) \\ m(\xi_1^2) &= m(\xi_2^2) \; , m(\xi_1^2) \; \text{GeV}(\xi_1^2) \\ m(\xi_1^2) &= m(\xi_2^2) \; , m(\xi_1^2) \; \text{GeV}(\xi_1^2) \\ m(\xi_1^2) &= m(\xi_1^2) \; , m(\xi_1^2) \; \text{GeV}(\xi_1^2) \\ m(\xi_1^2) &= m(\xi_1^2) \; , m(\xi_1^2) \; \text{GeV}(\xi_1^2) \\ m(\xi_1^2) &= m(\xi_1^2) \; , m(\xi_1^2) \; \text{GeV}(\xi_1^2) \; \text{GeV}(\xi_1^2) \\ m(\xi_1^2) &= m(\xi_1^2) \; , m(\xi_1^2) \; \text{GeV}(\xi_1^2) \; \text{GeV}(\xi_1^2) \\ m(\xi_1^2) &= m(\xi_1^2) \; \text{GeV}(\xi_1^2) \; \text{GeV}(\xi_1^2) \\ m(\xi_1^2) \; m(\xi_1^2) \; \text{GeV}(\xi_1^2)  \text{GeV}(\xi_1^2) \\ m(\xi_1^2) \; \text{GeV}(\xi_1^2)  \text{GeV}(\xi_1^2) \\ m(\xi_1^2) \; \text{GeV}(\xi_1^2)  \text{GeV}(\xi_1^2)  \text{GeV}(\xi_1^2) \\ m(\xi_1^2) \; \text{GeV}(\xi_1^2)  \text$	1403.5294 1403.5294 1407.0550 1402.7029 1403.5294, 1402.7029 ATLAS-CONF-2013.093 1405.5086
Long-lived particles	Direct $\tilde{\chi}_1^+ \tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^+$ Stable, stopped $\tilde{g}$ R-hadron GMSB, stable $\tilde{\tau}, \tilde{\chi}_1^0 \rightarrow \tilde{\tau}(\tilde{e}, \tilde{\mu}) + \tau(e, GMSB, \tilde{\chi}_1^0 \rightarrow gG, long-lived \tilde{\chi}_1^0\tilde{q}\tilde{q}, \tilde{\chi}_1^0 \rightarrow gq\mu (RPV)$	Disapp. trk 0 µ) 1.2 µ 2 γ 1 µ, displ. vtx	1 jet 1-5 jets	Yes Yes Yes	20.3 27.9 15.9 4.7 20.3	11         270 GeV         832 GeV           2         475 GeV         832 GeV           11         230 GeV         475 GeV           4         230 GeV         1.0 TeV	m({t_1^n})-m({t_1^n})=180 MeV, r({t_1^n})=0.2 res m({t_1^n})=100 GeV, 10 \mus<-r({t_1^n})<100 g 10<4mpV-50 0.4<-r({t_1^n})<2 res 1.5<-r<156 mm, BR(\mu)=1, m({t_1^n})=108 GeV	ATLAS-CONF-2013-069 1310.6584 ATLAS-CONF-2013-058 1304.6310 ATLAS-CONF-2013-092
ΡΡV	$\begin{array}{l} LFV pp \! \rightarrow \! \tilde{\mathbf{v}}_{\tau} + \vec{X}, \tilde{\mathbf{v}}_{\tau} \! \rightarrow \! \boldsymbol{c} + \mu \\ LFV pp \! \rightarrow \! \tilde{\mathbf{v}}_{\tau} + \vec{X}, \tilde{\mathbf{v}}_{\tau} \! \rightarrow \! \boldsymbol{c}(\mu) + \tau \\ Bilnear PPV CMSSM \\ \vec{X}_{1}^{+} \vec{X}_{1}, \vec{X}_{1}^{+} \rightarrow \! W \vec{X}_{1}^{0} \vec{X}_{1}^{0} \! \rightarrow \! \boldsymbol{c} \vec{v}_{\mu}, \vec{x}_{1} \! \rightarrow \! \boldsymbol{c} \vec{v}_{\mu} \\ \vec{X}_{1}^{+} \vec{X}_{1}, \vec{X}_{1}^{+} \rightarrow \! W \vec{X}_{1}^{0}, \vec{X}_{1}^{-} \! \rightarrow \! \boldsymbol{c} \vec{v}_{\mu} \\ \vec{X}_{1}^{+} \vec{X}_{1}, \vec{X}_{1}^{+} \rightarrow \! W \vec{X}_{1}^{0}, \vec{X}_{1}^{-} \! \rightarrow \! \boldsymbol{c} \vec{v}_{\mu} \\ \vec{x}_{1} \rightarrow \! \vec{x}_{1}, \vec{X}_{1}^{-} \rightarrow \! W \vec{X}_{1}^{0}, \vec{x}_{1}^{-} \! \rightarrow \! \boldsymbol{c} \vec{v}_{\mu} \\ \vec{x}_{1} \rightarrow \! \vec{x}_{1}, \vec{x}_{1}^{-} \! \rightarrow \! W \vec{X}_{1}^{0}, \vec{x}_{1}^{-} \! \rightarrow \! \boldsymbol{c} \vec{v}_{\mu} \\ \vec{x}_{1} \rightarrow \! \vec{x}_{1}, \vec{x}_{1}^{-} \! \rightarrow \! \mathbf{b} \vec{x} \end{array}$	$\begin{array}{c} 2 \ e, \mu \\ 1 \ e, \mu + \tau \\ 2 \ e, \mu \ (\text{SS}) \\ 4 \ e, \mu \\ 3 \ e, \mu + \tau \\ 0 \\ 2 \ e, \mu \ (\text{SS}) \end{array}$	0-3 b 6-7 jets 0-3 b	· · Ves Ves Ves Ves	4.6 4.6 20.3 20.3 20.3 20.3 20.3 20.3	5. 7.1 Tek 6. 7.1 Tek 7. 750 GeV 7. 450 GeV 7. 916 GeV 7. 916 GeV 7. 916 GeV	1.65         TeV         J <sup>1</sup> <sub>211</sub> , e0.10, J <sub>1210</sub> , e0.05           8         TeV         m <sup>3</sup> <sub>211</sub> , e0.10, J <sub>1210</sub> , e0.05           9         m <sup>3</sup> <sub>211</sub> , e0.10, J <sub>1210</sub> , e0.05           9         m <sup>3</sup> <sub>211</sub> , e0.10, J <sub>1210</sub> , e0.05           9         m <sup>3</sup> <sub>211</sub> , e0.01, J <sub>1210</sub> , e0.05           9         m <sup>3</sup> <sub>2110</sub> , e0.01, J <sub>1110</sub> , e0.01           9         m <sup>3</sup> <sub>2110</sub> , e0.02, m <sup>3</sup> <sub>2110</sub> , J <sub>1110</sub> , e0.01           9         B <sup>3</sup> <sub>2110</sub> , B <sup>3</sup> <sub>2110</sub> , J <sub>1110</sub> , e0.01           9         B <sup>3</sup> <sub>2110</sub> , B <sup>3</sup> <sub>2110</sub> , J <sub>1110</sub> , e0.01	1212.1272 1212.1272 1404.2500 1405.5086 1405.5086 ATLAS-CONF-2013-091 1404.250
Other	$\begin{array}{l} \text{Scalar gluon pair, sgluon } \rightarrow q \bar{q} \\ \text{Scalar gluon pair, sgluon } \rightarrow t \bar{t} \\ \text{WIMP interaction (D5, Dirac } \chi) \end{array}$	2 e, µ (SS) 0	4 jets 2 b mono-jet	Yes Yes	4.6 14.3 10.5	sgluon 100-287 GeV 350-600 GeV sgluon 350-600 GeV N* scale 704 GeV	incl. limit from 1110.2693 m(g)<80 GeV, limit of~687 GeV for D8	1210.4826 ATLAS-CONF-2013-051 ATLAS-CONF-2012-147
	Vs = 7 TeV full data	vs = 8 TeV artial data	√s = full	8 TeV data		10-1 1	Mass scale [TeV]	

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



To summarize the picture in the constrained MSSM:

- ▶ sparticles and  $H, A, H^{\pm}$  beyond the current LHC reach
- branching ratios of the light Higgs h close to the SM values
- ▶ the branching ration for  $B_s \rightarrow \mu\mu$  close to the SM value
- no dark matter signal in current direct or indirect searches
- ► The cMSSM looks like the SM with dark matter.
- ► The cMSSM could mean grim prospects for LHC phenomenology.
- ► The cMSSM cannot solve the hierarchy problem.

We find that the cMSSM is pretty dull. But is it already dead?

Estimate the *p*-value:

If the cMSSM at the best fit point is the true description of nature, what is the probability p to get a minimal  $\chi^2$  as bad or worse that the one observed?

For a set of observables with Gaussian uncertainties, only need # of degrees of freedom and  $\chi_{\min}$  to calculate the p-value.

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Unfortunately, the uncertainties are, in general, non-Gaussian, so we have to perform toy fits:

- generate (1000) pseudo-measurements by smearing the experimental observables about the best-fit prediction;
- ► repeat the global fit for each of these pseudo-measurements.

How often do we get a minimal  $\chi^2$  as bad or worse than the one of the best-fit point?  $\to$  p-value

## How dead is the cMSSM?



• without 
$$(g - 2)_{\mu}$$
:  
 $p = (51 \pm 3)\%$ 

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- without Higgs properties:  $p = (1.3 \pm 0.4)\%$
- including 10 Higgs rate and 4 Higgs mass measurements:
   p = (4.9 ± 0.7)%



- without  $(g 2)_{\mu}$ :  $p = (51 \pm 3)\%$
- without Higgs properties:  $p = (1.3 \pm 0.4)\%$
- including 4 Higgs rate and 1 Higgs mass measurements:
   p = (8.3 ± 0.8)%

The *p*-value depends on the parametrization of the Higgs observables.



- without  $(g 2)_{\mu}$ :  $p = (51 \pm 3)\%$
- without Higgs properties:  $p = (1.3 \pm 0.4)\%$
- including 4 Higgs rate and 1 Higgs mass measurements:
   p = (8.3 ± 0.8)%

The cMSSM is a dull zombie...



### Future global SUSY/BSM fits should

- include the Higgs observables;  $\checkmark$
- calculate the *p*-value using toy fits;  $\checkmark$
- address more general models;
- include a larger set of LHC observables.

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#### Use simplified models?

Do not analyse data in terms of



### Future global SUSY/BSM fits should

- include the Higgs observables;  $\checkmark$
- ► calculate the *p*-value using toy fits; √
- address more general models;
- include a larger set of LHC observables.

### Use simplified models?

but rather in terms of few simple topologies like



### However...

- how do we choose the right simplified models?
- need to translate interpretation of data obtained using simplified models to interpretation of physics models
- need to assume that acceptance and detector efficiency of simplified models is similar for a specific model; how to quantify the error?
- what about backgrounds? Specific models may have additional sources of background which are not included in simplified models

The error in the translation simplified model  $\leftrightarrow$  physics model



needs to be quantified

## Towards model independent searches: simplified models

 Compare simplified model T2 with squark production in the MSSM [Edelhäuser, Heisig, MK, Oymanns, Sonneveld (1410.0965)]

#### $\mathsf{acceptance}\,\times\,\mathsf{efficiency}$



 $m_{\overline{q}} \,[\,{
m GeV}\,]$ 

## Towards model independent searches: simplified models

Compare simplified model T2 with squark production in the MSSM

[Edelhäuser, Heisig, MK, Oymanns, Sonneveld (1410.0965)]

#### mass limits



 $\rightarrow$  simplified models provide a reliable tool to interpret LHC searches in a more model-independent way.

## Summary and conclusions

#### Where could new physics hide?

New physics could have a

- split spectrum and thus reduced production cross section (e.g. "natural" SUSY with light stops)
- different decay pattern (e.g. compressed spectra)

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#### For LHC13 we need to

- explore a wider range of BSM models
- move towards more model-independent searches (effective field theories, simplified models, ...)
- ► increase the precision of the theoretical predictions (higher-order corrections, pdfs, ...)

However, new physics could simply be unnatural ....

## anthropic desert

## Garden Eden of new physics



# Backup slides









