Global fits à la frequentist

F. Ronga (ETH Zurich)
Joint HEP-APP IOP meeting on SUSY
March 24 2010
Global fits à la frequentist?

- **Confronting a model to data**
  - combine measurements
  - compare with predictions
  - constrain the parameters
    - or exclude the model...

- **Key ingredients**
  - consistent set of measurements
    - and their errors
  - state-of-the-art predictions
    - and their errors
  - and a combination of the two
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Famous examples of global fits
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Famous examples of global fits
à la frequentist
Global fits à la...: framework

- **Consistency**
  - SLHA interface

- **Modularity**
  - Compare calculations
  - Add/remove predictions

- **State-of-the-art “tools”**
  - Directly from experts

- **Flexibility**
  - Several uses
Global fits à la...: framework

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  ‣ Several uses
    • \( \chi^2 \Rightarrow \) Minuit fit, MCMC
Global fits à la...: framework

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- **State-of-the-art “tools”**
  - Directly from experts

- **Flexibility**
  - Several uses
    - $\chi^2 \Rightarrow$ Minuit fit, MCMC
    - input to external tool
Building the $\chi^2$

$$\chi^2 = \sum_{i}^{N} \frac{(C_i - P_i)^2}{\sigma(C_i)^2 + \sigma(P_i)^2} + \sum_{j}^{M} \frac{(f_{\text{obs}}^\text{SM}_j - f_{\text{fit}}^\text{SM}_j)^2}{\sigma(f_{\text{SM}_j})^2}$$

- **Multi-parameter $\chi^2$ variable**
  - $C_i$ – experimental constraints
  - $P_i$ – predicted value for a given CMSSM parameter set
- **Fitting for all model parameters, e.g., CMSSM**
  - $M_0$, $M_{1/2}$, $A_0$, $\tan\beta$ ($\text{sign}(\mu) = 1$)
- **Including relevant SM uncertainties**
  - $m_{\text{top}}$, $m_Z$, $\Gamma_Z$, $\Delta\alpha_{\text{had}}$
### List of observables

#### Low energy observables
- $R(b \rightarrow s\gamma)$: SuFla*
- $R(B \rightarrow \tau\nu)$: SuFla
- $BR(K \rightarrow \tau\nu)$: SuFla
- $R(B \rightarrow X_s\ell\ell)$: SuFla
- $R(K \rightarrow \pi\nu\bar{\nu})$: SuFla
- $BR(B_s \rightarrow \ell\ell)$: SuFla
- $BR(B_d \rightarrow \ell\ell)$: SuFla
- $R(\Delta m_s)$: SuFla
- $R(\Delta m_s)/R(\Delta m_d)$: SuFla
- $R(\Delta m_K)$: SuFla
- $R(\Delta_0(K^*\gamma))$: SuperIso
- $\Delta(g - 2)$: FeynHiggs

#### Electroweak observables
- $\Delta \alpha_{\text{had}}^{(5)}(m_Z^2)$: FeynWZ
- $m_Z$: FeynWZ
- $\sigma_{\text{had}}^0$: FeynWZ
- $R_l$: FeynWZ
- $A_{fb}(\ell)$: FeynWZ
- $A_{\ell}(P_\tau)$: FeynWZ
- $R_b$: FeynWZ
- $R_c$: FeynWZ
- $A_{fb}(b)$: FeynWZ
- $A_{fb}(c)$: FeynWZ
- $A_b$: FeynWZ
- $A_c$: FeynWZ
- $A_{\ell}(\text{SLD})$: FeynWZ
- $\sin^2 \theta_w^\ell(Q_{fb})$: FeynWZ
- $m_W$: FeynWZ
- $m_t$: FeynWZ

#### Higgs sector observables
- $m_h^{\text{light}}$: FeynHiggs

#### Cosmology observables
- $\Omega h^2$: DarkSUSY
- $\sigma^S_{\text{SI}}$: DarkSUSY
- $\sigma_p$: DarkSUSY

* G. Isidori, P. Paradisi
List of observables

**Low energy observables**
- $R(b \rightarrow s\gamma)$ SuFla* micrOMEGAs
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**Higgs sector observables**
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- $\Omega h^2$ DarkSUSY micrOMEGAs
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**Electroweak observables**
- $\Delta\alpha^{(5)}_{\text{had}}(m_Z^2)$ FeynWZ
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- $m_W$ FeynWZ
- $m_t$ FeynWZ

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Fit methods & “data” samples

• Fit methods
  ‣ Markov Chain Monte Carlo (MCMC)
    ■ actually used as a mere sampling method (sampling density not used)
      • success and failure of the steps are defined by the $\chi^2$
  ‣ $\chi^2$ fit: Minuit minimisation
    ■ used for “scans” or in conjunction with MCMCs to get the overall best minimum

• Data samples for MCMCs
  ‣ MasterCode
    ■ about 25 million points for each model (CMSSM & NUHM1)
  ‣ Fittino
    ■ about 20 million points (x2 different starting points)
    ■ “toy” fits (uncertainty on fit parameters, model disambiguation)
Probing the parameter space

**MasterCode**
Best fit point:
M₀=60, M₁/₂=310, A₀=130, tanβ=11

**Fittino**
Best fit point:
M₀=76, M₁/₂=332, A₀=383, tanβ=13

Probing the parameter space

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Best fit point:
$M_0 = 60$, $M_{1/2} = 310$, $A_0 = 130$, $\tan\beta = 11$

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Higgs funnel!

$2 \times m_{\tilde{\chi}_0} \lesssim M_h$

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The predicted spectrum

MasterCode
CMSSM spectrum at best fit point

Fittino
CMSSM spectrum at best fit point

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The predicted spectrum

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CMSSM spectrum at best fit point

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CMSSM spectrum at best fit point

Present data favours low mass SUSY
The key players

- Percent change of 95% C.L. contour area as a function of relative uncertainty
  - In general, parameter space weakly constrained
  - $g$-2 still the strongest constraint

Predicting the Higgs mass

- *Not including the LEP limit*, what does the CMSSM predict with today's data?


**CMSSM**

- Higgs mass at best fit point: 108 GeV
- $\chi^2$ value at limit: 0.7
Predicting the Higgs mass

• Not including the LEP limit, what does the CMSSM predict with today’s data?


CMSSM
Higgs mass at best fit point: 108 GeV
$\chi^2$ value at limit: 0.7

Standard Model
Higgs mass at best fit point: 87 GeV
$\chi^2$ value at limit: 0.9

Latest Tevatron limit not included yet
Beyond CMSSM: NUHM I

- Non-Universal Higgs Mass: adding one parameter for the Higgs sector (not bound to $M_0$ anymore)


**CMSSM**

Higgs mass at best fit point: 108 GeV

$\chi^2$ value at limit: 0.7
Beyond CMSSM: NUHM1

- Non-Universal Higgs Mass: adding one parameter for the Higgs sector (not bound to $M_0$ anymore)

Higgs mass at best fit point: 108 GeV
$\chi^2$ value at limit: 0.7

Higgs mass at best fit point: 120 GeV
$\chi^2$ value at limit: N/A

Beyond CMSSM: NUHM1

- Non-Universal Higgs Mass: adding one parameter for the Higgs sector

Beyond CMSSM: NUHM1

- Non-Universal Higgs Mass: adding one parameter for the Higgs sector


Also low mass SUSY!
Beyond CMSSM: GMSB

- Gauge-mediated SUSY breaking
  - fit parameters: $\tan \beta$, $\Lambda$, $M_{\text{mess}}$, $C_{\text{grav}}$
  - discrete parameters: $\text{sign}(\mu)$, $N_5$ (fixed) [no $\Omega h^2$]

... (Graphs showing $\tan \beta$ vs. $\Lambda$, 68% and 95% CL contours, $N_5 = 1, \ldots, 4$)

GMSB mass spectrum
  - $N_5 = 1$
  - similar to CMSSM

Global fits and astrophysics (I)

- With and without relic density

![Graphs showing 95% CL contours for M0 and tanβ with and without WMAP](image)

Global fits and astrophysics (I)

• With and without relic density

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Global fits and astrophysics (II)

- Dark matter searches

Spin-independent WIMP scattering cross-section

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Global fits and astrophysics (II)

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Global fits and the LHC (I)

Where we stand today: CMS, ATLAS and the CMSSM

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Global fits and the LHC (II)

Dilepton edge measurement at CMS
1/fb integrated luminosity @ 14 TeV

Edge measurements at ATLAS
1/fb integrated luminosity @ 14 TeV

Tomorrow?
CMS, ATLAS and the CMSSM
Beyond CMSSM: pMSSM

• Removing assumptions on the SUSY breaking mechanism

› 18 parameters: today’s constraints not enough

› add 300/fb LHC scenario

Derived Mass Spectrum of SUSY Particles LE+LHC300 MSSM18

pMSSM mass spectrum @ SPS1a
(Higgs not directly accessible at LHC in this point)
Beyond CMSSM: pMSSM

- Removing assumptions on the SUSY breaking mechanism
  - 18 parameters: today’s constraints not enough
  - add 300/fb LHC scenario

A heroic effort!

How to reduce number of parameters?

pMSSM mass spectrum @ SPS1a
(Higgs not directly accessible at LHC in this point)
Conclusion

• Two independent global fits “à la frequentist”
  ‣ using the same substrate MasterCode and similar statistical treatment
    ■ but independent implementation
  ‣ leading to identical results

• Today’s data exploited *ad nauseam*
  ‣ in various models (CMSSM, NUHMI, GMSB)
  ‣ favour low mass SUSY
  ‣ show good prospects for astrophysics and LHC
  ‣ are still too weak to move away from SUSY breaking models

• Eagerly waiting for the LHC...
BEAM SETUP: FLAT TOP

Energy: 3500 GeV  I(B1): 5.89e+09  I(B2): 4.73e+09

Comments 24-03-2010 12:07:04:
beams circulating at 3.5 TeV
B1 in bucket 1, B2 in bucket 1001
I~6e9 for both beams

Collimator studies starting at ~ 12:00

BIS status and SMP flags

<table>
<thead>
<tr>
<th>B1</th>
<th>B2</th>
</tr>
</thead>
<tbody>
<tr>
<td>false</td>
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<tr>
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<td>true</td>
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LHC Operation in CCC: 77600, 70480
### Best fit: CMSSM vs. SM

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<thead>
<tr>
<th>Variable</th>
<th>Measurement</th>
<th>Fit</th>
<th>(\Omega h^2)</th>
</tr>
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<tr>
<td>(\Delta\alpha^{(5)}) (m_Z)</td>
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<td>0.02774</td>
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<td>m_Z [GeV]</td>
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<td>(c_{\text{had}}^b) [nb]</td>
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<td>(A_{b})</td>
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<td>(\sin^2\theta_{\text{eff}}(Q_{b}))</td>
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<td>$m_t$ [GeV]</td>
<td>[68,69]</td>
<td>[70]</td>
<td>173.1 ± 1.3</td>
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<td>$R_b$</td>
<td>[68,69]</td>
<td>[71]</td>
<td>0.21629 ± 0.00066</td>
<td>–</td>
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<tr>
<td>$R_c$</td>
<td>[68,69]</td>
<td>[71]</td>
<td>0.1721 ± 0.003</td>
<td>–</td>
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<tr>
<td>$A_{B_d}(b)$</td>
<td>[68,69]</td>
<td>[71]</td>
<td>0.0992 ± 0.0016</td>
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<tr>
<td>$A_{B_s}(c)$</td>
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</table>

| BR$_{b \rightarrow s\gamma}$/BR$_{b \rightarrow s\gamma}^{SM}$ | [74–78] | [79] | 1.117 ± 0.076$_{\text{exp}}$ ± 0.082$_{\text{th(SM)}}$ | 0.050 |
| BR($B_s \rightarrow \mu^+\mu^-$) | [80–83] | [79] | < 4.7 × 10$^{-8}$ | – |
| BR$_{B_d \rightarrow \tau\nu}$/BR$_{B_d \rightarrow \tau\nu}^{SM}$ | [82–84] | [85–87] | 1.25 ± 0.40$_{\text{exp+th}}$ | – |
| BR($B_d \rightarrow \mu^+\mu^-$) | [80–83] | [79] | < 2.3 × 10$^{-8}$ | 0.01 × 10$^{-8}$ |
| BR$_{BR_{K_L \rightarrow \pi\nu
u}}$/BR$_{K_L \rightarrow \pi\nu
u}^{SM}$ | [82,84] | [90] | 1.008 ± 0.014$_{\text{exp+th}}$ | – |
| BR$_{BR_{K_L \rightarrow \pi\nu
u}}$/BR$_{K_L \rightarrow \pi\nu
u}^{SM}$ | [91] | [92] | < 4.5 | – |
| $\Delta M_{B_s}^{\text{exp}}/\Delta M_{B_s}^{\text{SM}}$ | [91] | [93,94] | 0.97 ± 0.01$_{\text{exp}}$ ± 0.27$_{\text{th(SM)}}$ | – |
| $\Delta M_{B_d}^{\text{exp}}/\Delta M_{B_d}^{\text{SM}}$ | [80–83] | [79,93,94] | 1.00 ± 0.01$_{\text{exp}}$ ± 0.13$_{\text{th(SM)}}$ | – |
| $\alpha^{\text{exp}}_{\mu} - \alpha^{\text{SM}}_{\mu}$ | [95–98] | [99–101] | (30.2 ± 8.8) × 10$^{-10}$ | 2.0 × 10$^{-10}$ |
| $M_{h}$ [GeV] | [102–105] | [106,107] | > 114.4 (see text) | 1.5 |
| $\Omega_{\text{CDM}}h^2$ | [108–110] | [111] | 0.1099 ± 0.0062 | 0.012 |
## Constraints (II)

<table>
<thead>
<tr>
<th>Observable</th>
<th>Experimental Value</th>
<th>Uncertainty</th>
<th>Exp. Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mathcal{B}(B \rightarrow s\gamma)/\mathcal{B}(B \rightarrow s\gamma)_{\text{SM}}$</td>
<td>1.117</td>
<td>0.076</td>
<td>47</td>
</tr>
<tr>
<td>$\mathcal{B}(B_s \rightarrow \mu\mu)$</td>
<td>&lt; 4.7$\times$10$^{-8}$</td>
<td></td>
<td>47</td>
</tr>
<tr>
<td>$\mathcal{B}(B_d \rightarrow \ell\ell)$</td>
<td>&lt; 2.3$\times$10$^{-8}$</td>
<td></td>
<td>47</td>
</tr>
<tr>
<td>$\mathcal{B}(B \rightarrow \tau\nu)/\mathcal{B}(B \rightarrow \tau\nu)_{\text{SM}}$</td>
<td>1.15</td>
<td>0.40</td>
<td>48</td>
</tr>
<tr>
<td>$\mathcal{B}(B_s \rightarrow X_s\ell\ell)/\mathcal{B}(B_s \rightarrow X_s\ell\ell)_{\text{SM}}$</td>
<td>0.99</td>
<td>0.32</td>
<td>47</td>
</tr>
<tr>
<td>$\Delta m_{B_s}/\Delta m_{B_s}^{\text{SM}}$</td>
<td>1.11</td>
<td>0.01</td>
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<tr>
<td>$\Delta m_{B_d}/\Delta m_{B_d}^{\text{SM}}$</td>
<td>1.09</td>
<td>0.01</td>
<td>47</td>
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<tr>
<td>$\Delta \epsilon_K/\Delta \epsilon_K^{\text{SM}}$</td>
<td>0.92</td>
<td>0.14</td>
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<tr>
<td>$\mathcal{B}(K \rightarrow \mu\nu)/\mathcal{B}(K \rightarrow \mu\nu)_{\text{SM}}$</td>
<td>1.008</td>
<td>0.014</td>
<td>50</td>
</tr>
<tr>
<td>$\mathcal{B}(K \rightarrow \pi\nu\nu)/\mathcal{B}(K \rightarrow \pi\nu\nu)_{\text{SM}}$</td>
<td>&lt; 4.5</td>
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<td>51</td>
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<tr>
<td>$a_\mu^{\text{exp}} - a_\mu^{\text{SM}}$</td>
<td>30.2$\times$10$^{-10}$</td>
<td>8.8$\times$10$^{-10}$</td>
<td>[52,53]</td>
</tr>
<tr>
<td>$\sin^2 \theta_{\text{eff}}$</td>
<td>0.2324</td>
<td>0.0012</td>
<td>46</td>
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<tr>
<td>$\Gamma_Z$</td>
<td>2.4952 GeV</td>
<td>0.0023 GeV</td>
<td>46</td>
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<tr>
<td>$\Gamma_W$</td>
<td>9.14</td>
<td>0.025</td>
<td>46</td>
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<tr>
<td>$\Gamma_h$</td>
<td>0.021629</td>
<td>0.00066</td>
<td>46</td>
</tr>
<tr>
<td>$\Gamma_c$</td>
<td>0.1721</td>
<td>0.003</td>
<td>46</td>
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<tr>
<td>$\Gamma_b(b)$</td>
<td>0.0992</td>
<td>0.0016</td>
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<tr>
<td>$\Gamma_b(c)$</td>
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<td>0.0035</td>
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<td>$\Gamma_b(s)$</td>
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<td>0.020</td>
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<tr>
<td>$\Gamma_a$</td>
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<td>0.027</td>
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<td>$\Gamma_t$</td>
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<td>0.0021</td>
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<tr>
<td>$\Gamma_r$</td>
<td>0.1465</td>
<td>0.0032</td>
<td>46</td>
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<tr>
<td>$\Gamma_b(l)$</td>
<td>0.01714</td>
<td>0.00095</td>
<td>46</td>
</tr>
<tr>
<td>$\sigma_{\text{had}}$</td>
<td>41.640 nb</td>
<td>0.037 nb</td>
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</tr>
<tr>
<td>$m_h$</td>
<td>&gt; 114.4 GeV</td>
<td>3.0 GeV</td>
<td>[54,55,56]</td>
</tr>
<tr>
<td>$\Omega_{\text{CDM}}h^2$</td>
<td>0.1099</td>
<td>0.0062</td>
<td>57</td>
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<td>$1/\alpha_{\text{em}}$</td>
<td>127.925</td>
<td>0.016</td>
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<td>$G_F$</td>
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<td>0.00001$\times$10$^{-5}$ GeV$^{-2}$</td>
<td>58</td>
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<tr>
<td>$\alpha_s$</td>
<td>0.1176</td>
<td>0.0020</td>
<td>58</td>
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<tr>
<td>$m_Z$</td>
<td>91.1875 GeV</td>
<td>0.0021 GeV</td>
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<td>$m_W$</td>
<td>80.399 GeV</td>
<td>0.025 GeV</td>
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<tr>
<td>$m_t$</td>
<td>4.20 GeV</td>
<td>0.17 GeV</td>
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<tr>
<td>$m_t$</td>
<td>172.4 GeV</td>
<td>1.2 GeV</td>
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<tr>
<td>$m_C$</td>
<td>1.77684 GeV</td>
<td>0.00017 GeV</td>
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</tr>
<tr>
<td>$m_c$</td>
<td>1.27 GeV</td>
<td>0.11 GeV</td>
<td>46</td>
</tr>
</tbody>
</table>
Mass spectra (I)

CMSSM

NUHM1
Mass spectra (II)

Predicted Mass Spectrum of SUSY Particles LE mSUGRA

Predicted Mass Spectrum of SUSY Particles LE no h^2 GMSB N2=1

Derived Mass Spectrum of SUSY Particles mSUGRA LE+LHC 1 fb^{-1}

Derived Mass Spectrum of SUSY Particles LE+LHC300 MSSM18

F. Ronga (ETH Zurich) – Joint HEP-APP IOP meeting on SUSY – March 24, 2010