A common framework for indirect MSSM constraints

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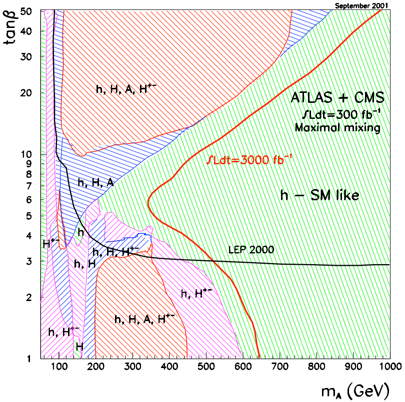
CERN – Switzerland

SUSY 2007 – Karlsruhe – July 31, 2007

Contents

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.

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

Common framework development

A common framework for indirect constraints

- Goal: a framework to provide consistent indirect constraints
- Collaboration of interested theorists and experimentalists 11.5

  Buchmüller, Oliver (CERN) – Exp.

  Cavanaugh, Richard (Uni. of Florida) – Exp.

  De Roeck, Albert (CERN & Uni. Antwerpen) – Exp.

  Heinemeyer, Sven (Santander) – Theo.

  Isidori, Gino (INFN Frascati) – Theo.

  Paradisi, Paride (Uni. of Valencia) Theo.

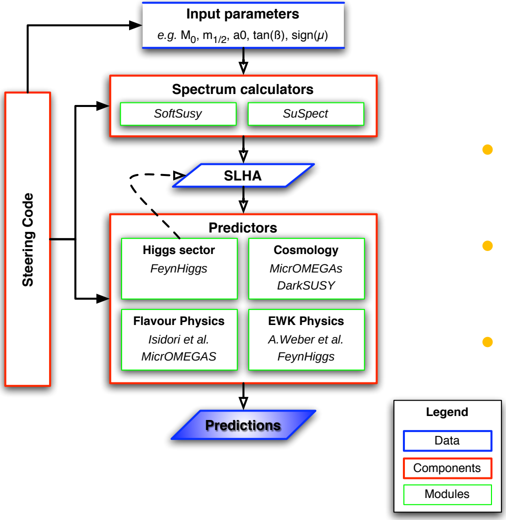
  Ronga, Frédéric (CERN) – Exp.

  Weber, Arne (Max Planck Inst. f. Phys. (Munich)) – Theo.

  Weiglein, Georg (Durham) – Theo.

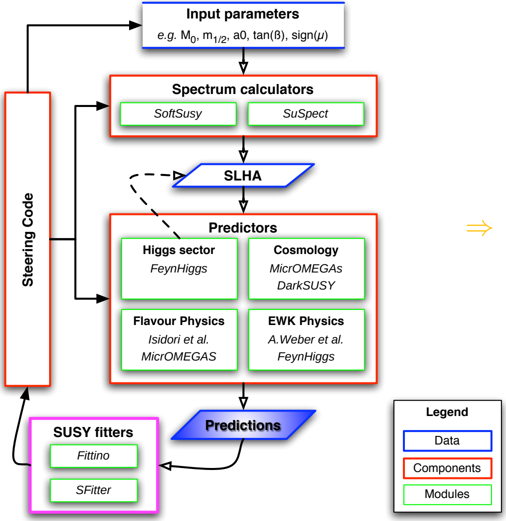
- Started at workshop on *Flavour Physics in the Era of the LHC*
- Main focus of the work:
  - Development of a *common tool* for indirect constraints
  - Compilation (and integration) of state-of-the-art predictions
  - Application of the tool

Flow-chart: general overview



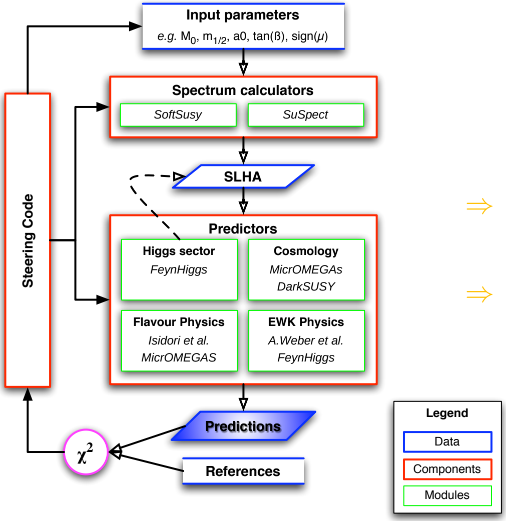
- Consistency
  Ensured using SLHA interface
- Flexibility
  Add/remove predictions
- Modularity
  Compare various calculations

Use-case I: input to external SUSY fitters



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

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



⇒ Constrain SUSY parameter space

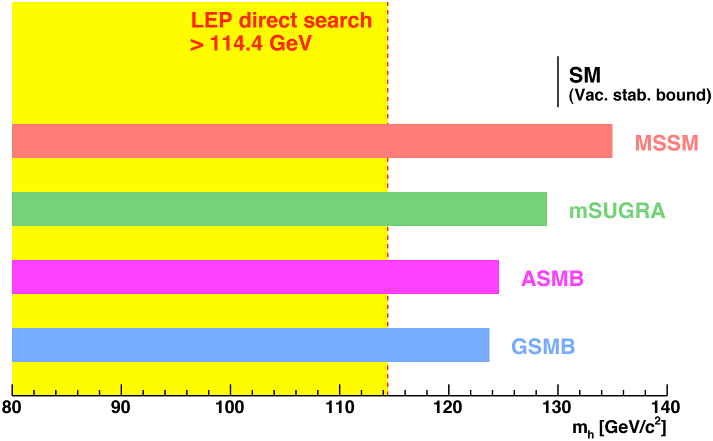
⇒ Will become even more stringent when combined with discoveries!

Lightest Higgs boson mass in the CMSSM

Preamble: limits on the Higgs boson mass

Many of the popular models require the lightest Higgs boson mass to be significantly below 200 GeV.

m_h limits from arXiv:hep-ph/0412214



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

χ^2 fit of the CMSSM parameters

- Multi-parameter χ^2 fit:

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

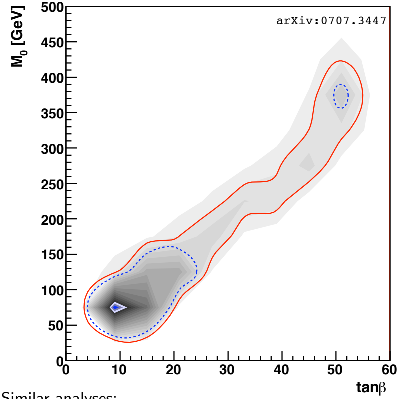
- fitting for all CMSSM parameters: M_0, $M_{1/2}$, A_0, $\tan\beta$;
- including relevant SM uncertainties (*e.g.* m_{top});

→ 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:

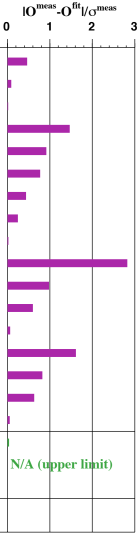
- Ellis, Heinemeyer, Olive, Weber, Weiglein – hep-ph/0706.0652
- Allanach, Cranmer, Lester, Weber – hep-ph/0705.0487
- Trotta, Austri, Roszkowski – hep-ph/0609126

⇒ Turn to fit *without* limit on m_h assessing preferred m_h value in CMSSM

Fit result: no constraint on m_h

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
$B_s\to\mu\mu$ [$\times 10^{-8}$]	< 8.00	0.33
Δa_μ [$\times 10^{-9}$]	2.95 ± 0.87	2.95
Ωh^2	0.113 ± 0.009	0.113



arXiv:0707.3447 [hep-ph]

- Absolute χ^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

CMSSM

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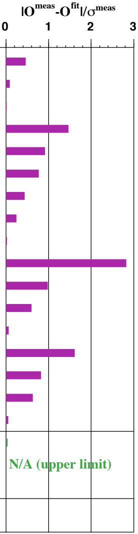
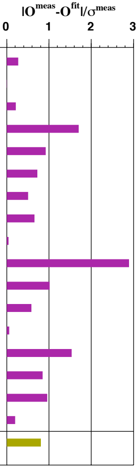


arXiv:0707.3447 [hep-ph]

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

SM

Variable	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	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^0_{had} [nb]	41.540 ± 0.037	41.477
R_l	20.767 ± 0.025	20.744
$A^{0,l}_{fb}$	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
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1038
$A^{0,c}_{fb}$	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
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.398 ± 0.025	80.374
m_t [GeV]	170.9 ± 1.8	171.3
Γ_W [GeV]	2.140 ± 0.060	2.091

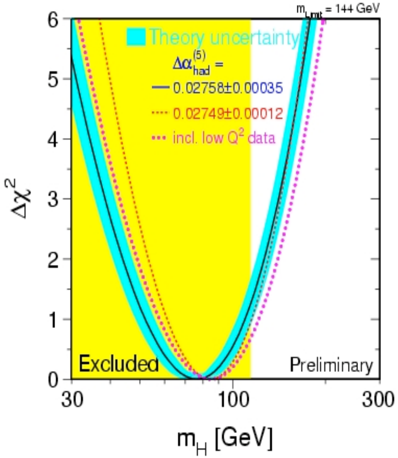


arXiv:hep-ex/0612034

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

χ^2 scan of the Higgs boson mass

SM



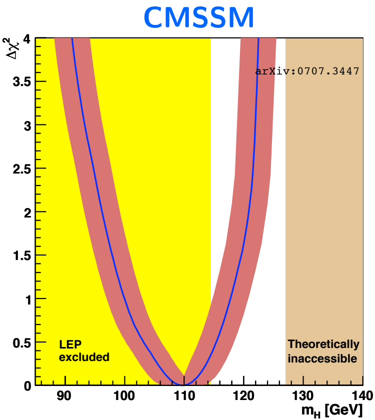
- Constrain m_h to scan value;
- minimize all model parameters in each point;

$\Rightarrow$ determine error on m_h prediction

SM fit:

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

χ^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

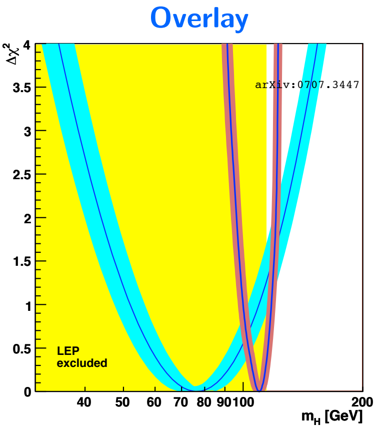
SM fit:

- $m_H = 78^{+33}_{-24}$ 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

χ^2 scan of the Higgs boson mass



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:

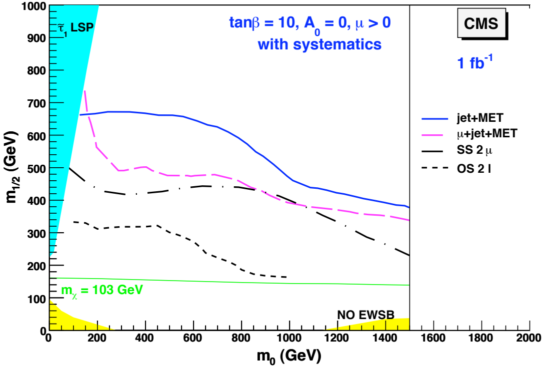
- $m_H = 78^{+33}_{-24}$ GeV$/c^2$
- 12% probability at exclusion limit *Including theoretical uncertainty*

CMSSM fit:

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

LHC Discovery potential: sparticle searches

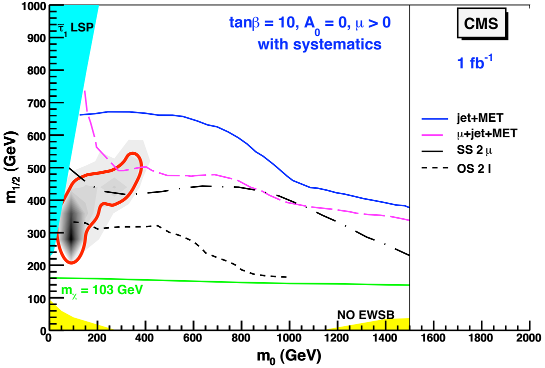
CMS early discovery reach for 1 fb^{-1} (ATLAS similar)



- 5σ discovery reach
- 95% contour (arXiv:0707.3447)

LHC Discovery potential: sparticle searches

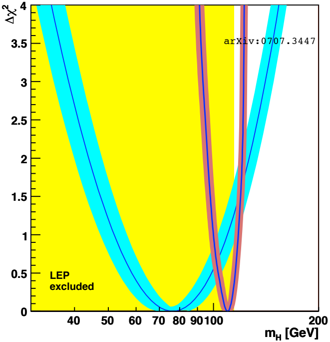
CMS early discovery reach for 1 fb^{-1} (ATLAS similar)

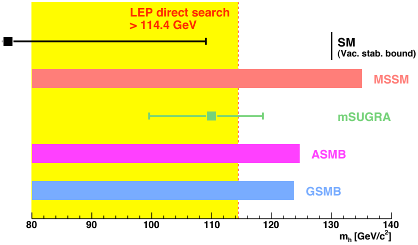


- 5σ discovery reach
- 95% contour (arXiv:0707.3447)

...if this is correct, signs of SUSY will emerge very early in the sparticle sector!

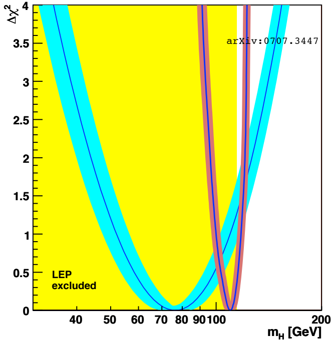
Summary: an experimentalist's perspective

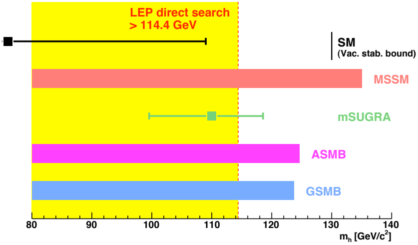




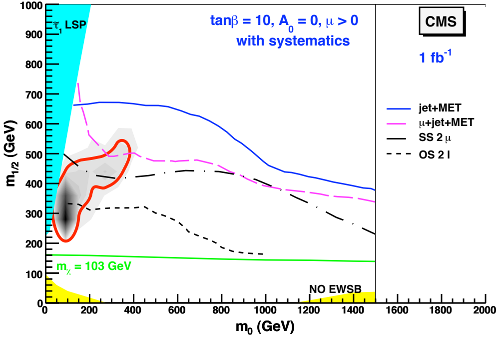
The Higgs seems to be around the corner. . .

Summary: an experimentalist's perspective





The Higgs seems to be around the corner. . .



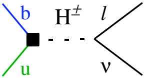
. . . and first signs of it might manifest itself early on in sparticle searches at the LHC!

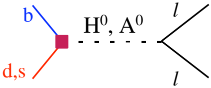
Backup slides

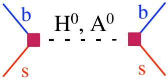
B Physics observables

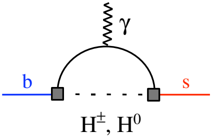
G. Isidori, Workshop on *Flavour Physics in the Era of the LHC*

Four key players in the quark-flavour sector:









$B^{\pm} \to l^{\pm} \nu$	$B_{s,d} \to l^{+} l^{-}$	ΔM_{B_s}	$B \to X_s \gamma$
↓	↓	↓	↓
~(10-50)% suppression	up to 100 × enhancement	~(0-20)% suppression	~(0-50)% enhancement

[qualitative general features for $M_H \sim 500$ GeV & $\tan\beta \sim 50$]

Sampling the CMSSM Parameter Space

2000 "toy experiments" produced:

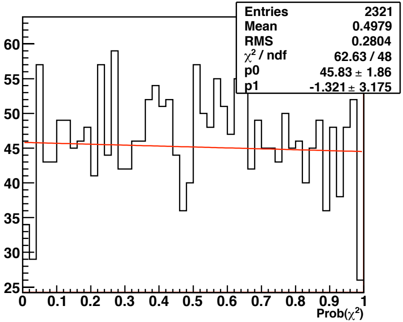
- predictions at χ^2 minimum smeared by their error;
- χ^2 fit of pseudo-experiments;
  - $\rightarrow$ randomised starting values;
- determine best fit CMSSM parameters

Assess validity of fit

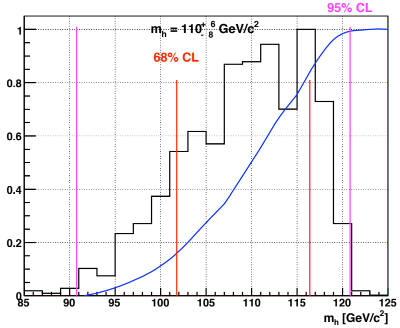
- check χ^2 probability distribution;
- cross-check parameter and prediction errors;

Checks from pseudo-experiments

χ^2 probability distribution (inc. LEP limit)

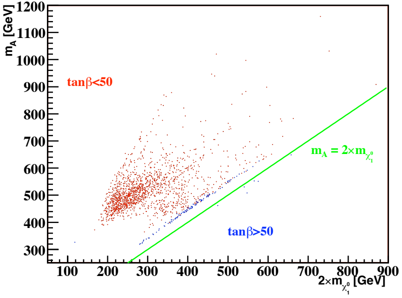


m_h distribution (w/o LEP limit) ($\sim$900 experiments only)



Dark matter constraints

"A funnel" at large tan β



$\tilde{\tau}$–$\tilde{\chi}_1^0$ "co-annihilation"