A framework for consistent combination of indirect constraints on the MSSM

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Flavour as a Window to New Physics – June 10, 2008

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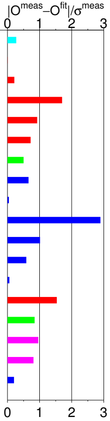
Using external constraints: EW fit

From http://lepewwg.web.cern.ch/LEPEWWG/plots/winter2007/

Comprehensive use of indirect constraints!

- ⇒ test the consistency of the SM;
- ⇒ predict the Higgs mass

	Measurement	Fit
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02758 ± 0.00035	0.02768
m_Z [GeV]	91.1875 ± 0.0021	91.1875
Γ_Z [GeV]	2.4952 ± 0.0023	2.4957
σ_{had}^0 [nb]	41.540 ± 0.037	41.477
R_l	20.767 ± 0.025	20.744
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.01645
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481
R_b	0.21629 ± 0.00066	0.21586
R_c	0.1721 ± 0.0030	0.1722
$A_{fb}^{0,b}$	0.0992 ± 0.0016	0.1038
$A_{fb}^{0,c}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1481
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.398 ± 0.025	80.374
Γ_W [GeV]	2.140 ± 0.060	2.091
m_t [GeV]	170.9 ± 1.8	171.3



Using external constraints: EW fit

From http://lepewwg.web.cern.ch/LEPEWWG/plots/winter2007/

Comprehensive use of indirect constraints!

⇒ test the consistency of the SM;

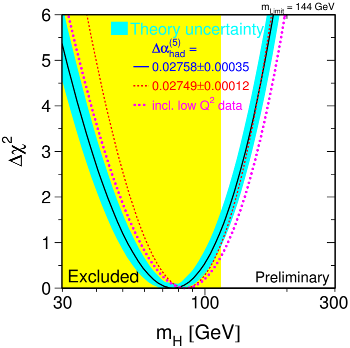
⇒ predict the Higgs mass

Higgs mass scan ("blue band"):

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

⇒ determine error on m_h prediction:

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



Using external constraints: the MSSM case

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

"All other data" → today's external constraints

- 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_{top}, m_{W})
- Cosmology/Astroparticle data:
  - *e.g.*, relic density

Exploiting this data requires:

⇒ "tools" to predict the observables

⇒ combination of the tools

Using external constraints: the MSSM case

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Common framework development

A common framework for indirect constraints

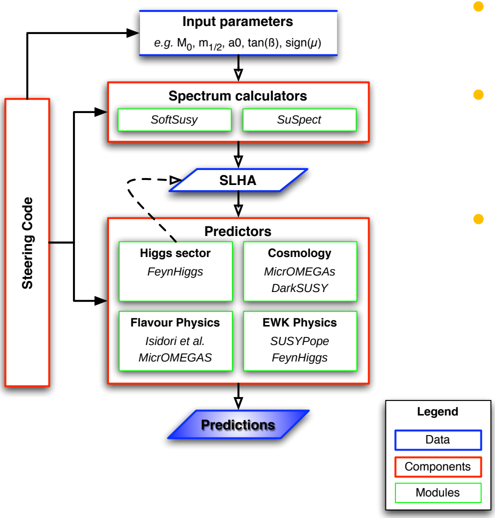
O. Buchmüller *et al.*, PLB 657/1-3 pp. 87-94

- 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.
  Flächer, Henning (CERN) – Exp.
  Isidori, Gino (INFN Frascati) – 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.
  Heinemeyer, Sven (Santander) – Theo.
  Mahmoudi, Farvah N. (Uppsala) – Theo.
  Paradisi, Paride (Uni. of Valencia) – Theo.
  Weber, Arne (Max Planck Inst. (Munich)) – Theo.

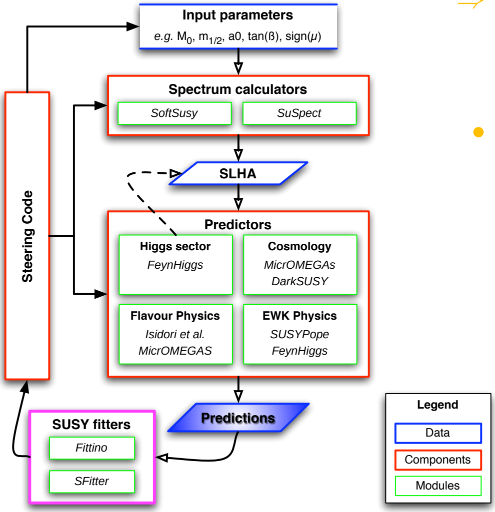
- Started at workshop on *Flavour Physics in the Era of the LHC*
  ⇒ See (draft) report, sec. 5.2
- Main focus of the work:
  - Development of a *common tool* for indirect constraints
  - Compilation (and integration) of state-of-the-art predictions
  - Application of the tool

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

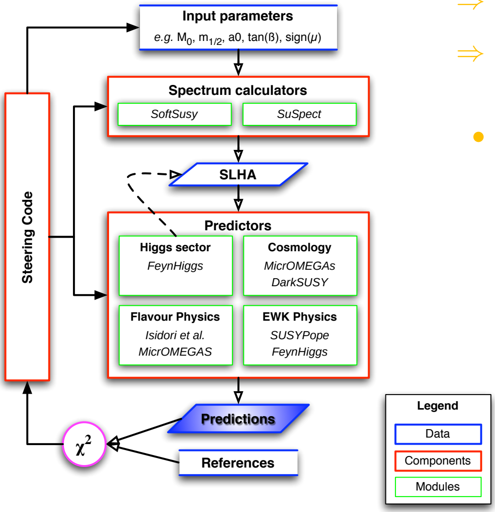
Use-case I: input to external SUSY fitters



⇒ Provide consistent predictions (low-energy, EW, etc.) to LHC/ILC-oriented fitters.

- Work started in this direction with the `Fittino` collaboration

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



⇒ Constrain SUSY parameter space

⇒ Will become even more stringent when combined with discoveries!

- Various modes:
  - Overall best minimum (`Minuit`)
  - χ^2 scan
  - Markov chain Monte Carlo

List of available predictions [relevant today already]

Low energy observables

$\mathrm{R}(b \to s\gamma)$	Isidori & Paradisi
$\mathrm{R}(B \to \tau\nu)$	Isidori & Paradisi
$\mathrm{BR}(K \to \tau\nu)$	Isidori & Paradisi
$\mathrm{R}(B \to X_s \ell\ell)$	Isidori & Paradisi
$\mathrm{R}(K \to \pi\nu\bar{\nu})$	Isidori & Paradisi
$\mathrm{BR}(B_s \to \ell\ell)$	Isidori & Paradisi
$\mathrm{BR}(B_d \to \ell\ell)$	Isidori & Paradisi
$\mathrm{R}(\Delta m_s)$	Isidori & Paradisi
$\mathrm{R}(\Delta m_s)/\mathrm{R}(\Delta m_d)$	Isidori & Paradisi
$\mathrm{R}(\Delta m_K)$	Isidori & Paradisi
$\mathrm{R}(\Delta_0(K^*\gamma))$	SuperIso
$\Delta(g-2)$	FeynHiggs

Higgs sector observables

m_h^{light}	FeynHiggs

Cosmology observables

Ωh^2	micrOMEGAs
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
$A_{\mathrm{fb}}(\mathrm{b})$	SUSY-Pope
$A_{\mathrm{fb}}(\mathrm{c})$	SUSY-Pope
A_{b}	SUSY-Pope
A_{c}	SUSY-Pope
$A_\ell(\mathrm{SLD})$	SUSY-Pope
$\sin^2\theta_{\mathrm{w}}^\ell(Q_{\mathrm{fb}})$	SUSY-Pope
m_{W}	SUSY-Pope
m_{t}	SUSY-Pope

Example applications

χ^2 fit of the CMSSM parameters

- Multi-parameter χ^2 fit:

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

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

C_i: experimental constraint

P_i: predicted value for a given CMSSM parameter set

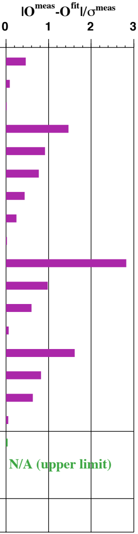
- fitting for all CMSSM (aka mSUGRA) parameters:
  - M_0 – common scalar mass (at GUT scale)
  - $M_{1/2}$ – common gaugino mass (at GUT scale)
  - A_0 – tri-linear mass parameter (at GUT scale)
  - $\tan\beta$ – ratio of Higgs vacuum expectation values
  - sign(μ) – sign of Higgs mixing parameter (fixed)

- including relevant SM uncertainties ($m_{\rm top}$, $m_{\rm Z}$, $\Delta\alpha^{(5)}_{\rm had}$)

χ^2 fit – 1. Overall best minimum

CMSSM

Variable	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02774
m_Z [GeV]	91.1875 ± 0.0021	91.1873
Γ_Z [GeV]	2.4952 ± 0.0023	2.4952
σ^0_{had} [nb]	41.540 ± 0.037	41.486
R_l	20.767 ± 0.025	20.744
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01641
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1479
R_b	0.21629 ± 0.00066	0.21613
R_c	0.1721 ± 0.0030	0.1722
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1037
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0741
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1479
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.398 ± 0.025	80.382
m_t [GeV]	170.9 ± 1.8	170.8
$R(b\to s\gamma)$	1.13 ± 0.12	1.12
$B_s\to\mu\mu$ [$\times10^{-8}$]	< 8.00	0.33
Δa_μ [$\times10^{-9}$]	2.95 ± 0.87	2.95
Ωh^2	0.113 ± 0.009	0.113



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

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

SM

Variable	Measurement	Fit
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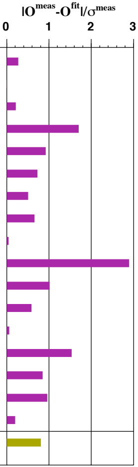
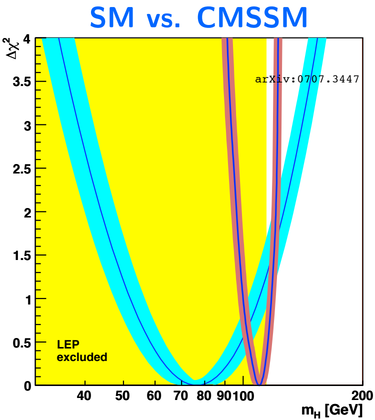


arXiv:hep-ex/0612034

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

χ^2 fit – 2. Scan of the Higgs boson mass



- 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

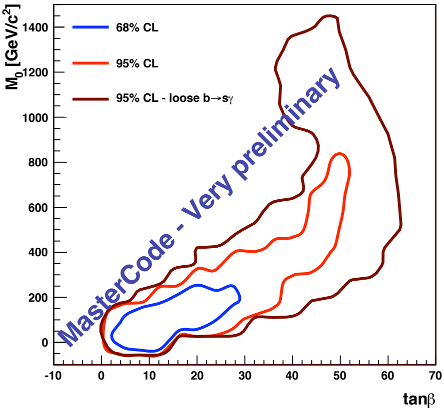
CMSSM fit:

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

3. Sampling the parameter space

- Markov chain Monte Carlo (14 starting points, 1.6M steps kept)
- Estimating the effect of various constraints

⇒ Very preliminary: for illustration only



- low $\tan\beta$, low M_0 favoured
- high $\tan\beta$, high(er) M_0 compatible

LEP limit on m_h included

Conclusion

What we are currently working on

- Updating the predictions and sampling with full new set
- Evaluating the impact of most sensitive observables

  ⇒ parameter sampling with loosened constraints:

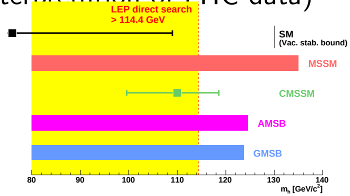
    - $\Delta(g-2)$ (varying error and deviation)
    - $b \to s\gamma$ (varying exp. error)
    - Ωh^2 (removing, using as upper bound)

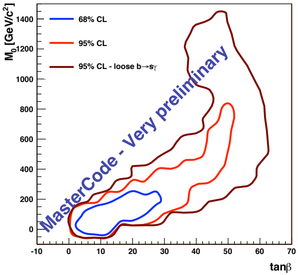
- Probing other models:
  - Non-Universal Higgs Mass (NUHM I+II)
  - "phenomenological" MSSM (+ additional assumptions)
- Sharing the code:
  - Polish our code and make it public;
  - provide predictions (started!)

Summary

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

  ... are ongoing
- Application to today's data...
  - favoured mSUGRA parameters
  - Higgs mass "prediction"
  - sampling of parameter space





⇒ Now is time to get constraints from the