

# CMSSM & LHC

Workstatt seminar  
SS 2012 Felix Brieger

## CMSSM $\subset$ MSSM

"constrained minimal supersymmetry  $\rightarrow$  Standard Model"

In general:

$$\begin{aligned} \mathcal{L}_{\text{SUSY}} = & -\frac{1}{2} \sum_{a=1}^3 M_a \lambda^a \lambda^a + \text{h.c.} \\ & + \sum_{i,j=1}^3 (m_{\tilde{Q}_{ij}}^2 \tilde{Q}_i^\dagger \tilde{Q}_j + m_{\tilde{U}_{ij}}^2 \tilde{U}_i^\dagger \tilde{U}_j + m_{\tilde{D}_{ij}}^2 \tilde{D}_i^\dagger \tilde{D}_j + m_{\tilde{L}_{ij}}^2 \tilde{L}_i^\dagger \tilde{L}_j + m_{\tilde{E}_{ij}}^2 \tilde{E}_i^\dagger \tilde{E}_j) \\ & + \sum_{i,j=1}^3 (a_{U_{ij}} \tilde{Q}_i \tilde{U}_j H_u + a_{D_{ij}} \tilde{Q}_i \tilde{D}_j H_d + a_{E_{ij}} \tilde{L}_i \tilde{E}_j H_d + \text{h.c.}) \\ & + m_{H_u}^2 |H_u|^2 + m_{H_d}^2 |H_d|^2 + (B_\mu H_u H_d + \text{h.c.}) \end{aligned}$$

$\sim 100$  physical parameters (+ Yukawas + gauge couplings +  $\mu$ )  
scale-dependent  $\rightarrow$  RGEs

CMSSM: assume

- \* ① gravity mediation
- \* ② grand unification
- \* ③ SUSY broken by GUT singlet
- \* ④ life is (unreasonably?) simple

①+②  $\Rightarrow$  specify parameters at  $M_{\text{GUT}} \approx 2 \cdot 10^{16}$  GeV  
Below  $M_{\text{GUT}}$ , EFT is MSSM

③  $\Rightarrow M_1(M_{\text{GUT}}) = M_2(M_{\text{GUT}}) = M_3(M_{\text{GUT}}) \equiv M_{1/2}$   
gauge mass unification

④ At  $M_{\text{GUT}}$ :

$$\left. \begin{aligned} m_{\tilde{Q}}^2 = m_{\tilde{U}}^2 = m_{\tilde{D}}^2 = m_{\tilde{L}}^2 = m_{\tilde{E}}^2 = m_0^2 \mathbb{I} \\ m_{H_u}^2 = m_{H_d}^2 = m_0^2 \end{aligned} \right\} \begin{array}{l} \text{universal scalar} \\ \text{soft masses} \end{array}$$

$$a_{U,D,E} = A_0 \cdot Y_{U,D,E} \quad \text{universal trilinears}$$

$\uparrow$   
Yukawas

What about  $\mu$  &  $B_\mu$ ?  $\hookrightarrow$  Trade for  $\tan\beta$ ,  $m_z$ ,  $\text{sign}(\mu)$

$$\left. \begin{aligned} \sin 2\beta &= \frac{2B_\mu}{m_{H_u}^2 + m_{H_d}^2 + 2|\mu|^2} \\ m_z^2 &= \frac{m_{H_d}^2 - m_{H_u}^2}{\sqrt{1 - \sin^2 2\beta}} - m_{H_u}^2 - m_{H_d}^2 - 2|\mu|^2 \end{aligned} \right\} \begin{array}{l} \text{at} \\ \text{EW} \\ \text{scale} \end{array}$$

Free parameters:

$$\boxed{M_{1/2}, m_0, A_0, \tan\beta, \text{sign}(\mu)}$$

Why universal  $m_0$  and  $A_0$ ?

- \* convenience
- \* no flavour problems
- \* "predicted" by minimal SUGRA "models"

e.g. Polonyi:  $W = W_{\text{MSSM}} + fX + c \quad c = (2-\sqrt{3})f/M_p$   
 $K = K_{\text{MSSM}} + |X|^2$

$$\hookrightarrow \langle X \rangle = (\sqrt{3} - 1) M_p + \sqrt{3} f \theta^2 \quad \frac{\theta}{\sqrt{2}}$$

Get soft terms from expanding

$$V = e^{\frac{K}{M_p^2}} \left( \left| \frac{\partial W}{\partial \phi_i} \right|^2 + \frac{\partial K}{\partial \phi_i} \frac{W}{M_p^2} \right)^2 - 3|W|^2$$

More realistic:

- \* NUHM ( $m_{H_u}^2, m_{H_d}^2$  non-universal)
- \* separate 3rd generation
- \* more general MFV patterns
- \* pick your favourite model prediction, e.g. DMH:  $m_{H_u}^2 + |\mu|^2 = m_{H_d}^2 + |\mu|^2 = \beta_\mu @ M_{GUT}$

CMSSM spectrum

- \*  $M_1 : M_2 : M_3 \equiv 1 : 2 : 6$   
typically  $\beta$ -ino LSP
- \* small mass splittings between 1st and 2nd generation sfermions  
(mass differences induced by small Yukawas through RG running)
- \* squarks heavier than sleptons for 1st and 2nd gen.  
(gluino contribution to masses large and +ve)

SUSY @ LHC

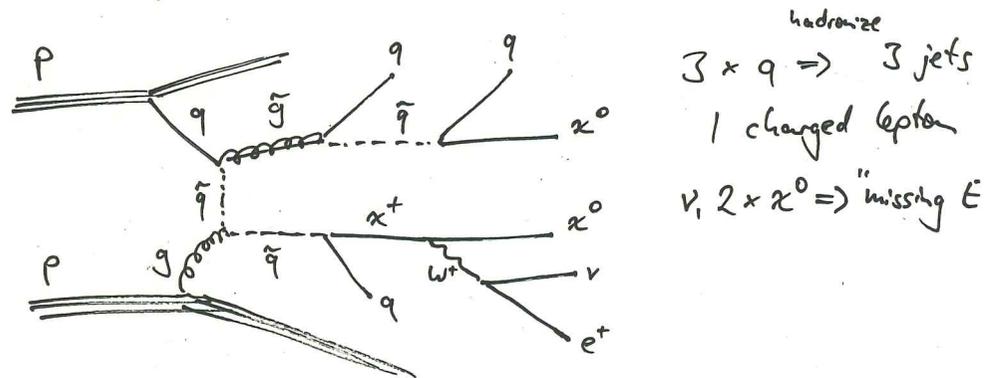
2 major sources of constraints:

- ① no signal in jets + MET (+ leptons)  $\Rightarrow$  gluinos & 1st gen. squarks heavy
- ②  $m_{h_0} \approx 125$  GeV  $\Rightarrow$  3rd gen. squarks heavy and/or strongly mixed

①

R-parity: SUSY particles produced pairwise  
LHC collides protons: mainly get coloured particles, gluinos or 1st gen. squarks

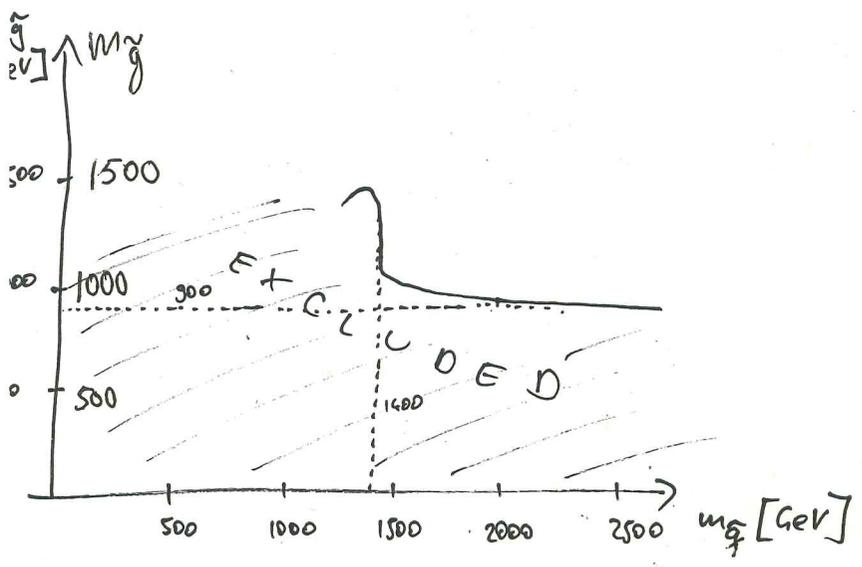
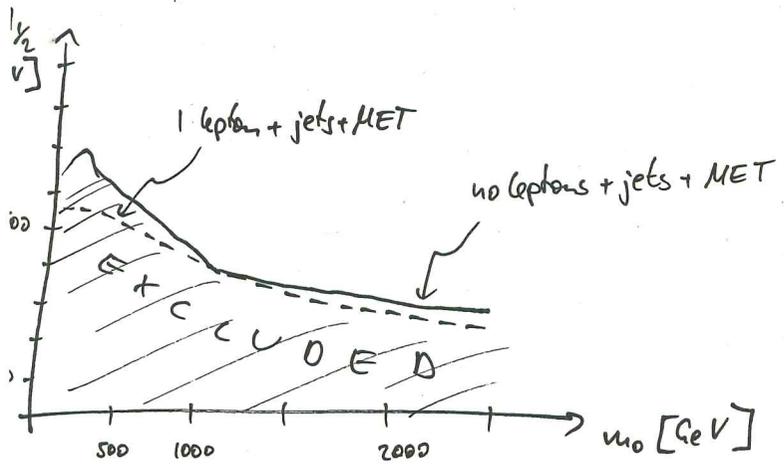
Typical process:



SM produces plenty of jets in QCD,  
missing energy from neutrinos (and unmeasured)

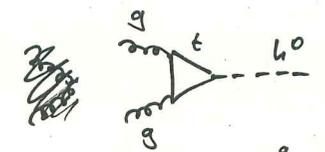
To distinguish signal from background:  
hard cuts on MET and transverse momenta

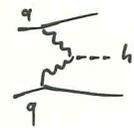
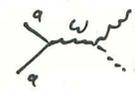
ATLAS,  $4.7 \text{ fb}^{-1}$ , CMSSM,  $\tan \beta = 10$ ,  $A_0 = 0$ ,  $\mu > 0$



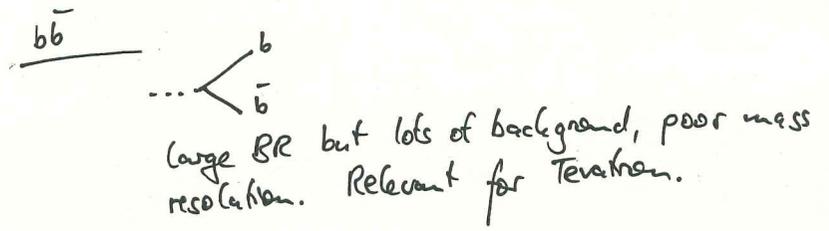
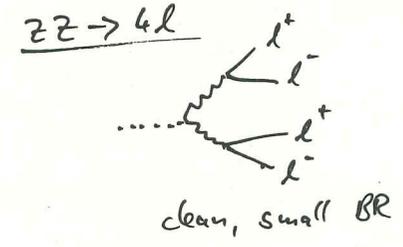
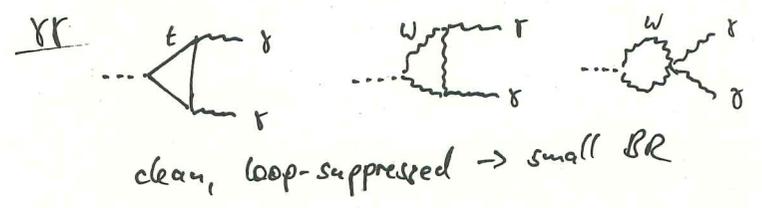
② LHC Higgs searches

production mainly in gluon fusion



(also VBF , associated with W  etc.)

decays:



others  
γγ, WW, ...

- Experiments:
- \* ATLAS has excess in  $\gamma\gamma$  and  $4l$  around 125 GeV
  - \* CMS has excess in  $\gamma\gamma$  around 125 GeV (and in  $ZZ$  around 120)
  - \* Tevatron sees broad excess all over allowed range

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Previous lecture:

in decoupling limit ( $m_{H^0} \gg m_Z$ )

$$m_{H^0}^2 = m_{H^0}^2(\text{tree}) + m_{H^0}^2(1\text{-loop}) + \dots$$

$$= m_Z^2 \cos^2 2\beta + \frac{3}{4\pi^2} \frac{m_t^4}{v^2} \left[ \log \frac{m_s^2}{m_t^2} + \frac{X_t^2}{m_s^2} \left( 1 - \frac{X_t^2}{12m_s^2} \right) \right] + \dots$$

\*  $m_t = m_t(m_t)$  running top mass

\*  $v = 174 \text{ GeV}$

\*  $m_s^2 = \overline{m_{\tilde{t}_1}^2} \overline{m_{\tilde{t}_2}^2}$  average stop mass  
~ optimal scale to evaluate 1-loop contribution

\*  $X_t = A_t - \mu/\tan\beta$  stop mixing parameter

Experiment (preliminary):

$$m_{H^0}^2 \stackrel{?}{=} (125 \text{ GeV})^2$$

$$= (91 \text{ GeV})^2 + (86 \text{ GeV})^2$$

$\uparrow$   $\uparrow$   $\uparrow$   
 $\tan\beta \geq 5$  tree 1-loop

Need large loop contributions:

$$\text{either } \left[ \frac{m_s}{m_t} \text{ large} \right] \text{ or } \left[ \frac{X_t^2}{m_s^2} \left( 1 - \frac{X_t^2}{12m_s^2} \right) \text{ large} \right]$$

\*  $m_s \gg m_t$ : heavy stops  $\rightarrow$  naturalness problem

\*  $\frac{X_t}{m_s}$  contribution maximal at  $\left| \frac{X_t}{m_s} \right| \approx \sqrt{6}$  "maximal mixing scenario"

In CMSSM, for illustration:

no mixing ( $X_t = 0$ ): need  $m_s \gtrsim 3 \text{ TeV}$  for  $m_{H^0} > 123 \text{ GeV}$

maximal mixing ( $\left| \frac{X_t}{m_s} \right| \approx 2$ ):  $m_s \gtrsim 1 \text{ TeV}$

Bottom line

\* no squarks or gluinos found  $\Rightarrow$  1st generation squarks and gluino probably  $\gtrsim 1 \text{ TeV}$

\* "heavy" Higgs  $\Rightarrow$  stops probably  $\gtrsim 1 \text{ TeV}$

\* many models are more difficult to probe than the CMSSM: limits weaker