A common framework for indirect MSSM constraints

Frédéric Ronga

CERN – Switzerland


Contents

1 Interplay between flavour Physics and LHC
2 Common framework development
3 Lightest Higgs boson mass in the CMSSM
Interplay between flavour Physics and LHC

LHC discovery reach in the MSSM sector

4 Higgs observable at LHC
3 Higgs observable at LHC
2 Higgs observable at LHC
1 Higgs observable at LHC

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 where 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.
Interplay between flavour Physics and LHC

Interpretation of New Physics Discoveries

Key ingredients: Direct discoveries & all other data

Direct discoveries

• at the LHC
• at a high energy linear collider (ILC)

“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., $m_{\text{top}}$, $m_W$)

• Cosmology/Astroparticle data
  ■ e.g., relic density
Common framework development
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.
  
  
  Isidori, Gino (INFN Frascati) – Theo.
  
  Ronga, Frédéric (CERN) – Exp.
  
  Weiglein, Georg (Durham) – Theo.
  
  Cavanaugh, Richard (Uni. of Florida) – Exp.
  
  Heinemeyer, Sven (Santander) – Theo.
  
  Paradisi, Paride (Uni. of Valencia) – Theo.
  

- Started at workshop on *Flavour Physics in the Era of the LHC*

- 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
Common framework development

Flow-chart: general overview

- Consistency
  
  *Ensured using SLHA interface*

- Flexibility
  
  *Add/remove predictions*

- Modularity
  
  *Compare various calculations*

Steering Code

Predictors

Input parameters

- \( M_0 \), \( m_{1/2} \), \( a_0 \), \( \tan(\beta) \), \( \text{sign}(\mu) \)

Spectrum calculators

- SoftSusy
- SuSpect

SLHA

Predictors

- Higgs sector
  - FeynHiggs
- Cosmology
  - MicrOMEGAs
  - DarkSUSY
- Flavour Physics
  - Isidori et al.
  - MicrOMEGAs
- EWK Physics
  - A. Weber et al.
  - FeynHiggs

Predictions

Legend

- Data
- Components
- Modules
Common framework development

**Use-case I: input to external SUSY fitters**

- **Steering Code**
  - **Predictors**
    - **Input parameters**
      - e.g. $M_0$, $m_{1/2}$, $a_0$, $\tan(\beta)$, $\text{sign}(\mu)$
    - **Spectrum calculators**
      - SoftSusy
      - SuSpect
      - SLHA
    - **Predictors**
      - Higgs sector
        - FeynHiggs
      - Cosmology
        - MicrOMEGAs
        - DarkSUSY
      - Flavour Physics
        - Isidori et al.
        - MicrOMEGAS
      - EWK Physics
        - A.Weber et al.
        - FeynHiggs
      - **SUSY fitters**
        - Fittino
        - SFitter
  - **Predictions**
    - Provide consistent predictions (low-energy, EW, etc.) to LHC/ILC-oriented fitters.
Use-case II: fit today’s data ($\chi^2$ minimisation)

- Input parameters: $e.g., M_0, m_{1/2}, a_0, \tan(\beta), \text{sign}(\mu)$
- Spectrum calculators: SoftSusy, SuSpect
- Predictors: Higgs sector (FeynHiggs), Cosmology (MicrOMEGAs, DarkSUSY), Flavour Physics (Isidori et al., MicrOMEGAS), EWK Physics (A. Weber et al., FeynHiggs)
- SLHA
- Predictions
- References

⇒ Constrain SUSY parameter space
⇒ Will become even more stringent when combined with discoveries!
Lightest Higgs boson mass in the CMSSM
Many of the popular models require the lightest Higgs boson mass to be significantly below 200 GeV.

\[ m_h \text{ limits from arXiv:hep-ph/0412214} \]

⇒ It could just be around the corner! (if it exists...)

F.J. Ronga (CERN)
Multi-parameter $\chi^2$ fit:

$$\chi^2 = \sum_i^N \frac{(C_i - P_i)^2}{\sigma(C_i)^2 + \sigma(P_i)^2} + \sum_i^M \frac{(f_{SM}^{obs} - f_{SM}^{fit})^2}{\sigma(f_{SM}^{SM})^2}$$

- fitting for all CMSSM parameters: $M_0$, $M_{1/2}$, $A_0$, $\tan \beta$;
- including relevant SM uncertainties (e.g. $m_{\text{top}}$);

→ details in O. Buchmüller et al., arXiv:0707.3447 [hep-ph]

Natural extension of J. Ellis et al., arXiv:0706.0652 [hep-ph]
“Preferred” parameter space

From fits on 2000 pseudo-experiments

- overall preferred minimum at low \( \tan \beta \), low squark mass;
- less preferred region at high \( \tan \beta \), higher squark mass;
- consistent with previous studies.

Note: includes limit from LEP

Similar analyses:
- Trotta, Austri, Roszkowski – hep-ph/0609126

⇒ Turn to fit without limit on \( m_h \) assessing preferred \( m_h \) value in CMSSM
**Lightest Higgs boson mass in the CMSSM**

**Fit result:** no constraint on $m_h$

### CMSSM

<table>
<thead>
<tr>
<th>Variable</th>
<th>Measurement</th>
<th>Fit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta\alpha_{\text{had}}^{(5)}(m_Z)$</td>
<td>$0.02758 \pm 0.00035$</td>
<td>$0.02774$</td>
</tr>
<tr>
<td>$m_Z$ [GeV]</td>
<td>$91.1875 \pm 0.0021$</td>
<td>$91.1873$</td>
</tr>
<tr>
<td>$\Gamma_Z$ [GeV]</td>
<td>$2.4952 \pm 0.0023$</td>
<td>$2.4952$</td>
</tr>
<tr>
<td>$c_{\text{had}}^0$ [nb]</td>
<td>$41.540 \pm 0.037$</td>
<td>$41.486$</td>
</tr>
<tr>
<td>$R_l$</td>
<td>$20.767 \pm 0.025$</td>
<td>$20.744$</td>
</tr>
<tr>
<td>$A_{\text{tb}}^{0,l}$</td>
<td>$0.01714 \pm 0.00095$</td>
<td>$0.01641$</td>
</tr>
<tr>
<td>$A_l(P_c)$</td>
<td>$0.1465 \pm 0.0032$</td>
<td>$0.1479$</td>
</tr>
<tr>
<td>$R_b$</td>
<td>$0.21629 \pm 0.00066$</td>
<td>$0.21613$</td>
</tr>
<tr>
<td>$R_c$</td>
<td>$0.1721 \pm 0.0030$</td>
<td>$0.1722$</td>
</tr>
<tr>
<td>$A_{\text{tb}}^{0,b}$</td>
<td>$0.0992 \pm 0.0016$</td>
<td>$0.1037$</td>
</tr>
<tr>
<td>$A_{\text{tb}}^{0,c}$</td>
<td>$0.0707 \pm 0.0035$</td>
<td>$0.0741$</td>
</tr>
<tr>
<td>$A_b$</td>
<td>$0.923 \pm 0.020$</td>
<td>$0.935$</td>
</tr>
<tr>
<td>$A_c$</td>
<td>$0.670 \pm 0.027$</td>
<td>$0.668$</td>
</tr>
<tr>
<td>$A_l(SLD)$</td>
<td>$0.1513 \pm 0.0021$</td>
<td>$0.1479$</td>
</tr>
<tr>
<td>$\sin^2\theta_{\text{eff}}(Q_{\text{tb}})$</td>
<td>$0.2324 \pm 0.0012$</td>
<td>$0.2314$</td>
</tr>
<tr>
<td>$m_W$ [GeV]</td>
<td>$80.398 \pm 0.025$</td>
<td>$80.382$</td>
</tr>
<tr>
<td>$m_t$ [GeV]</td>
<td>$170.9 \pm 1.8$</td>
<td>$170.8$</td>
</tr>
<tr>
<td>$R(b\rightarrow s \gamma)$</td>
<td>$1.13 \pm 0.12$</td>
<td>$1.12$</td>
</tr>
<tr>
<td>$B_s\rightarrow \mu \mu$ [$\times 10^{-8}$]</td>
<td>$&lt; 8.00$</td>
<td>$0.33$</td>
</tr>
<tr>
<td>$\Delta a_t$ [$\times 10^{-9}$]</td>
<td>$2.95 \pm 0.87$</td>
<td>$2.95$</td>
</tr>
<tr>
<td>$\Omega h^2$</td>
<td>$0.113 \pm 0.009$</td>
<td>$0.113$</td>
</tr>
</tbody>
</table>

- Absolute $\chi^2$ minimum: $\chi^2/\text{ndof} = 17.0/13$
- 20% goodness-of-fit probability

$\Rightarrow$ Fits today’s data well
## Fit result: no constraint on $m_h$

<table>
<thead>
<tr>
<th>Variable</th>
<th>Measurement</th>
<th>Fit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta \alpha_{\text{had}}^{(5)}(m_Z)$</td>
<td>$0.02758 \pm 0.00035$</td>
<td>$0.02774$</td>
</tr>
<tr>
<td>$m_Z$ [GeV]</td>
<td>$91.1875 \pm 0.0021$</td>
<td>$91.1873$</td>
</tr>
<tr>
<td>$\Gamma_Z$ [GeV]</td>
<td>$2.4952 \pm 0.0023$</td>
<td>$2.4952$</td>
</tr>
<tr>
<td>$\sigma_{\text{had}}^0$ [nb]</td>
<td>$41.450 \pm 0.037$</td>
<td>$41.486$</td>
</tr>
<tr>
<td>$R_1$</td>
<td>$20.767 \pm 0.025$</td>
<td>$20.744$</td>
</tr>
<tr>
<td>$A_{\tau}^{0,b}$</td>
<td>$0.01614 \pm 0.00095$</td>
<td>$0.01641$</td>
</tr>
<tr>
<td>$A_{\tau}(P_{\tau})$</td>
<td>$0.1465 \pm 0.0032$</td>
<td>$0.1479$</td>
</tr>
<tr>
<td>$R_b$</td>
<td>$0.21629 \pm 0.00066$</td>
<td>$0.21613$</td>
</tr>
<tr>
<td>$R_c$</td>
<td>$0.1721 \pm 0.0030$</td>
<td>$0.1722$</td>
</tr>
<tr>
<td>$A_{\tau}^{0,b}$</td>
<td>$0.0992 \pm 0.0016$</td>
<td>$0.1037$</td>
</tr>
<tr>
<td>$A_{\tau}^{0,c}$</td>
<td>$0.0707 \pm 0.0035$</td>
<td>$0.0741$</td>
</tr>
<tr>
<td>$A_b$</td>
<td>$0.923 \pm 0.020$</td>
<td>$0.935$</td>
</tr>
<tr>
<td>$A_c$</td>
<td>$0.670 \pm 0.027$</td>
<td>$0.668$</td>
</tr>
<tr>
<td>$A_{\tau}(\text{SLD})$</td>
<td>$0.1513 \pm 0.0021$</td>
<td>$0.1479$</td>
</tr>
<tr>
<td>$\sin^2 \theta_{\text{eff}}^{(Q_{\tau})}$</td>
<td>$0.2324 \pm 0.0012$</td>
<td>$0.2314$</td>
</tr>
<tr>
<td>$m_W$ [GeV]</td>
<td>$80.398 \pm 0.025$</td>
<td>$80.382$</td>
</tr>
<tr>
<td>$m_t$ [GeV]</td>
<td>$170.9 \pm 1.8$</td>
<td>$170.8$</td>
</tr>
<tr>
<td>$R(b \to s\gamma)$</td>
<td>$1.13 \pm 0.12$</td>
<td>$1.12$</td>
</tr>
<tr>
<td>$B_s \to \mu\mu$ [$\times 10^{-8}$]</td>
<td>$&lt; 8.00$</td>
<td>$0.33$</td>
</tr>
<tr>
<td>$\Delta a_{\mu}$ [$\times 10^{-9}$]</td>
<td>$2.95 \pm 0.87$</td>
<td>$2.95$</td>
</tr>
<tr>
<td>$\Omega h^2$</td>
<td>$0.113 \pm 0.009$</td>
<td>$0.113$</td>
</tr>
</tbody>
</table>

$\chi^2$/ndof = 17.0/13 (20% prob.)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Measurement</th>
<th>Fit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta \alpha_{\text{had}}^{(5)}(m_Z)$</td>
<td>$0.02758 \pm 0.00035$</td>
<td>$0.02768$</td>
</tr>
<tr>
<td>$m_Z$ [GeV]</td>
<td>$91.1875 \pm 0.0021$</td>
<td>$91.1875$</td>
</tr>
<tr>
<td>$\Gamma_Z$ [GeV]</td>
<td>$2.4952 \pm 0.0023$</td>
<td>$2.4957$</td>
</tr>
<tr>
<td>$\sigma_{\text{had}}^0$ [nb]</td>
<td>$41.450 \pm 0.037$</td>
<td>$41.477$</td>
</tr>
<tr>
<td>$R_1$</td>
<td>$20.767 \pm 0.025$</td>
<td>$20.744$</td>
</tr>
<tr>
<td>$A_{\tau}^{0,b}$</td>
<td>$0.01614 \pm 0.00095$</td>
<td>$0.01641$</td>
</tr>
<tr>
<td>$A_{\tau}(P_{\tau})$</td>
<td>$0.1465 \pm 0.0032$</td>
<td>$0.1481$</td>
</tr>
<tr>
<td>$R_b$</td>
<td>$0.21629 \pm 0.00066$</td>
<td>$0.21586$</td>
</tr>
<tr>
<td>$R_c$</td>
<td>$0.1721 \pm 0.0030$</td>
<td>$0.1722$</td>
</tr>
<tr>
<td>$A_{\tau}^{0,b}$</td>
<td>$0.0992 \pm 0.0016$</td>
<td>$0.1038$</td>
</tr>
<tr>
<td>$A_{\tau}^{0,c}$</td>
<td>$0.0707 \pm 0.0035$</td>
<td>$0.0742$</td>
</tr>
<tr>
<td>$A_b$</td>
<td>$0.923 \pm 0.020$</td>
<td>$0.935$</td>
</tr>
<tr>
<td>$A_c$</td>
<td>$0.670 \pm 0.027$</td>
<td>$0.668$</td>
</tr>
<tr>
<td>$A_{\tau}(\text{SLD})$</td>
<td>$0.1513 \pm 0.0021$</td>
<td>$0.1481$</td>
</tr>
<tr>
<td>$\sin^2 \theta_{\text{eff}}^{(Q_{\tau})}$</td>
<td>$0.2324 \pm 0.0012$</td>
<td>$0.2314$</td>
</tr>
<tr>
<td>$m_W$ [GeV]</td>
<td>$80.398 \pm 0.025$</td>
<td>$80.374$</td>
</tr>
<tr>
<td>$m_t$ [GeV]</td>
<td>$170.9 \pm 1.8$</td>
<td>$171.3$</td>
</tr>
<tr>
<td>$\Gamma_W$ [GeV]</td>
<td>$2.140 \pm 0.060$</td>
<td>$2.091$</td>
</tr>
</tbody>
</table>

$\chi^2$/ndof = 18.2/13 (15% prob.)

---


F.J. Ronga (CERN)
Constrain $m_h$ to scan value;
minimize all model parameters in each point;
$\Rightarrow$ determine error on $m_h$ prediction

**SM fit:**
- $m_H = 78^{+33}_{-24}$ GeV/$c^2$
- 12% probability at exclusion limit

*Including theoretical uncertainty*
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*

**CMSSM fit:**
- $m_h = 110^{+8}_{-10} \pm 3$ GeV/$c^2$
- 20% probability at exclusion limit
  *Including theoretical uncertainty*
Difficult to detect experimentally at this low mass, but...

- Constrain $m_h$ to scan value;
- minimize all model parameters in each point;
  $\Rightarrow$ determine error on $m_h$ prediction

**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*
Lightest Higgs boson mass in the CMSSM

LHC Discovery potential: sparticle searches

CMS early discovery reach for 1 fb$^{-1}$ (ATLAS similar)

- $5\sigma$ discovery reach
- 95% contour

(arXiv:0707.3447)
LHC Discovery potential: sparticle searches

CMS early discovery reach for 1 fb$^{-1}$ (ATLAS similar)

- $5\sigma$ discovery reach
- 95% contour

(arXiv:0707.3447)

... if this is correct, signs of SUSY will emerge very early in the sparticle sector!
The Higgs seems to be around the corner...
The Higgs seems to be around the corner...

...and first signs of it might manifest itself early on in sparticle searches at the LHC!
Backup slides
**B Physics observables**

G. Isidori, Workshop on *Flavour Physics in the Era of the LHC*

Four key players in the quark-flavour sector:

- $B^\pm \rightarrow l^\pm \nu$
  - $\sim (10-50)\%$ suppression
- $B_{s,d} \rightarrow l^+ l^-$
  - up to $100 \times$ enhancement
- $\Delta M_{B_s}$
  - $\sim (0-20)\%$ suppression
- $B \rightarrow X_s \gamma$
  - $\sim (0-50)\%$ enhancement

[qualitative general features for $M_H \sim 500 \text{ GeV} \& \tan\beta \sim 50$]
Sampling the CMSSM Parameter Space

2000 “toy experiments” produced:

- predictions at $\chi^2$ minimum smeared by their error;
- $\chi^2$ fit of pseudo-experiments;
  → randomised starting values;
- determine best fit CMSSM parameters

Assess validity of fit

- check $\chi^2$ probability distribution;
- cross-check parameter and prediction errors;
Checks from pseudo-experiments

$\chi^2$ probability distribution (inc. LEP limit)

$m_h$ distribution (w/o LEP limit) (~900 experiments only)

Entries 2321
Mean 0.4979
RMS 0.2804
$\chi^2$/ndf 62.63/48
p0 1.86 ± 45.83
p1 3.175 ± -1.321

$25 \quad 30 \quad 35 \quad 40 \quad 45 \quad 50 \quad 55 \quad 60$

$0 \quad 0.1 \quad 0.2 \quad 0.3 \quad 0.4 \quad 0.5 \quad 0.6 \quad 0.7 \quad 0.8 \quad 0.9 \quad 1$

Prob($\chi^2$)

$m_h$ [GeV/c^2]

95% CL

68% CL

$m_h = 110^{+6}_{-8}$ GeV/c^2

F.J. Ronga (CERN)
**Dark matter constraints**

“A funnel” at large $\tan\beta$

\[ m_A = 2m_{\tilde{\chi}} \]

$\tilde{\tau} - \tilde{\chi}_1^0$ “co-annihilation”