SUSY / BSM Fits: how to get ready for LHC physics?

Georg Weiglein

DESY

Hamburg, 07 / 2010

Searches for new physics: different approaches

- Top–down: Model-dependent approach

  Confront experimental results with specific model(s), test how well the considered model describes the data

  $\Rightarrow$ Approach followed in SM / SUSY fits

Searches for new physics: different approaches

- Top–down: Model-dependent approach

  Confront experimental results with specific model(s), test how well the considered model describes the data

  $\Rightarrow$ Approach followed in SM / SUSY fits

- Bottom–up: Try to avoid model-dependence as much as possible

  Cross-section limits

  Characteristic features of an observed excess, distributions, topologies: di-lepton edges, transverse mass variables, informations about mass, couplings, spin, $\mathcal{CP}$ properties of observed states

  Description in terms of “simplified models”, effective Lagrangians?

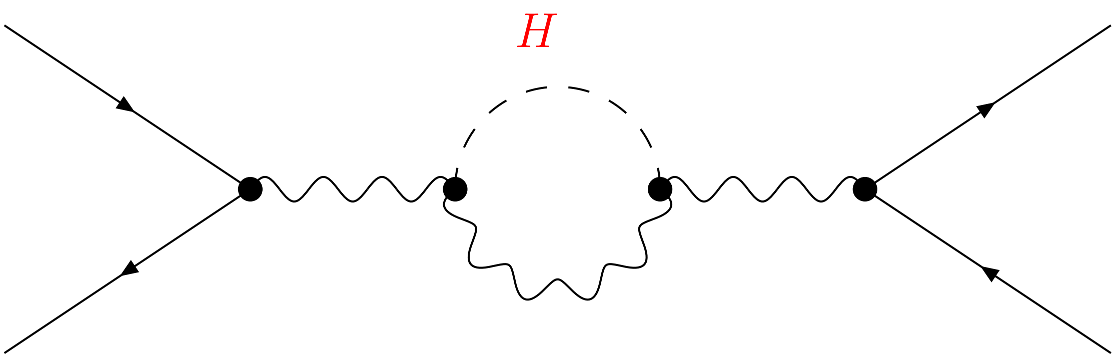
The role of electroweak precision observables

EW precision data:
$M_Z, M_W, \sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}}, \ldots$

Theory:
SM, MSSM, ...

$\Downarrow$

Sensitivity to loop effects of new physics



$\Rightarrow$ Exploitation of loop effects of new physics requires a model-dependent approach

$\Rightarrow$ Need high-precision predictions for relevant observables in different models

How about S, T, U ***parameters?***

Combine most sophisticated SM predictions for electroweak precision observables (EWPO) with parametrisation of small effects of new physics: pure one-loop concept

How about S, T, U parameters?

Combine most sophisticated SM predictions for electroweak precision observables (EWPO) with parametrisation of small effects of new physics: pure one-loop concept

However: S, T, U parametrisation is applicable only to a subset of Z-pole observables $+ M_{\rm W}$ in models where higher-order contributions enter via gauge-boson self-energies only

For many EWPO this assumption is not valid:
$(g-2)_\mu$, $\mathrm{BR}(b \to s\gamma)$, $\ldots$ cannot be described in terms of S, T, U parameters

How about S, T, U parameters?

Combine most sophisticated SM predictions for electroweak precision observables (EWPO) with parametrisation of small effects of new physics: pure one-loop concept

However: S, T, U parametrisation is applicable only to a subset of Z-pole observables $+ M_{\mathrm{W}}$ in models where higher-order contributions enter via gauge-boson self-energies only

For many EWPO this assumption is not valid:
$(g-2)_\mu$, $\mathrm{BR}(b \to s\gamma)$, $\ldots$ cannot be described in terms of S, T, U parameters

Comparison: which kind of higher-order corrections are probed by the EWPO?

Sensitivity of the EWPO – example: SM prediction for M_W vs. experimental result

Current experimental value: $M_\mathrm{W}^\mathrm{exp} = 80.399 \pm 0.023\ \mathrm{GeV}$

Theoretical uncertainties from unknown higher-order corrections: $\delta M_\mathrm{W}^\mathrm{intr} \approx 0.004\ \mathrm{GeV}$

Sensitivity of the EWPO – example: SM prediction for $M_{\rm W}$ vs. experimental result

Current experimental value: $M_{\rm W}^{\rm exp} = 80.399 \pm 0.023~{\rm GeV}$
Theoretical uncertainties from unknown higher-order corrections: $\delta M_{\rm W}^{\rm intr} \approx 0.004~{\rm GeV}$

SM prediction:
Tree-level: $M_{\rm W}^{\rm tree} = 80.939~{\rm GeV}$ $\Rightarrow$ off by $\approx 24\sigma$

Sensitivity of the EWPO – example: SM prediction for M_W vs. experimental result

Current experimental value: $M_\mathrm{W}^\mathrm{exp} = 80.399 \pm 0.023\ \mathrm{GeV}$
Theoretical uncertainties from unknown higher-order corrections: $\delta M_\mathrm{W}^\mathrm{intr} \approx 0.004\ \mathrm{GeV}$

SM prediction:
Tree-level: $M_\mathrm{W}^\mathrm{tree} = 80.939\ \mathrm{GeV} \Rightarrow$ off by $\approx 24\sigma$
One-loop ($M_\mathrm{H} = 100\ \mathrm{GeV}$): $\delta M_\mathrm{W}^\alpha \approx 18.5\sigma$

Sensitivity of the EWPO – example: SM prediction for M_{W} vs. experimental result

Current experimental value: $M_{\mathrm{W}}^{\mathrm{exp}} = 80.399 \pm 0.023~\mathrm{GeV}$
Theoretical uncertainties from unknown higher-order corrections: $\delta M_{\mathrm{W}}^{\mathrm{intr}} \approx 0.004~\mathrm{GeV}$

SM prediction:
Tree-level: $M_{\mathrm{W}}^{\mathrm{tree}} = 80.939~\mathrm{GeV} \Rightarrow$ off by $\approx 24\sigma$
One-loop ($M_{\mathrm{H}} = 100~\mathrm{GeV}$): $\delta M_{\mathrm{W}}^{\alpha} \approx 18.5\sigma$
Two-loop $\mathcal{O}(\alpha\alpha_{\mathrm{s}})$: $\delta M_{\mathrm{W}}^{\alpha\alpha_{\mathrm{s}}} \approx 2.5\sigma$

Sensitivity of the EWPO – example: SM prediction for M_W vs. experimental result

Current experimental value: $M_\mathrm{W}^\mathrm{exp} = 80.399 \pm 0.023 \ \mathrm{GeV}$
Theoretical uncertainties from unknown higher-order corrections: $\delta M_\mathrm{W}^\mathrm{intr} \approx 0.004 \ \mathrm{GeV}$

SM prediction:
Tree-level: $M_\mathrm{W}^\mathrm{tree} = 80.939 \ \mathrm{GeV}$ $\Rightarrow$ off by $\approx 24\sigma$
One-loop ($M_\mathrm{H} = 100 \ \mathrm{GeV}$): $\delta M_\mathrm{W}^{\alpha} \approx 18.5\sigma$
Two-loop $\mathcal{O}(\alpha\alpha_\mathrm{s})$: $\delta M_\mathrm{W}^{\alpha\alpha_\mathrm{s}} \approx 2.5\sigma$
Two-loop $\mathcal{O}(\alpha^2)$: $\delta M_\mathrm{W}^{\alpha^2} \approx 2\sigma$

Sensitivity of the EWPO – example: SM prediction for $M_{\rm W}$ vs. experimental result

Current experimental value: $M_{\rm W}^{\rm exp} = 80.399 \pm 0.023~{\rm GeV}$
Theoretical uncertainties from unknown higher-order corrections: $\delta M_{\rm W}^{\rm intr} \approx 0.004~{\rm GeV}$

SM prediction:
Tree-level: $M_{\rm W}^{\rm tree} = 80.939~{\rm GeV}$ $\Rightarrow$ off by $\approx 24\sigma$
One-loop ($M_{\rm H} = 100~{\rm GeV}$): $\delta M_{\rm W}^{\alpha} \approx 18.5\sigma$
Two-loop $\mathcal{O}(\alpha\alpha_{\rm s})$: $\delta M_{\rm W}^{\alpha\alpha_{\rm s}} \approx 2.5\sigma$
Two-loop $\mathcal{O}(\alpha^2)$: $\delta M_{\rm W}^{\alpha^2} \approx 2\sigma$
Three-loop: $\delta M_{\rm W}^{\alpha^3} \approx 0.5\sigma$

Sensitivity of the EWPO – example: SM prediction for M_W vs. experimental result

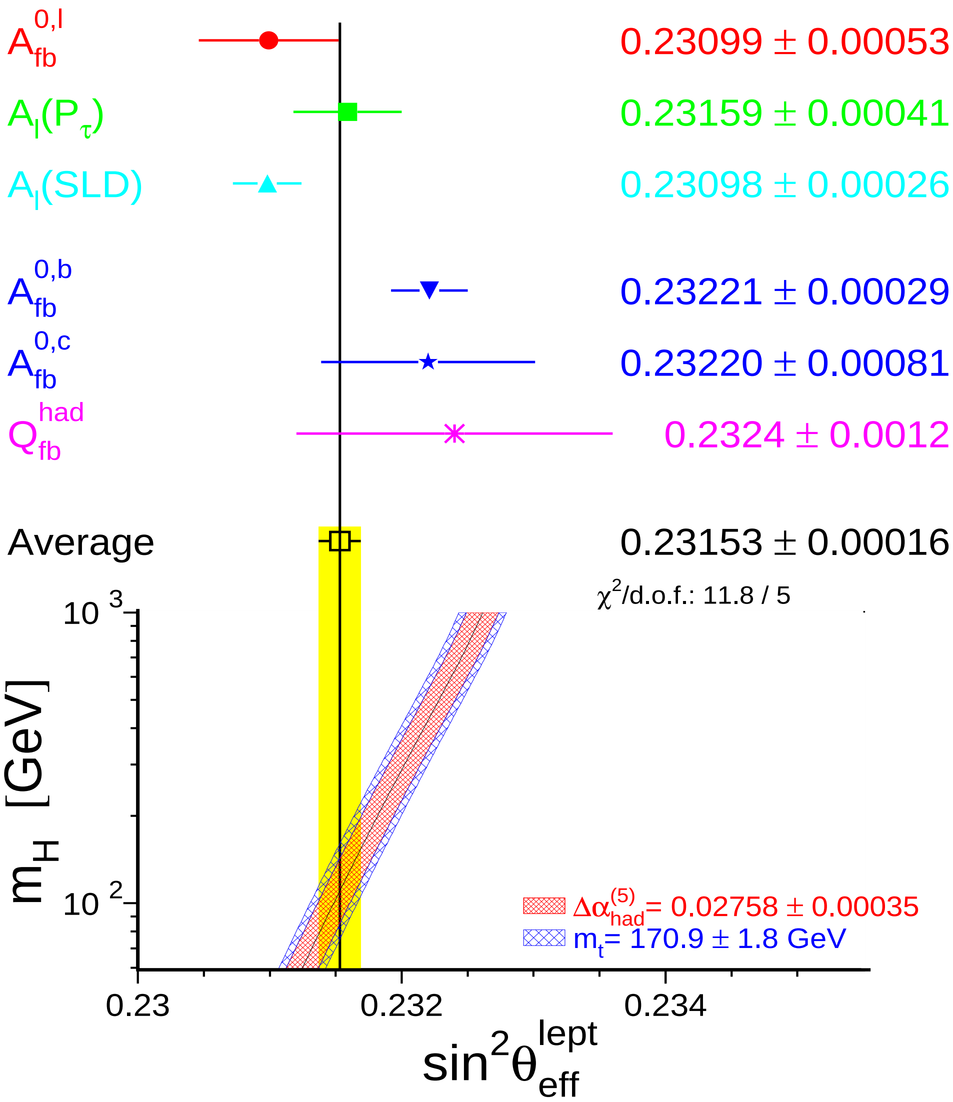
Current experimental value: $M_W^{exp} = 80.399 \pm 0.023$ GeV
Theoretical uncertainties from unknown higher-order corrections: $\delta M_W^{intr} \approx 0.004$ GeV

SM prediction:
Tree-level: $M_W^{tree} = 80.939$ GeV $\Rightarrow$ off by $\approx 24\sigma$
One-loop ($M_H = 100$ GeV): $\delta M_W^{\alpha} \approx 18.5\sigma$
Two-loop $\mathcal{O}(\alpha\alpha_s)$: $\delta M_W^{\alpha\alpha_s} \approx 2.5\sigma$
Two-loop $\mathcal{O}(\alpha^2)$: $\delta M_W^{\alpha^2} \approx 2\sigma$
Three-loop: $\delta M_W^{\alpha^3} \approx 0.5\sigma$

$\Rightarrow$ Comparison of M_W prediction in the SM with the experimental result is sensitive to two-loop and even three-loop corrections

Without a proper inclusion of the relevant two-loop effects the result of the comparison would be misleading

$\sin^2\theta_{\rm eff}$: *unclear experimental situation*



[*LEPEWWG '07*]

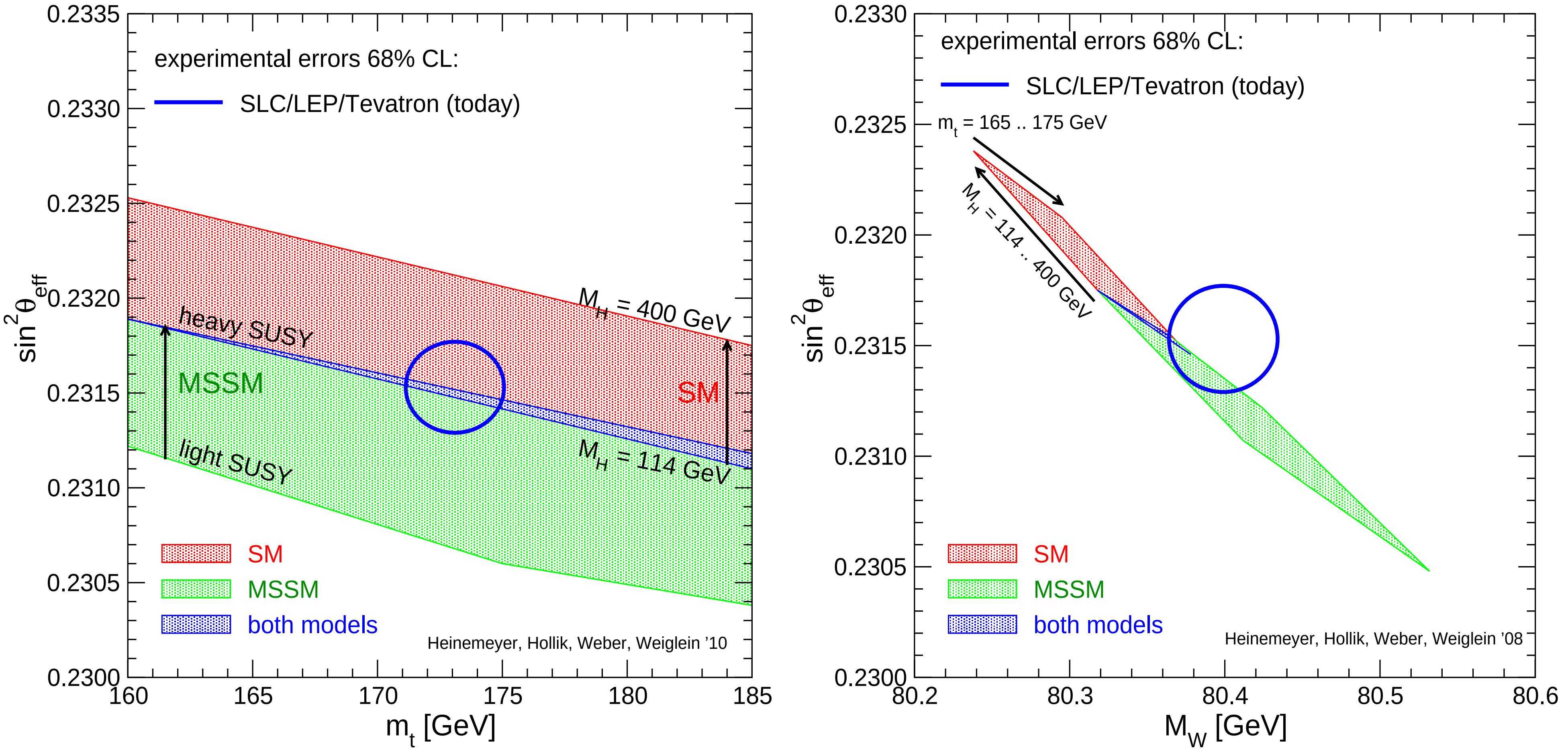
$\sin^2\theta_{\rm eff}$ has a high sensitivity to $M_{\rm H}$ and effects of new physics

But:
large discrepancy between $A_{\rm LR}$ (SLD) and $A_{\rm FB}$ (LEP),

has big impact on constraints on new physics

$\sin^2\theta_{\mathrm{eff}} = 0.23153 \pm 0.00016$*: central value, errors added in quadrature*

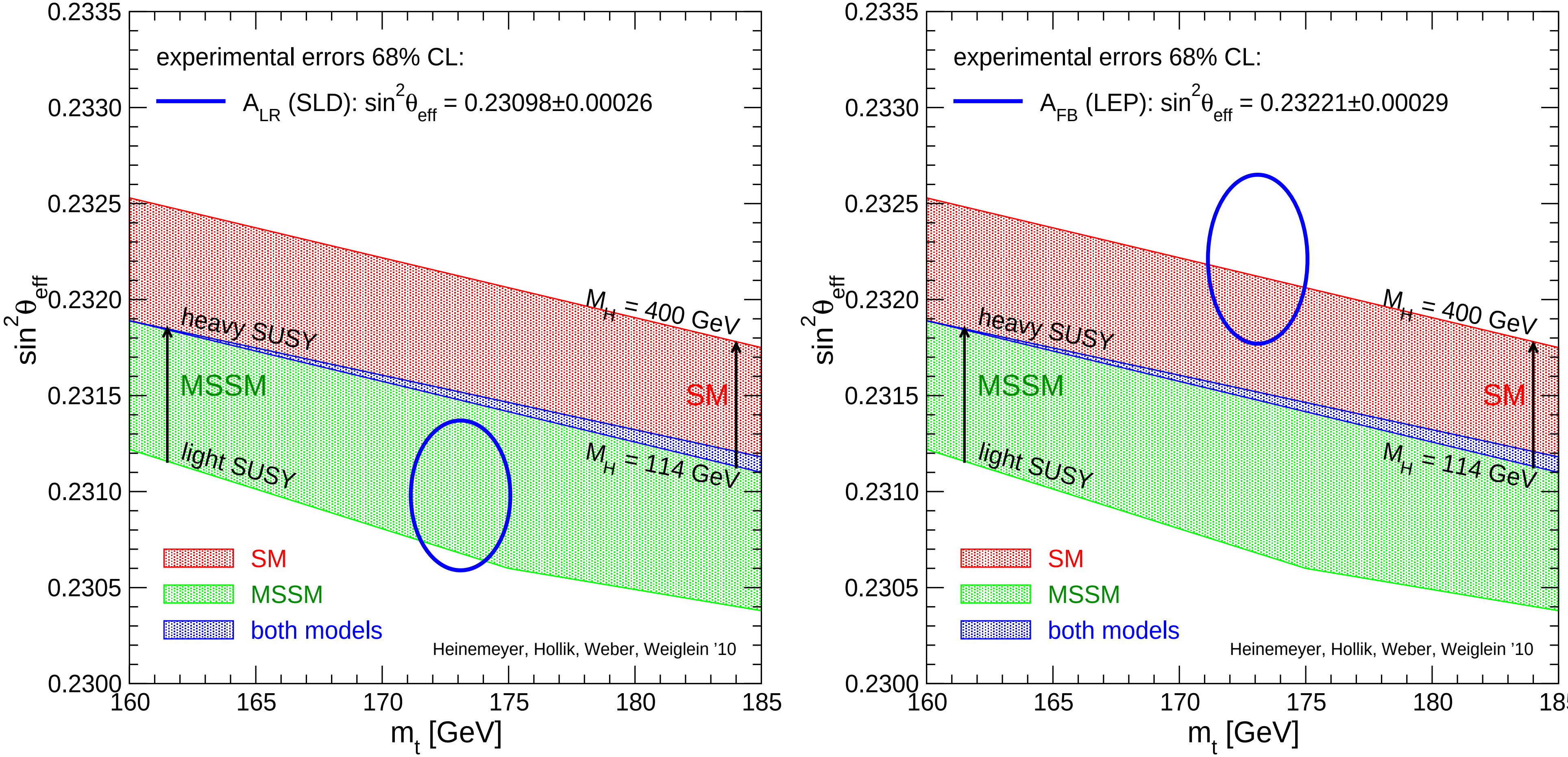
[*S. Heinemeyer, W. Hollik, A.M. Weber, G. W. '10*]



$\Rightarrow$ Good agreement of indirect prediction with experimental result for both models

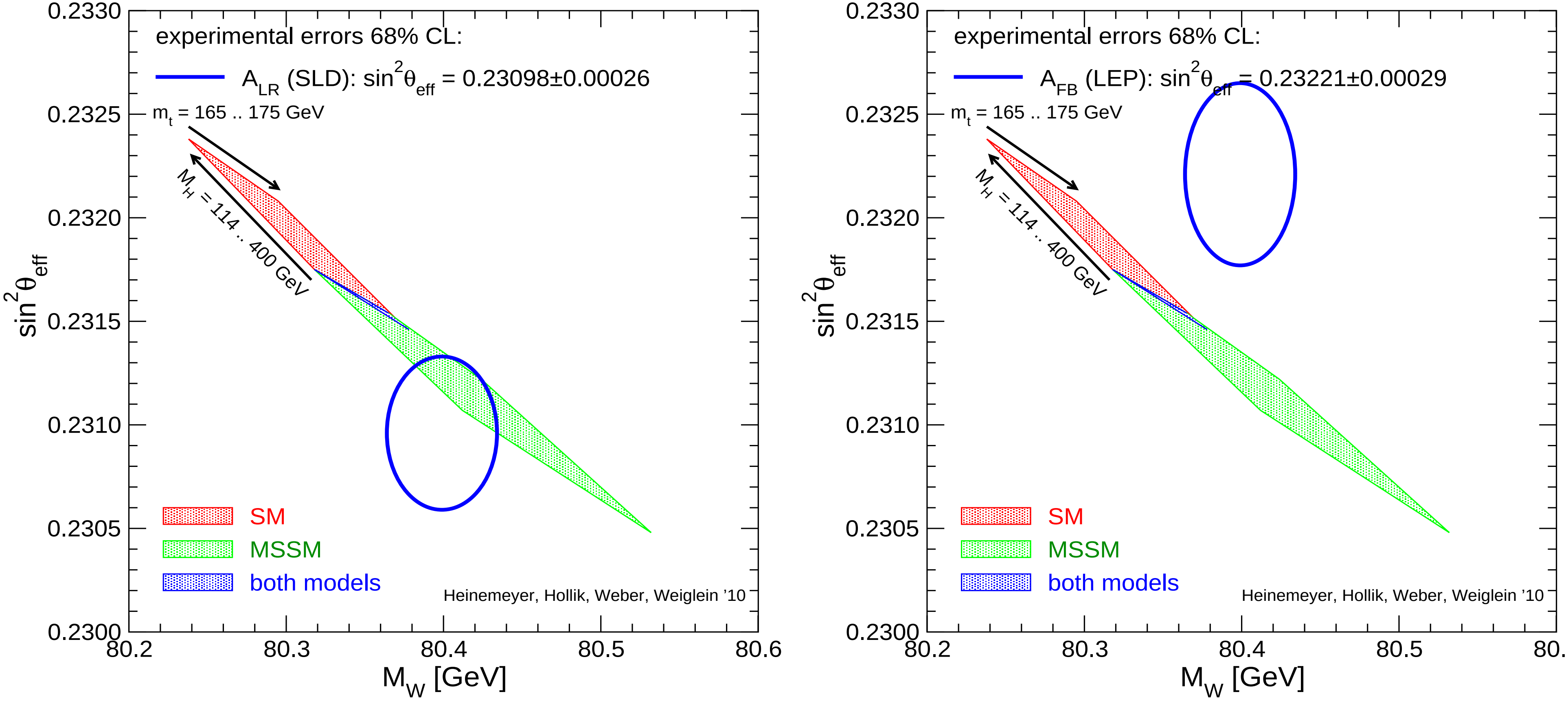
$\sin^2\theta_{\mathrm{eff}}$ *prediction vs. measured values from* A_{LR} *(SLD) and* A_{FB} *(LEP)*

[*S. Heinemeyer, W. Hollik, A.M. Weber, G. W. '10*]

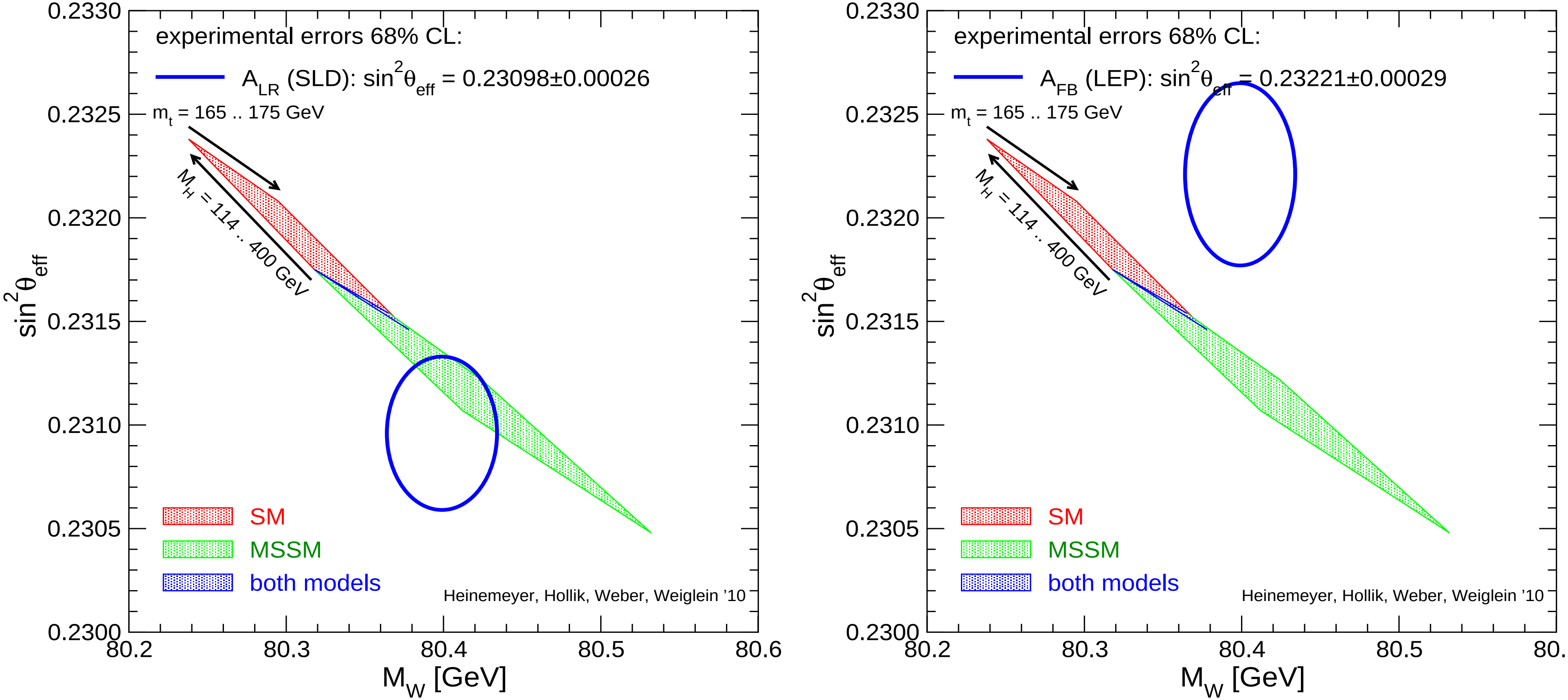


$\Rightarrow$ Large impact on indirect constraints

$\sin^2\theta_{\rm eff}$ *prediction vs. measured values from* $A_{\rm LR}$ *(SLD) and* $A_{\rm FB}$ *(LEP)*

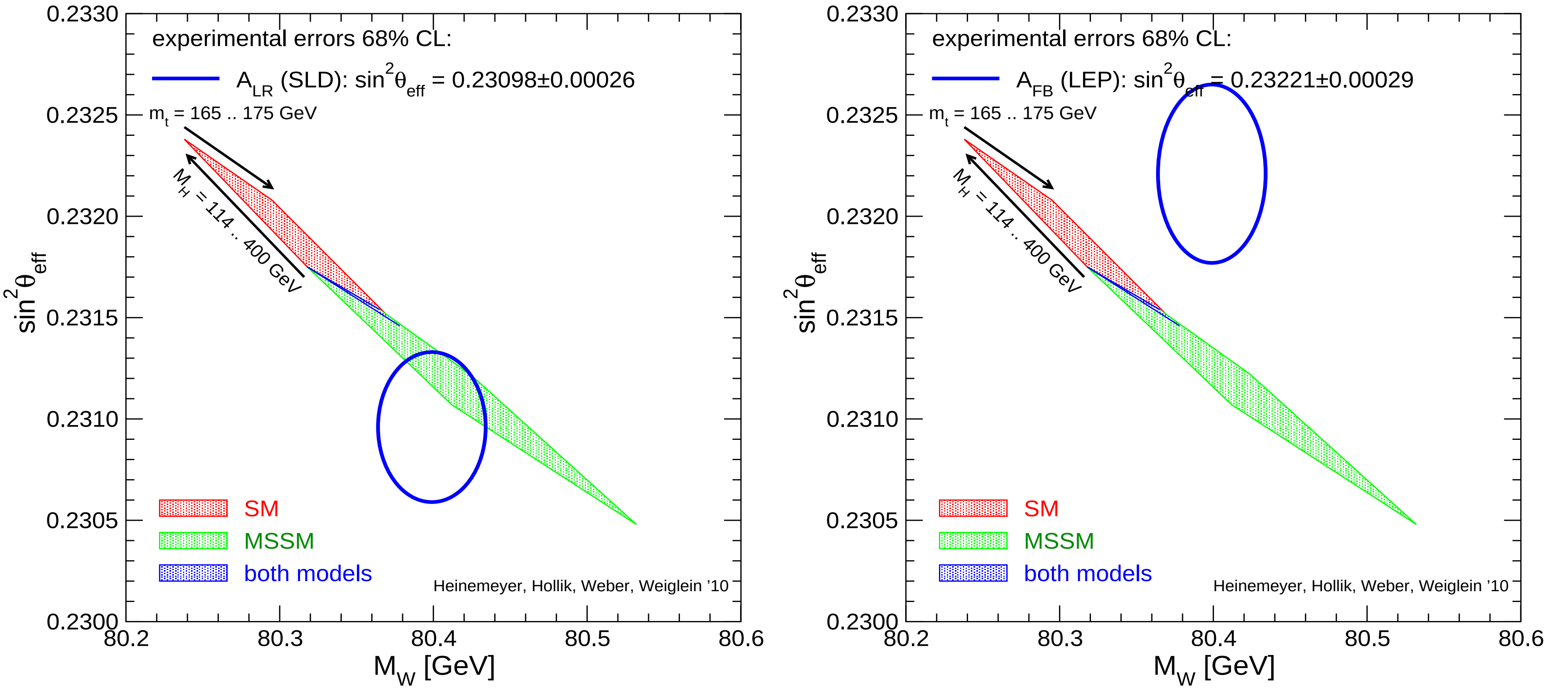


$\sin^2\theta_{\rm eff}$ *prediction vs. measured values from* $A_{\rm LR}$ *(SLD) and* $A_{\rm FB}$ *(LEP)*



$\Rightarrow$ Precise $\sin^2\theta_{\rm eff}$ measurement would have the potential to rule out the SM and the MSSM in one go!

$\sin^2\theta_{\rm eff}$ *prediction vs. measured values from* $A_{\rm LR}$ *(SLD) and* $A_{\rm FB}$ *(LEP)*



$\Rightarrow$ Precise $\sin^2\theta_{\rm eff}$ measurement would have the potential to rule out the SM and the MSSM in one go!

$\Rightarrow$ Impact of $\sin^2\theta_{\rm eff}$ as an EWPO is largely affected by its unclear experimental situation

EWPO: present and future

Within the model-dependent approach the powerful tool of electroweak precision observables can be applied

EWPO: present and future

Within the model-dependent approach the powerful tool of electroweak precision observables can be applied

While in a constrained model like the CMSSM with four parameters the inclusion of hypothetical LHC results would reduce the impact of the EWPO (see Peter's talk yesterday), this is not expected to happen when we aim at testing the CMSSM assumptions

EWPO: present and future

Within the model-dependent approach the powerful tool of electroweak precision observables can be applied

While in a constrained model like the CMSSM with four parameters the inclusion of hypothetical LHC results would reduce the impact of the EWPO (see Peter's talk yesterday), this is not expected to happen when we aim at testing the CMSSM assumptions

$\Rightarrow$ Constraints from EWPO, cold dark matter, . . . will be crucial for testing the validity of new physics models and for discriminating between competing models

Crucial questions: how can we determine the underlying structure of physics at the TeV scale?

Crucial questions: how can we determine the underlying structure of physics at the TeV scale?

- Fits in different models can tell us which models describe the data better or worse

Crucial questions: how can we determine the underlying structure of physics at the TeV scale?

- Fits in different models can tell us which models describe the data better or worse
- However, statements are possible only about the considered set of models

  The fits do not tell us whether other models may fit the data equally well or even better

Crucial questions: how can we determine the underlying structure of physics at the TeV scale?

- Fits in different models can tell us which models describe the data better or worse
- However, statements are possible only about the considered set of models

  The fits do not tell us whether other models may fit the data equally well or even better
- How well can we determine the nature of TeV scale physics in this way?

Crucial questions: how can we determine the underlying structure of physics at the TeV scale?

- Fits in different models can tell us which models describe the data better or worse
- However, statements are possible only about the considered set of models

  The fits do not tell us whether other models may fit the data equally well or even better
- How well can we determine the nature of TeV scale physics in this way?
- Currently available data (EWPO, CDM, search limits) do not provide sensitivity beyond the simplest / most restricted versions of new physics models (CMSSM, . . .)

How to incorporate LHC results?

How to incorporate LHC results?

- We should encourage ATLAS and CMS to present search results in a model-independent approach

How to incorporate LHC results?

- We should encourage ATLAS and CMS to present search results in a model-independent approach
An interpretation just in mSUGRA with $\tan\beta = 2$ would we of little use . . .

How to incorporate LHC results?

- We should encourage ATLAS and CMS to present search results in a model-independent approach
  An interpretation just in mSUGRA with $\tan\beta = 2$ would we of little use . . .

- How to use model-independent results in a model-dependent fit?
  $\Rightarrow$ Fits with additional assumptions
  e.g.: fit in MSSM18, assuming that di-lepton edge observed by ATLAS and CMS arises from $\tilde{\chi}_2^0 \to l^+ l^- \tilde{\chi}_1^0$

How to incorporate LHC results?

- We should encourage ATLAS and CMS to present search results in a model-independent approach
  An interpretation just in mSUGRA with $\tan\beta = 2$ would we of little use . . .

- How to use model-independent results in a model-dependent fit?
  $\Rightarrow$ Fits with additional assumptions
  e.g.: fit in MSSM18, assuming that di-lepton edge observed by ATLAS and CMS arises from $\tilde{\chi}^0_2 \to l^+ l^- \tilde{\chi}^0_1$

- How well can one identify which particles appear in cascades / dilepton edges etc. observed at the LHC?

BSM fits

BSM fits

- Which models?

  SUSY: CMSSM, NUHM, MSSM18, MSSM24, . . . , NMSSM, E6MSSM, . . .

  Extra dimensions, Z' models

BSM fits

- Which models?

  SUSY: CMSSM, NUHM, MSSM18, MSSM24, . . . , NMSSM, E6MSSM, . . .

  Extra dimensions, Z' models

- A fit framework for a wide class of models?

  How to get a comprehensive and coherent set of theory predictions at a similar level of accuracy?

  How about higher-order corrections for non-renormalisable models?

  How to quantify theoretical uncertainties?

  Relation to more model-independent approaches? (Data compared to lowest-order predictions in simplified models) Impact of EWPO?

Theoretical uncertainties

- “Parametric” uncertainties:

  uncertainties induced by the experimental errors of the input parameters

  Easy to take into account (in principle) in a global fit

- “Intrinsic” uncertainties:

  uncertainties due to unknown higher-order corrections

  Size of the intrinsic uncertainties depends on the parameter region that one is probing (e.g.: SUSY: $\tan\beta$, μ, X_{t}, $m_{\tilde{\mathrm{g}}}$, $\ldots$)

  How to quantify the theory uncertainties of new physics models as a function of the parameters of the model?

Conclusions

Conclusions

- Global fits will be a powerful tool for constraining the possible nature of new physics at the TeV scale

Conclusions

- Global fits will be a powerful tool for constraining the possible nature of new physics at the TeV scale

- It is still quite some way to go to get to a fit framework that allows us to test a wide variety of models in a coherent way

Conclusions

- Global fits will be a powerful tool for constraining the possible nature of new physics at the TeV scale

- It is still quite some way to go to get to a fit framework that allows us to test a wide variety of models in a coherent way

- There are lots of things to do for this working group . . .