Tools for the Interplay Between LHC and SuperB

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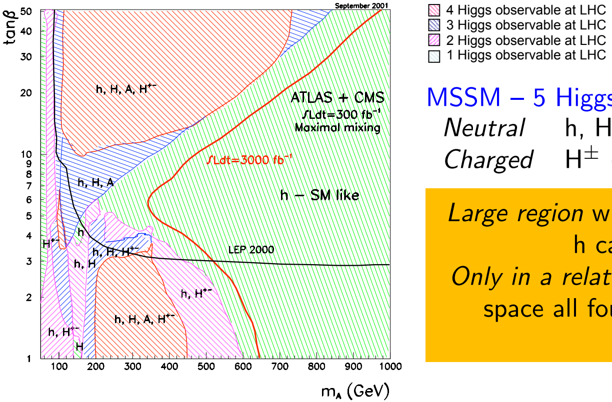
ETH Zurich – Switzerland

SuperB workshop, Valencia – January 9, 2007

Contents

On the importance of the interplay (I)



MSSM – 5 Higgs bosons:

Neutral	h, H (*CP* even), A (*CP* odd)
Charged	$H^{\pm}$ (one observable)

Large region where only the light SM-like h can be detected. *Only in a relatively small region* of phase space all four Higgs bosons can be discovered

Adding information from discoverable sparticles will help in the interpretation of the undetectable heavy Higgs sector. Yet, an unambiguous MSSM parameter extraction over the entire phase space cannot be guaranteed.

On the importance of the interplay (II)

Key ingredients: Direct discoveries & **all other data**:

"All other data"

- Low Energy (precision) data:
  - Flavour Physics (in particular B Physics)
  - Other low-energy observables (*e.g.*, $g-2$)
- High energy (precision) data
  - Precision electroweak observables (*e.g.*, $m_{\rm top}$, $m_{\rm W}$)
- Cosmology/Astroparticle data
  - *e.g.*, relic density

Exploiting this interplay requires:

⇒ "tools" to predict the observables

⇒ combination of the tools

Common framework development

A common framework for indirect constraints

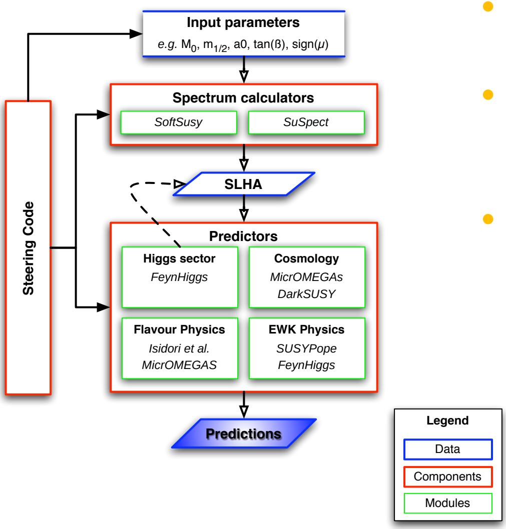
- Goal: a framework to provide consistent indirect constraints
- Collaboration of interested theorists and experimentalists

  Buchmüller, Oliver (CERN) – Exp.
  De Roeck, Albert (CERN & Uni. Antwerpen) – Exp.
  Heinemeyer, Sven (Santander) – Theo.
  Olive, Keith (Uni. of Minnesota) – Theo.
  Ronga, Frédéric (CERN) – Exp.
  Weiglein, Georg (Durham) – Theo.
  Cavanaugh, Richard (Uni. of Florida) – Exp.
  Ellis, John (CERN) – Theo.
  Isidori, Gino (INFN Frascati) – Theo.
  Paradisi, Paride (Uni. of Valencia) – Theo.
  Weber, Arne (Max Planck Inst. (Munich)) – Theo.

- Started at workshop on *Flavour Physics in the Era of the LHC*
  ⇒ See (draft) report, sec. 5.2
- Main focus of the work:
  - Development of a *common tool* for indirect constraints
  - Compilation (and integration) of state-of-the-art predictions
  - Application of the tool

O. Buchmüller *et al.*, PLB 657/1-3 pp 87-94

Flow-chart: general overview



- Consistency
  Relies on SLHA interface
- Modularity
  Compare calculations
  Add/remove predictions
- State-of-the art calculations
  Direct use of code from experts

The SUSY Les Houches Accord

- Text-file based interface
- Consistent definition of observables (on agreement...)
- Flexible and extendable "block" structure
- Version 2 to improve on flavour Physics side (*e.g., NMFV*)
- Reference:
  B. Allanach *et al.*,
  arXiv:0801.0045 [hep-ph]

```
# SOFTSUSY2.0.11
# B.C. Allanach, Comput. Phys. Commun. 143 (2002) 305-331
Block SPINFO         # Program information
     1    SOFTSUSY   # spectrum calculator
     2    2.0.11     # version number
Block MODSEL  # Select model
     1    1    # sugra
Block SMINPUTS    # Standard Model inputs
     1     1.279089567e+02    # alpha_em^(-1)(MZ) SM MSbar
     2     1.166370000e-05    # G_Fermi
     3     1.187000000e-01    # alpha_s(MZ)MSbar
     4     9.118760000e+01    # MZ(pole)
     5     4.200000000e+00    # mb(mb)
     6     1.600000000e+02    # Mtop(pole)
     7     1.751640860e+00    # Mtau(pole)
Block MINPAR  # SUSY breaking input parameters
     3     2.772830258e+01    # tanb
     4     1.000000000e+00    # sign(mu)
     1     8.000000000e+01    # m0
     2     2.315986873e+02    # m12
     5     1.635072275e+02    # A0
# Low energy data in SOFTSUSY: MIXING=-1 TOLERANCE=1.0e-03
# mgut=2.234873065e+16 GeV
Block MASS   # Mass spectrum
#PDG code      mass               particle
        24     8.032985208e+01    # MW
        25     1.046781032e+02    # h0
        35     2.648237588e+02    # H0
        36     2.646455512e+02    # A0
        37     2.772215402e+02    # H+
        ...
```

List of available predictions [relevant today already]

Low energy observables

$\mathrm{BR}(b \to s\gamma)$	Isidori & Paradisi	MicrOMEGAs
$\mathrm{BR}(B_s \to \mu\mu)$	Isidori & Paradisi	MicrOMEGAs
$\mathrm{BR}(B \to \tau\nu)$	Isidori & Paradisi	
$\mathrm{BR}(K \to \tau\nu)$	Isidori & Paradisi	
$\mathrm{BR}(b \to X_s\ell\ell)$	Isidori & Paradisi	
$\mathrm{BR}(K \to \pi\nu\bar{\nu})$	Isidori & Paradisi	
$\mathrm{BR}(B_s \to \ell\ell)$	Isidori & Paradisi	
$\mathrm{BR}(B_d \to \ell\ell)$	Isidori & Paradisi	
Δm_s	Isidori & Paradisi	
$\Delta m_s/\Delta m_d$	Isidori & Paradisi	
Δm_K	Isidori & Paradisi	
$g-2$	FeynHiggs	

Higgs sector observables

m_h^{light}	FeynHiggs

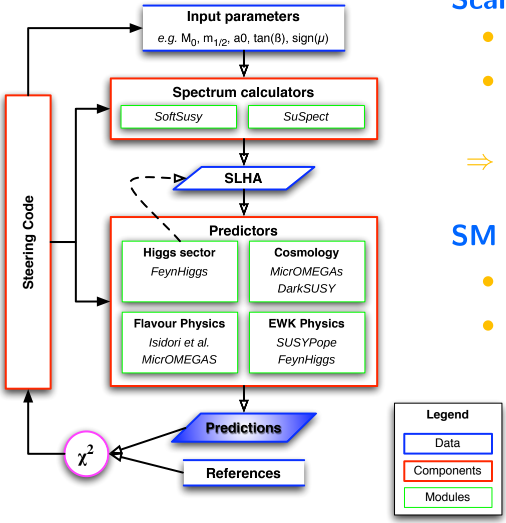
Cosmology observables

Ωh^2	MicrOMEGAs	DarkSUSY
σ_p^{SI}	DarkSUSY	

Electroweak observables

$\Delta\alpha_{\mathrm{had}}^{(5)}(m_Z^2)$	SUSY-Pope
m_Z	SUSY-Pope
Γ_Z	SUSY-Pope
σ_{had}^0	SUSY-Pope
R_l	SUSY-Pope
$A_{\mathrm{fb}}(\ell)$	SUSY-Pope
$A_\ell(P_\tau)$	SUSY-Pope
R_b	SUSY-Pope
R_c	SUSY-Pope
$A_{\mathrm{fb}}(b)$	SUSY-Pope
$A_{\mathrm{fb}}(c)$	SUSY-Pope
A_b	SUSY-Pope
A_c	SUSY-Pope
$A_\ell(\mathrm{SLD})$	SUSY-Pope
$\sin^2\theta_w^\ell(Q_{\mathrm{fb}})$	SUSY-Pope
m_W	SUSY-Pope
m_t	SUSY-Pope

Use-case: fit (today's) data (χ^2 minimisation)



Scan of the Higgs boson mass

- Constrain m_h to scan value;
- minimize all model parameters in each point;

⇒ determine error on m_h prediction

SM fit:

- $m_H = 78^{+33}_{-24}$ GeV$/c^2$
- 12% probability at exclusion limit *Including theoretical uncertainty*

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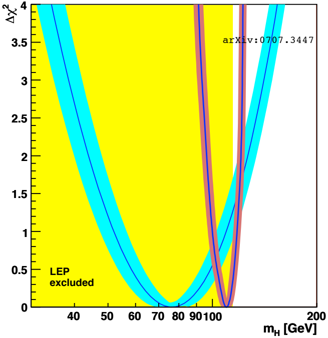

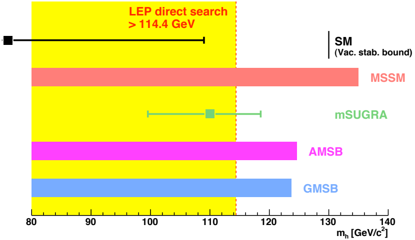

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SM fit:

- $m_H = 78^{+33}_{-24}$ GeV$/c^2$
- 12% probability at exclusion limit
  Including theoretical uncertainty

CMSSM fit:

- $m_h = 110^{+8}_{-10} \pm 3$ GeV$/c^2$
- 20% probability at exclusion limit
  Including theoretical uncertainty

Status and perspective

Recent progress

- New flavour code (G. Isidori and P. Paradisi)
  Now with SLHA interface
- New models: NUHM I, NUHM II (+ CMSSM, "Pheno. MSSM")
- Used in different modes
  χ^2 minimisation, pseudo-experiments, Markov Chain Monte Carlo, standalone

Future plans

- Improving the flavour sector description (SLHA2)
- Publicly providing consistent predictions

Impact of future LHC constraints

A dream for the future of LHC

Imagine. . .

- LHC has collected 300/fb of data;
- CMSSM is a good description of physical laws;
- (minimal flavour violation still holds;)
- data favours the "SPS1a" point.

. . . then:

⇒ What would flavour predictions look like?

- How would SuperB perform?
- How much would it take to constrain these predictions? And/or contradict MFV?

⇒ How would SuperB help in the extraction of MSSM parameters?

- You will have more ideas then I do. . .

Note: *very* preliminary study!

The SPS1a benchmark point

A (too) good point for LHC!

$$\begin{aligned} M_0 &= +100\ \mathrm{GeV}/c^2 \\ M_{1/2} &= +250\ \mathrm{GeV}/c^2 \\ A_0 &= -100\ \mathrm{GeV}/c^2 \\ \tan\beta &= +10 \\ \mathrm{sign}(\mu) &= +1 \end{aligned}$$

Allows cascade decay

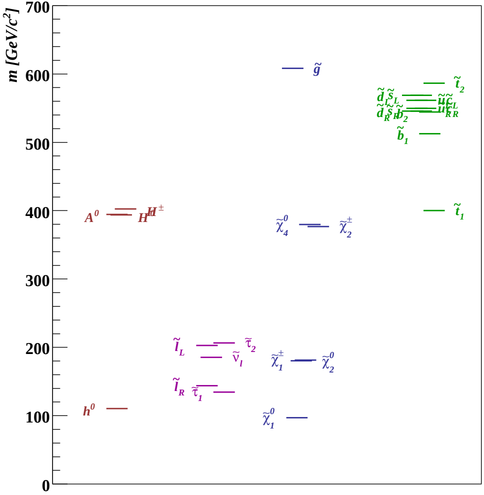
$\tilde{q}_L \to \tilde{\chi}^0_2 q \to \tilde{\ell}_R \ell q \to \tilde{\chi}^0_1 \ell\ell q$

for "edge" measurements:

$$\left(m^2_{ll}\right)^{\mathrm{edge}} = \frac{\left(m^2_{\tilde{\chi}^0_2} - m^2_{\tilde{l}_R}\right)\left(m^2_{\tilde{l}_R} - m^2_{\tilde{\chi}^0_1}\right)}{m^2_{\tilde{l}_R}}$$

$$\left(m^2_{qll}\right)^{\mathrm{edge}} = \frac{\left(m^2_{\tilde{q}_L} - m^2_{\tilde{\chi}^0_2}\right)\left(m^2_{\tilde{\chi}^0_2} - m^2_{\tilde{\chi}^0_1}\right)}{m^2_{\tilde{\chi}^0_2}}$$

$$\left(m^2_{ql}\right)^{\mathrm{edge}}_{\mathrm{min}} = \frac{\left(m^2_{\tilde{q}_L} - m^2_{\tilde{\chi}^0_2}\right)\left(m^2_{\tilde{\chi}^0_2} - m^2_{\tilde{l}_R}\right)}{m^2_{\tilde{\chi}^0_2}}$$



SUSY spectrum at SPS1a

Note: *SPS1a is close to the overall preferred minimum with today's data.*

LHC performance at SPS1a [hep-ph/0410364]

Performance based on 300/fb (2014)

SUSY spectrum [GeV]

	Mass	Error
$\tilde{\chi}_1^0$	96.9	4.8
$\tilde{\chi}_2^0$	179.8	4.7
$\tilde{\chi}_4^0$	375.6	5.1
$\tilde{e}_R$	144.1	4.8
$\tilde{e}_L$	202.6	5.0
$\tilde{\mu}_R$	144.1	4.8
$\tilde{\mu}_L$	202.6	5.0
$\tilde{\tau}_1$	134.7	8.0
$\tilde{q}_R$	547.5	12.0
$\tilde{q}_L$	565.0	8.7
$\tilde{b}_1$	514.9	7.5
$\tilde{b}_2$	544.1	7.9
$\tilde{g}$	608.0	8.0
h^0	112.9	0.25

Edge measurements [GeV]

$(m_{\ell\ell})^{\text{edge}}$	58.878	0.085
$(m_{q\ell\ell})^{\text{edge}}$	451.1	4.5
$(m_{ql})^{\text{edge}}_{\text{min}}$	317.5	3.1

All ideal masses generated by `SoftSusy`

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⇒ Impact on CMSSM parameters

- include this spectrum as constraints;
- combine with today's constraints;
- get best fit values and errors:

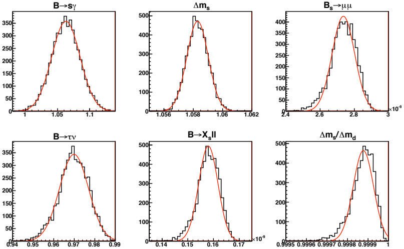
$$M_0 = 100.0 \pm 1.5$$
$$M_{1/2} = 250.0 \pm 1.1$$
$$A_0 = 100 \pm 30$$
$$\tan\beta = 9.8 \pm 1.2$$

All ideal masses generated by `SoftSusy`

Flavour Physics predictions

Strong impact of LHC constraints on Flavour Sector!

$$
\begin{array}{lcl}
R(B \to s\gamma) & = & 1.063 \pm 0.022 \\
R(\Delta m_s) & = & 1.0582 \pm 0.0007 \\
R(B \to \tau\nu) & = & 0.970 \pm 0.007 \\
R(B \to X_s \ell\ell) & = & 0.910 \pm 0.003 \\
R(\Delta m_s / \Delta m_d) & = & 0.99988 \pm 0.00005 \\
B_s \to \mu\mu & = & 2.736\text{e-}09 \pm 0.066\text{e-}9 \\
B_d \to \mu\mu & = & 1.580\text{e-}10 \pm 0.038\text{e-}10
\end{array}
$$



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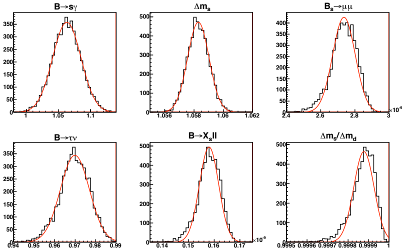

But...

- this point is especially good for L(H)C;
- we assumed MFV;
- correlations are not taken into account.

Discussion

Summary & Discussion

- Extraction of SUSY parameters will need all players
- Efforts to combine. . .
  - various sets of constraints
  - in various models
  - and various ways

  . . . are ongoing
- Our code could help answer a few questions for SuperB. . .
  - observing deviations from minimal flavour violation;
  - adding constraints for the extraction of MSSM parameters.