Direct vs. Indirect Searches and SUSY Benchmarks at Colliders

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Prospects for SUSY searches at the LHC (and the ILC) studied in detail only for few benchmark points

most comprehensive results available for SPS 1a point

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- Exclusion bounds
- Study different aspects of phenomenology at future colliders

  $\Rightarrow$ develop analysis strategies for different scenarios

  assess capabilities of LHC, ILC, flavour factories, . . .

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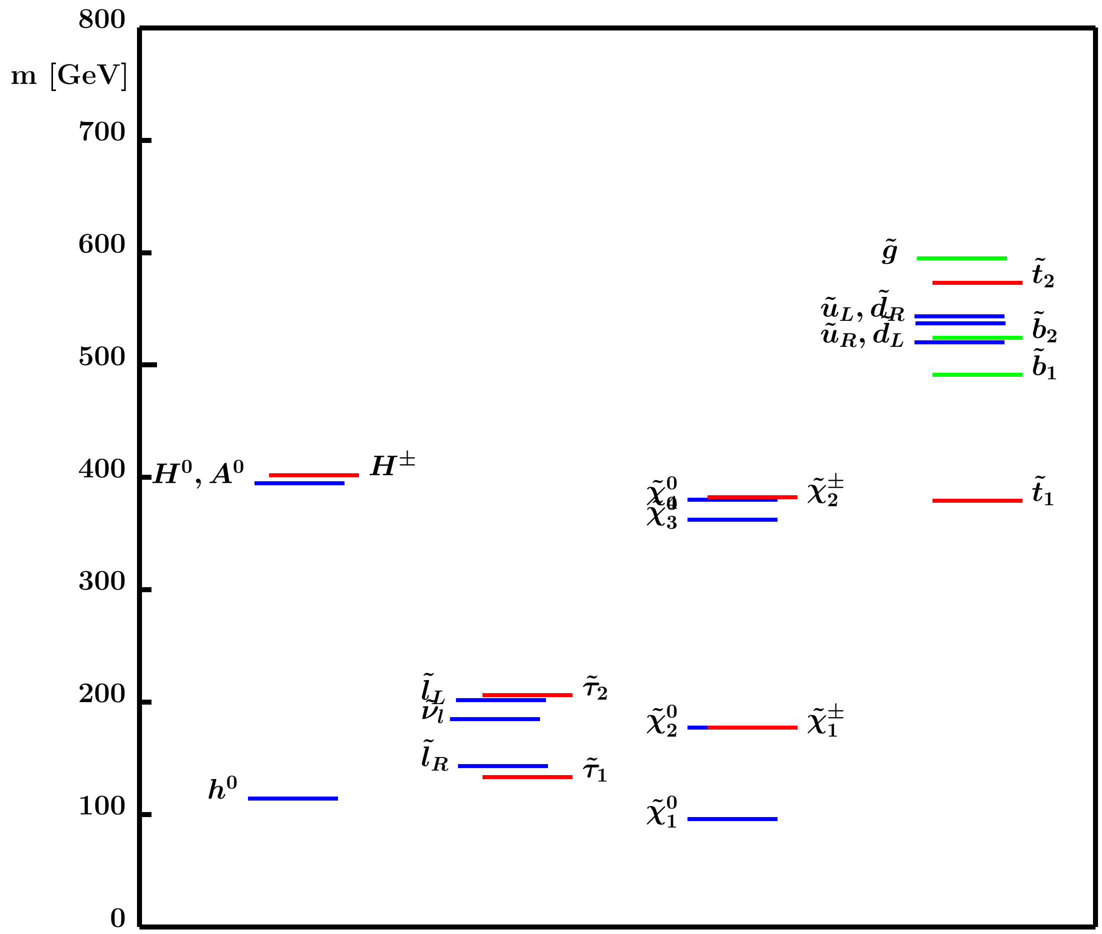
Subsequently further proposals, model lines along 'WMAP strips', . . . [*M. Battaglia et al. '03*]

Mass spectrum in SPS1a scenario

SPS 1a: “bulk” region of mSUGRA scenario (‘best case scenario’)

$$m_0 = 100\,\mathrm{GeV},\ m_{1/2} = 250\,\mathrm{GeV},\ A_0 = -100\,\mathrm{GeV},\ \tan\beta = 10,\quad \mu > 0$$



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How well can the LHC probe properties of SUSY models in less favourable senarios?

Larger $\tan\beta$ values $\Rightarrow$ leptonic decays predominantly into τ’s, scenarios with heavier mass spectrum, . . .

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$\Rightarrow$ Indirect searches can probe effects of new heavy particles, complementary to direct searches

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  Example: *LHC / ILC Report*

  $\Rightarrow$ Need more results on detailed simulations from LHC in order to assess interplay with other machines

Needed for combination of direct and indirect information:

- Coherent framework:

  Different codes need to be consistently combined

  Parameters appearing in different contexts have to have the same meaning

  Example: SLHA $\longrightarrow$ SPA Project

- Reliable estimate of theoretical uncertainties:

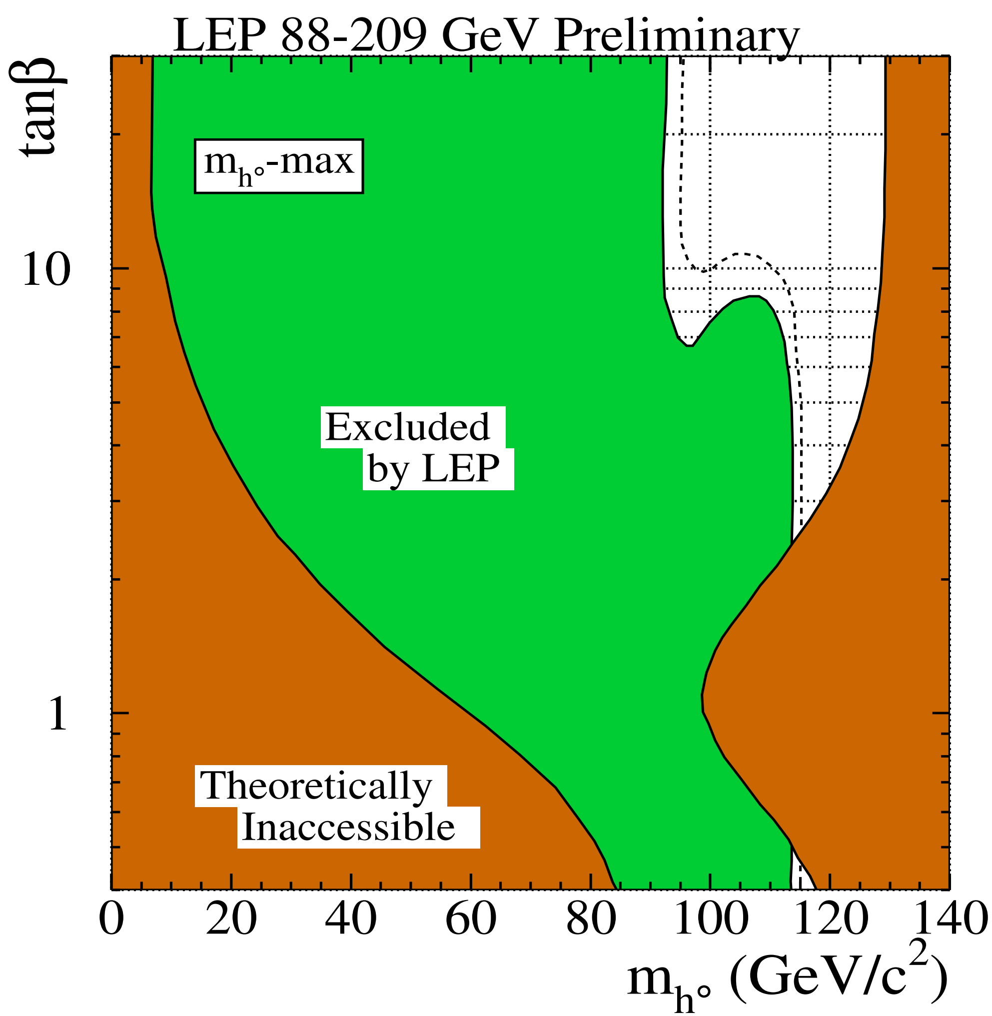
  – from experimental errors of input parameters

  – from unknown higher-order corrections

  Example: LEP constraints on $\tan\beta$

Constraints from the Higgs search at LEP: $m_h^{\max}$-scenario

Experimental search vs. upper m_h-bound (*FeynHiggs* 1.0)



[*LEP Higgs Working Group '01*]

$m_h > 91.0$ GeV

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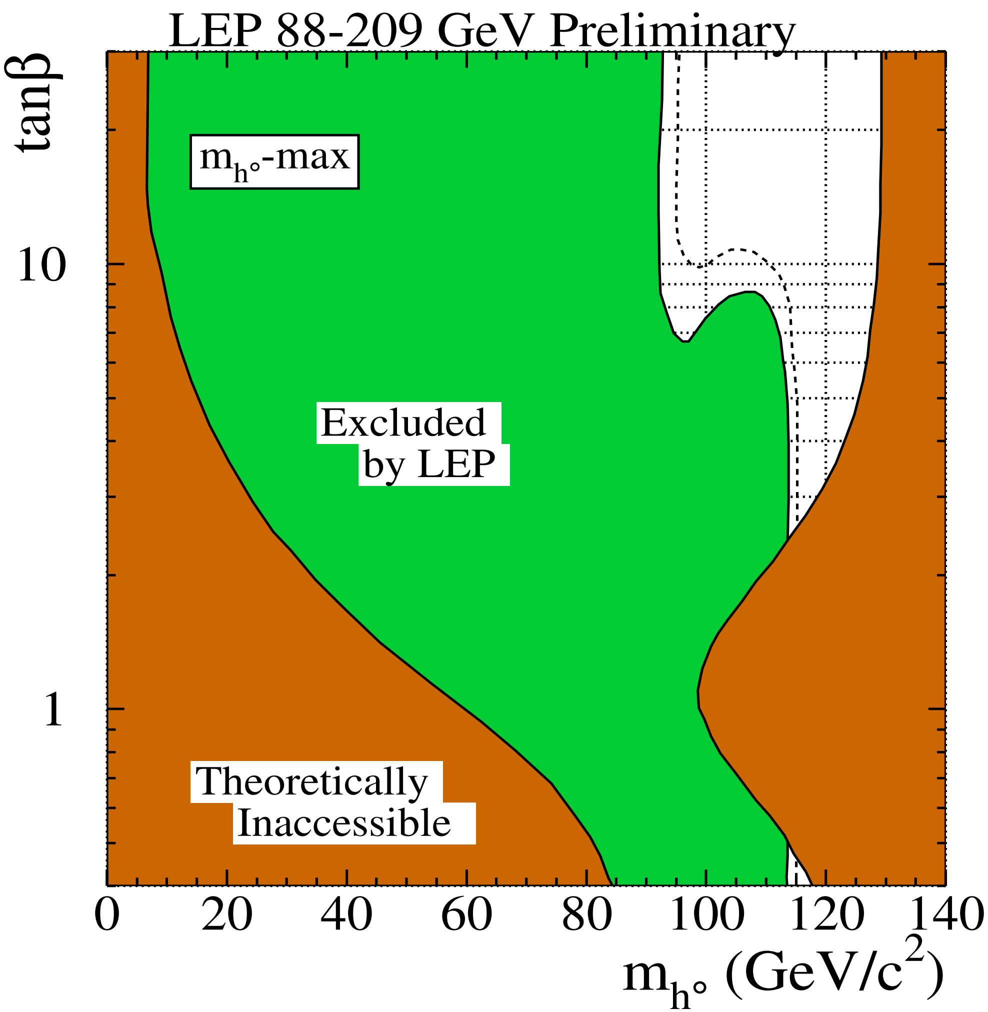

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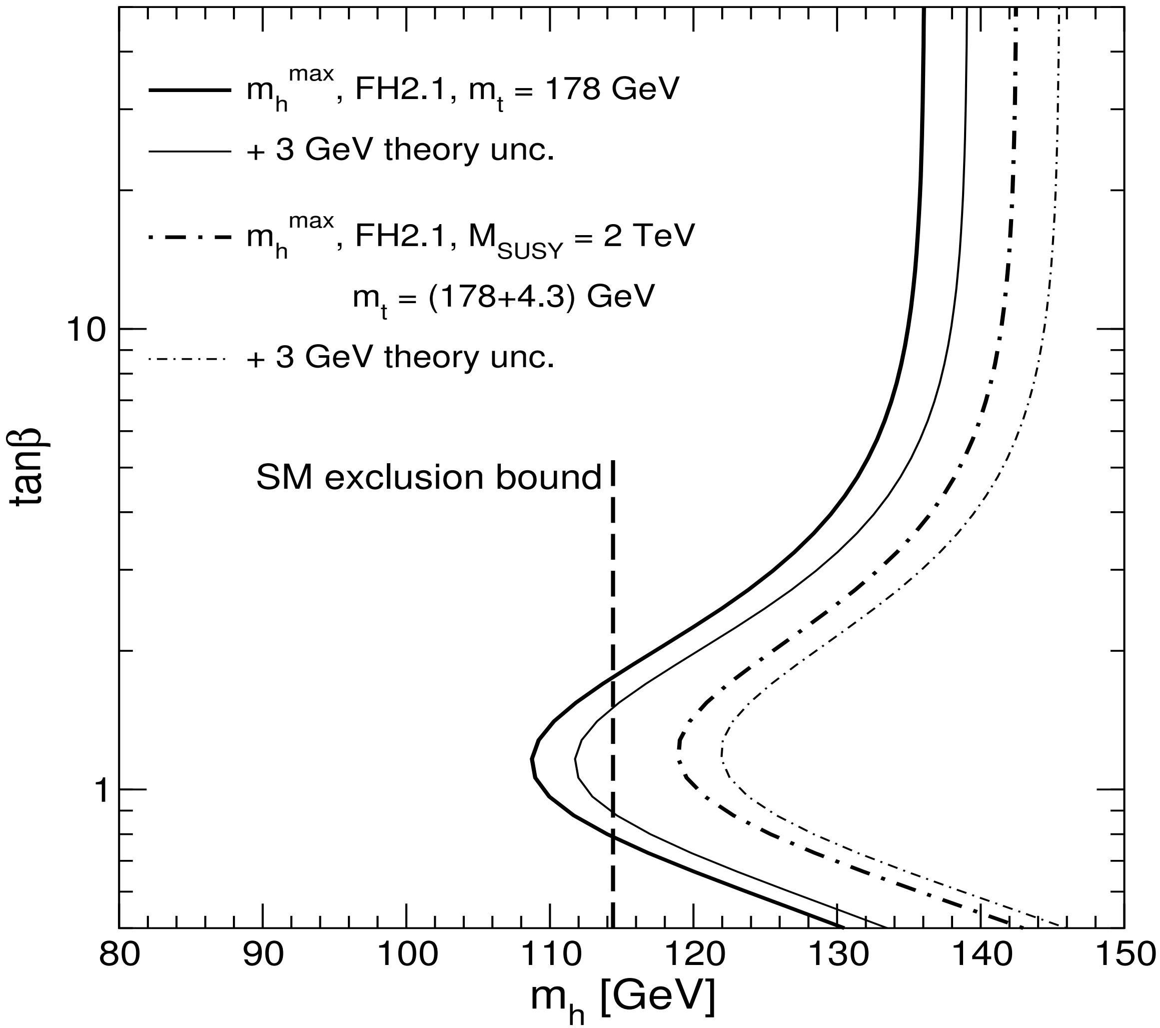
$\Rightarrow$ "Excluded" $\tan\beta$ region: $0.5 < \tan\beta < 2.4$

Impact of experimental error of m_t and uncertainty from unknown higher orders on $\tan\beta$ bound from LEP



[*S. Heinemeyer, W. Hollik, G. W. '04*]

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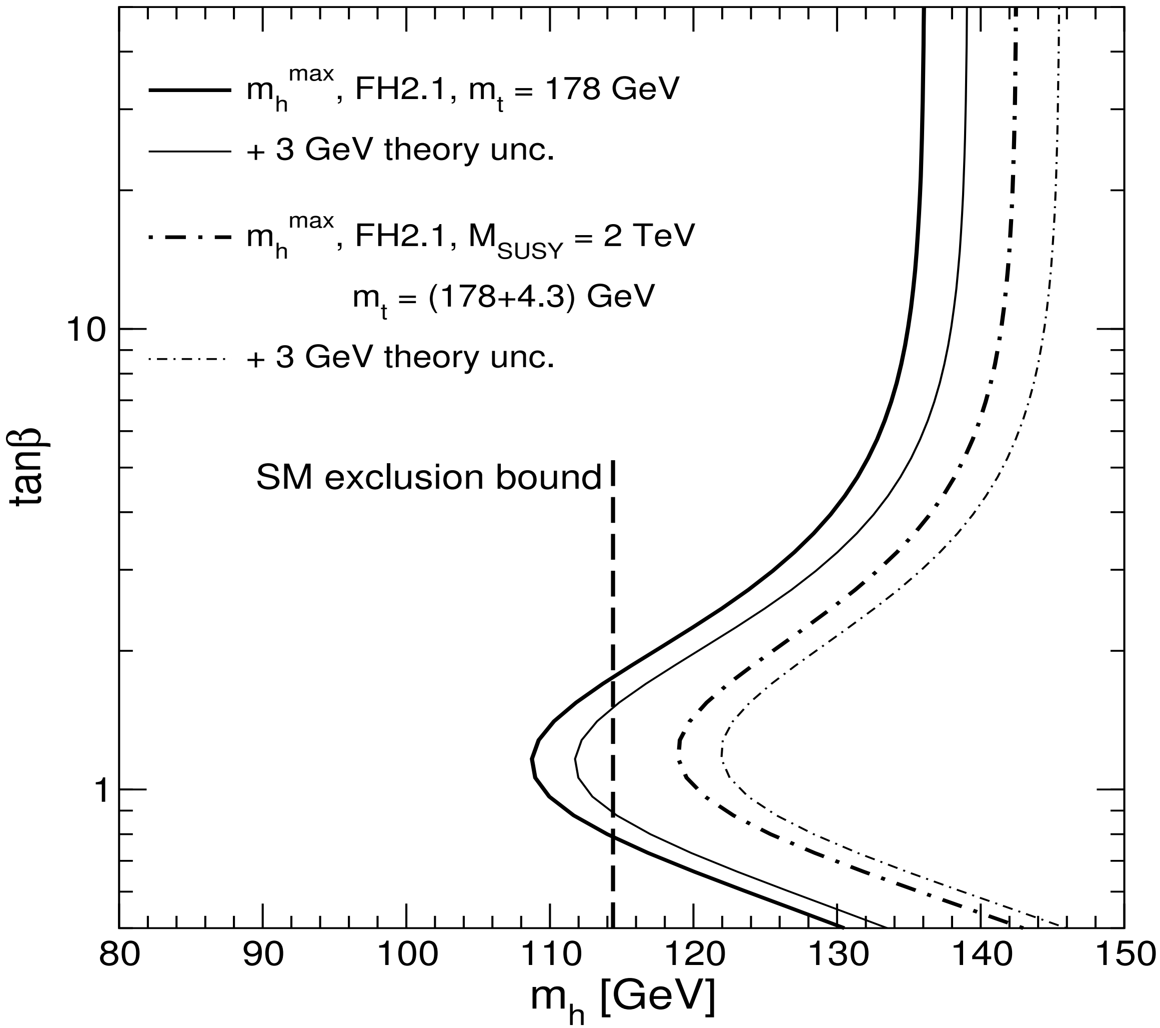

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$\Rightarrow$ No $\tan\beta$ region can be excluded if theoretical uncertainties are taken into account

Models of new physics

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Higher-order corrections in non-renormalisable models?

$\mathcal{CP}$ violation in the MSSM Higgs sector

MSSM Higgs sector is $\mathcal{CP}$-conserving at tree level

Complex parameters enter via loop corrections:

– μ: Higgsino mass parameter

– $A_{t,b,\tau}$: trilinear couplings

– $M_{1,2}$: gaugino mass parameter (one phase can be eliminated)

– $m_{\tilde{\mathrm{g}}}$: gluino mass

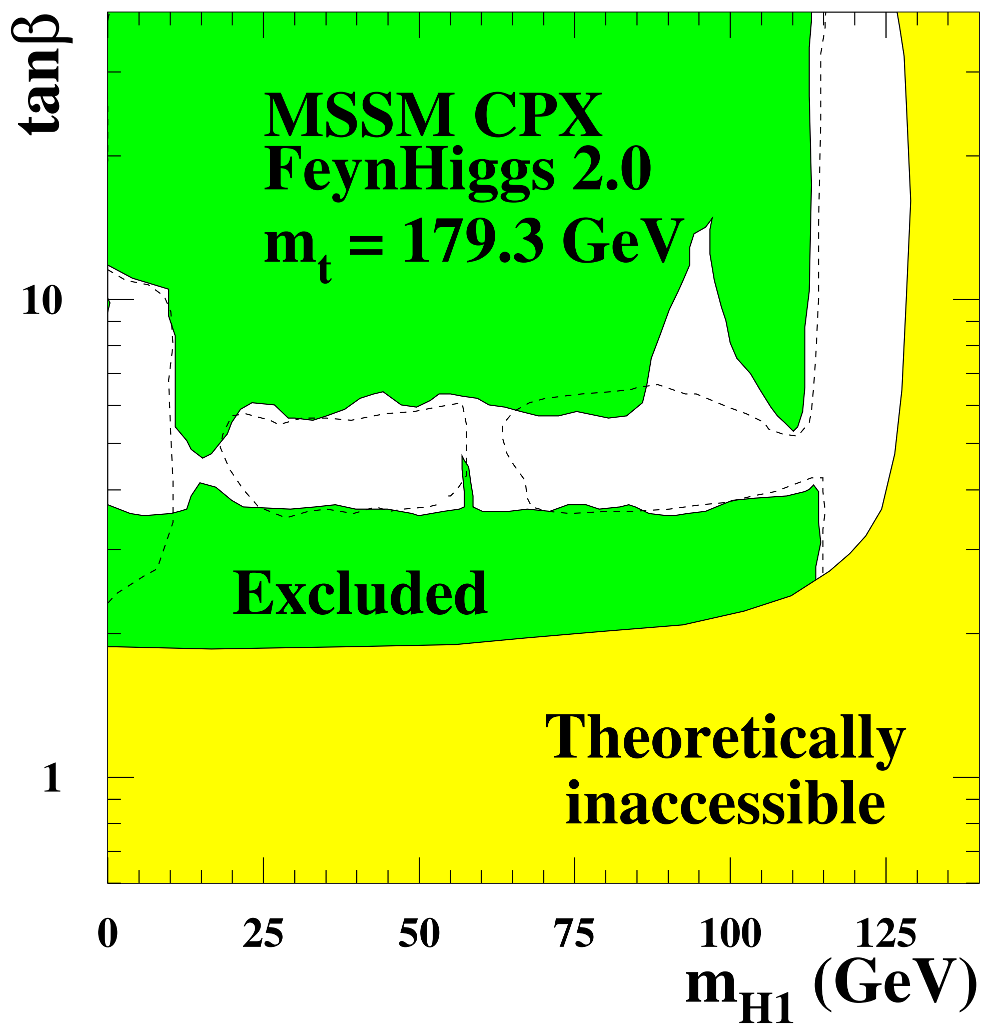
$\Rightarrow$ can induce $\mathcal{CP}$-violating effects

$\Rightarrow$ Mixing between neutral Higgs bosons h_1, h_2, h_3

Complex phases can have large effects on Higgs couplings

CPX scenario

[*LEP Higgs Working Group '04*]



⇒ light SUSY Higgs not ruled out

When does it make sense to combine indirect and direct information?

Indirect constraints: $b \to s\gamma$, $B_s \to \mu^+\mu^-$, $\ldots$, $(g-2)_\mu$, dark matter relic density, . . .

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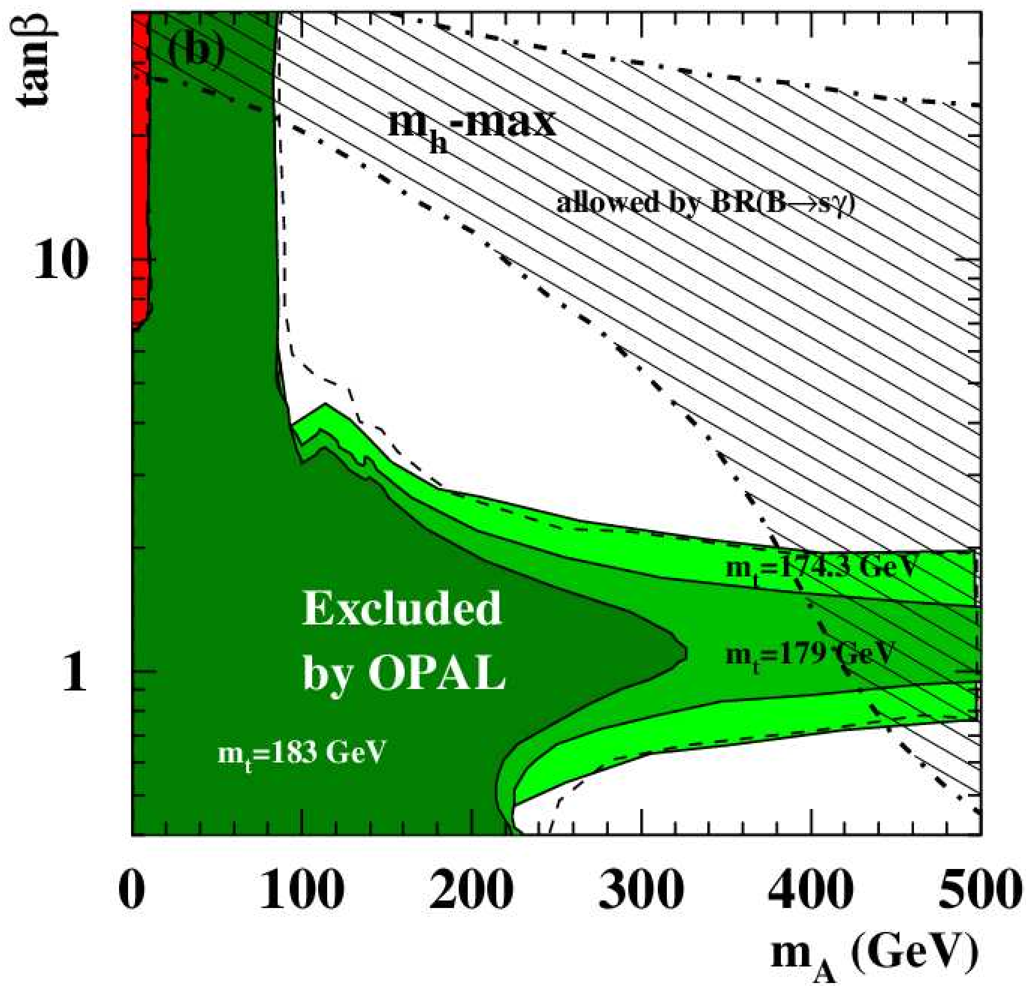
Example: Impact of small flavour mixing on rare b decays

$\Rightarrow$ Combination of collider searches and external constraints most useful if the same sector of the theory is tested in both cases (e.g.: effect of a large complex phase)

Examples: Higgs sector $\oplus$ $b \to s\gamma$ vs. Higgs sector $\oplus$ $(g-2)_\mu$

Counter example: LEP Higgs benchmarks

LEP Higgs benchmarks: benchmarks for conservative exclusion bounds, not test of particular model



[*OPAL '04*]

$\Rightarrow$ Inclusion of indirect constraints is of limited use in this case

Combination of indirect and direct information

⇒ Combination of all available information improves test of particular model

E.g.: does the MSSM, CMSSM, NMSSM, . . . correctly describe the data?

⇒ Careful treatment of underlying assumptions, experimental and theoretical uncertainties necessary,
coherent framework, . . .

⇒ Requirements on tools:

Large effort required on coherent set of tools:

well-defined interface, transition between parameters of different schemes, estimate of theoretical uncertainties, . . .

Example: *FeynHiggs,* `www.feynhiggs.de`

[*S. Heinemeyer, W. Hollik, G. W. '98*] [*T. Hahn, S. Heinemeyer, W. Hollik, G. W. '04*]

Home of FeynHiggs

This is the home page of the Fortran program FeynHiggs.

FeynHiggs is a Fortran code for the diagrammatic calculation of the masses of the masses and mixing angles of the Higgs bosons in the MSSM at the two-loop level.

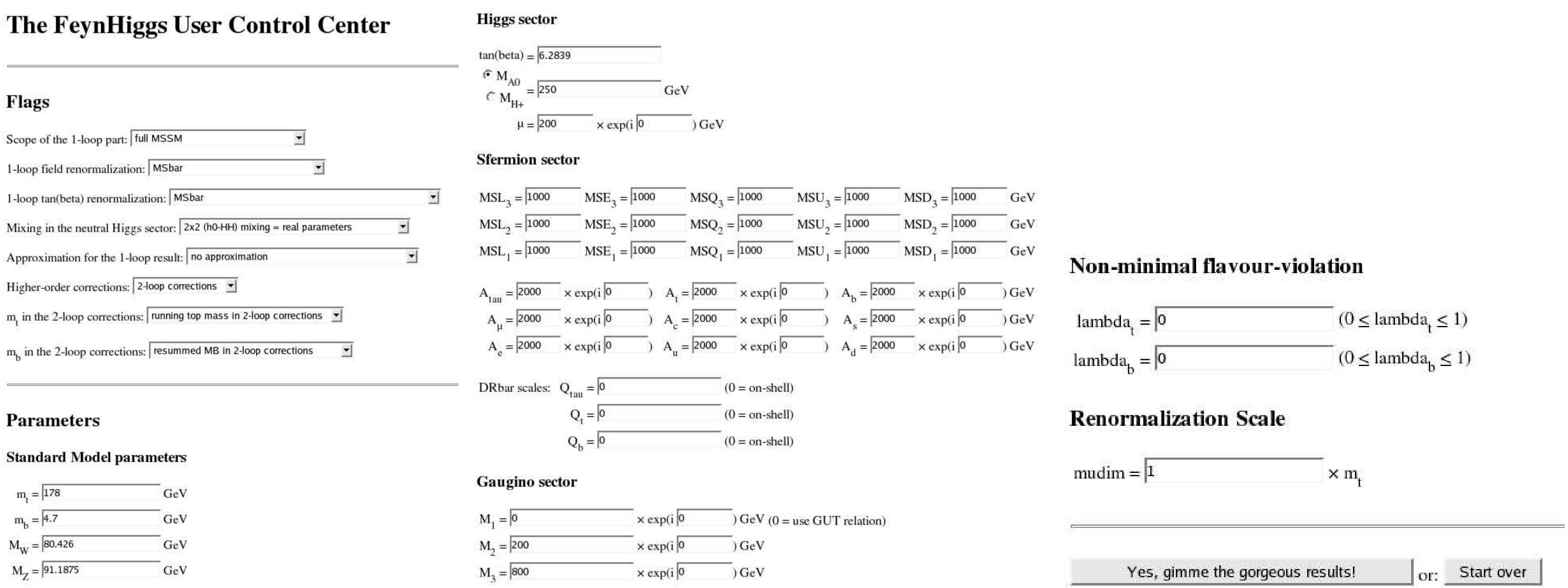
There are now three options:

- **The real and complex case including Higgs decays: FeynHiggs2.2.3beta**

  This beta version includes all features ever implemented into FeynHiggs:
  - complete set of one-loop corrections
  - all known two-loop corrections applicable in Feynman-Diagrammatic approach
  - evaluation of the charged Higgs sector
  - evaluation of the theory error of the Higgs masses and mixing angles due to unknown higher-order corrections
  - evaluation of the leading corrections from NMFV models
  - evaluation of all relevant mixing matrices
  - complete set of Higgs decay branching ratios
  - additional couplings: Higgs gauge boson, Higgs self couplings
  - the Higgs production cross section at a gamma gamma collider
  - transistion from on-shell to DRbar (and vice versa) parameters
  - easy link to other Fortran/C++ codes
  - easy link within Mathematica
  - help via man pages
  - SPS benchmark scenarios and Les Houches benchmark scenarios are given as predifined input
  - FH2.2 is able to process Les Houches Accord data (see hep-ph/0408283 by T. Hahn)
  - The following check items are evaluated:
    - one- and two-loop contributions to (g-2)mu (in this version: two-loop only via an approximation, to be changed soon), see hep-ph/0312264, hep-ph/0405255 (by S. Heinemeyer, D. Stöckinger, G. Weiglein) for details.
    - one- and two-loop contributions to Delta rho

  For FeynHiggs2.2.3beta, go here.

FeynHiggs: on-line version on the web; link as subroutine



FeynHiggs can easily be linked to other programs as subroutine (stand-alone program, no external libraries necessary) $\Rightarrow$ calculation of Higgs-sector observables

FeynHiggs: ***work in progress***

- NMFV effects have recently been included
  $\longrightarrow$ *see Siannah's talk*

- Estimate of theoretical uncertainties for each parameter point:

  new feature, currently being tested

- Implementation of routines for evaluation of electric dipole moments:

  should be ready soon

$\Rightarrow$ Aim to match 'requirements on tools', so that scenarios for flavour physics can be consistently tested in other sectors

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