Z-pole physics at the ILC with polarised beams: why is it needed?

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- Electroweak precision observables (EWPO) — lessons from the present state
- What makes $\sin^2\theta_{\rm eff}$ special for the ILC?
- Conclusions

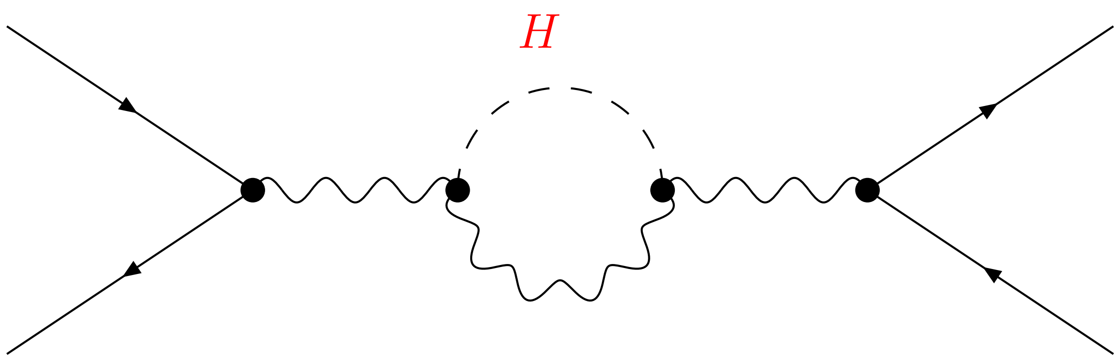
Electroweak precision observables (EWPO) — lessons from the present state

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

Theory:
SM, MSSM, . . .

$\Downarrow$

Test of theory at the quantum level



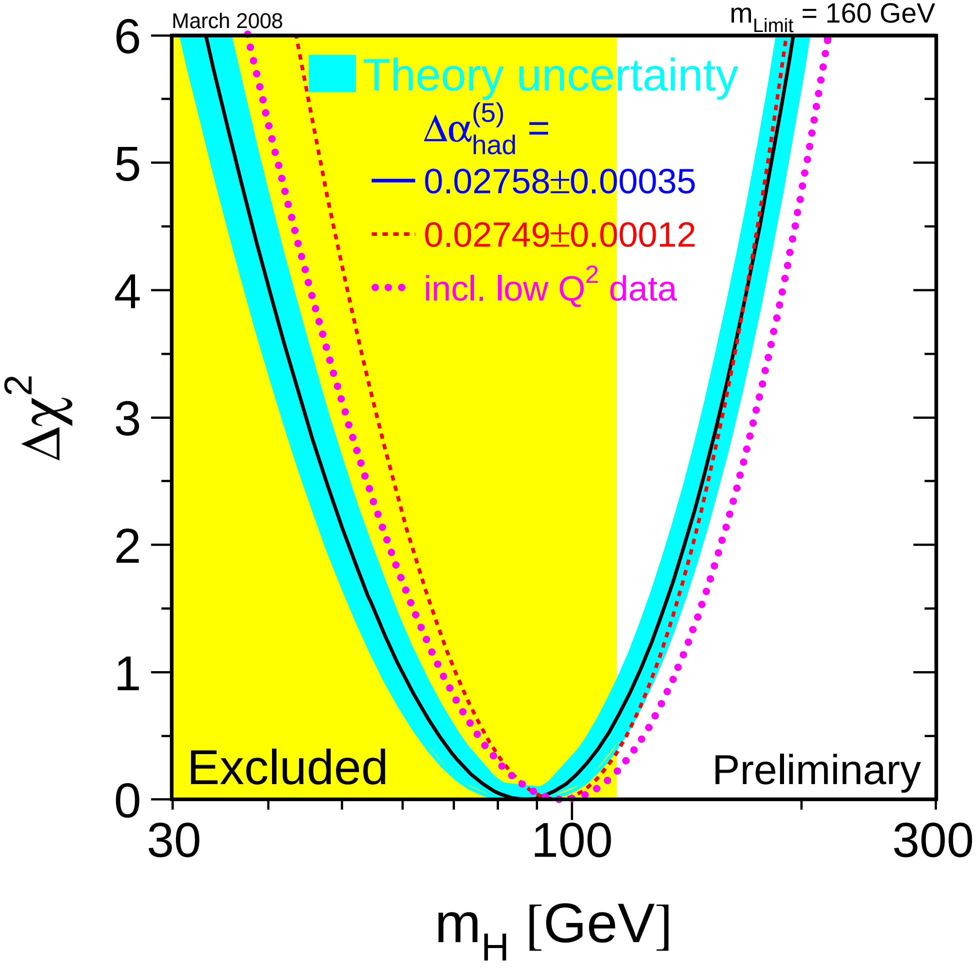
$\Downarrow$

Sensitivity to effects from unknown parameters: M_H, $M_{\tilde{t}}$, . . .

Window to "new physics"

Current information from EWPO: Constraints on $M_{\rm H}$ from global fit to all data in the SM

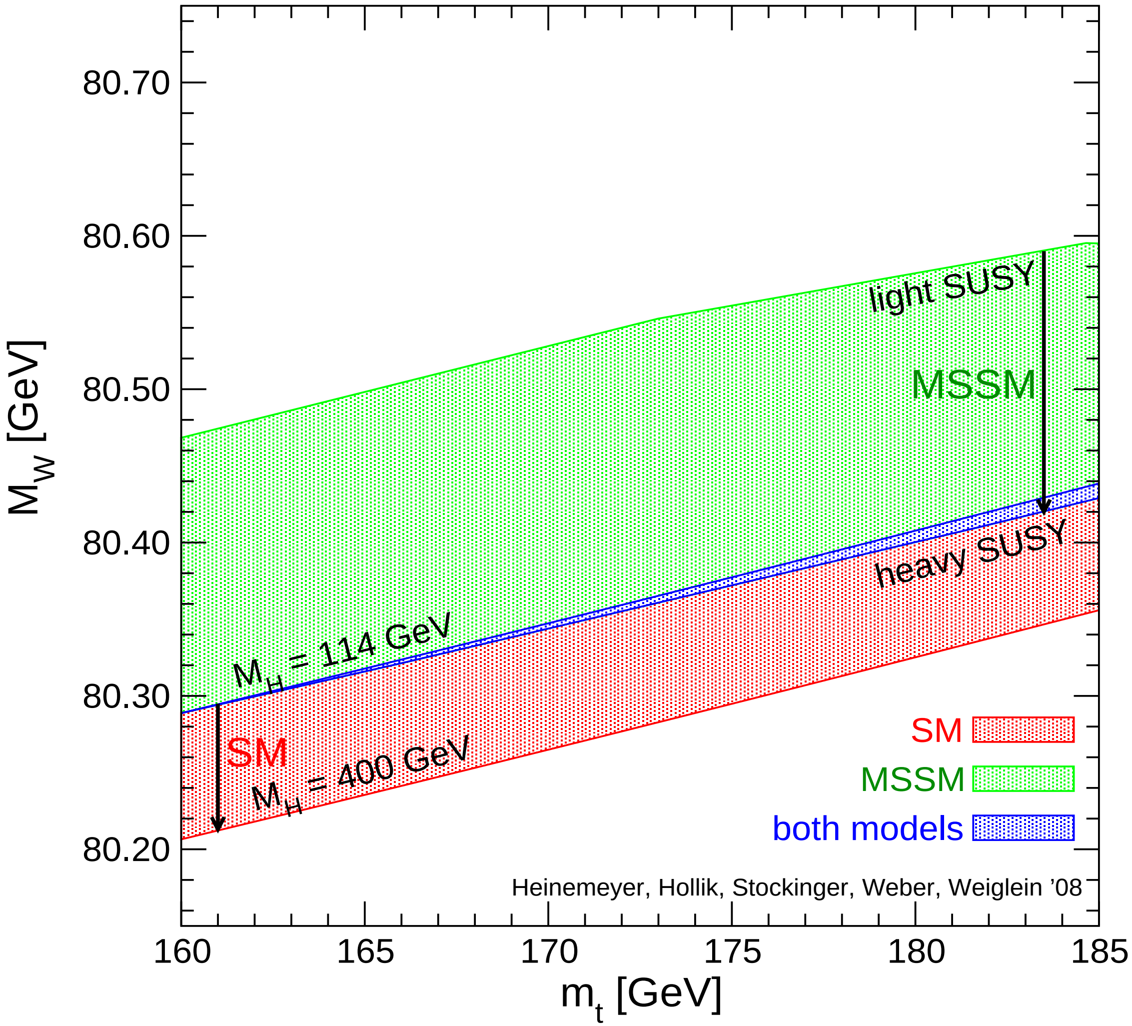
[*LEPEWWG '08*]



⇒ Preference for light Higgs, slight tension between indirect bound on $M_{\rm H}$ in the SM and direct search limit

Prediction for M_{W} (parameter scan): SM vs. MSSM

Prediction for M_{W} in the SM and the MSSM:



[*S. Heinemeyer, W. Hollik, A.M. Weber, G. W. '08*]

MSSM: SUSY parameters varied

SM: M_{H} varied

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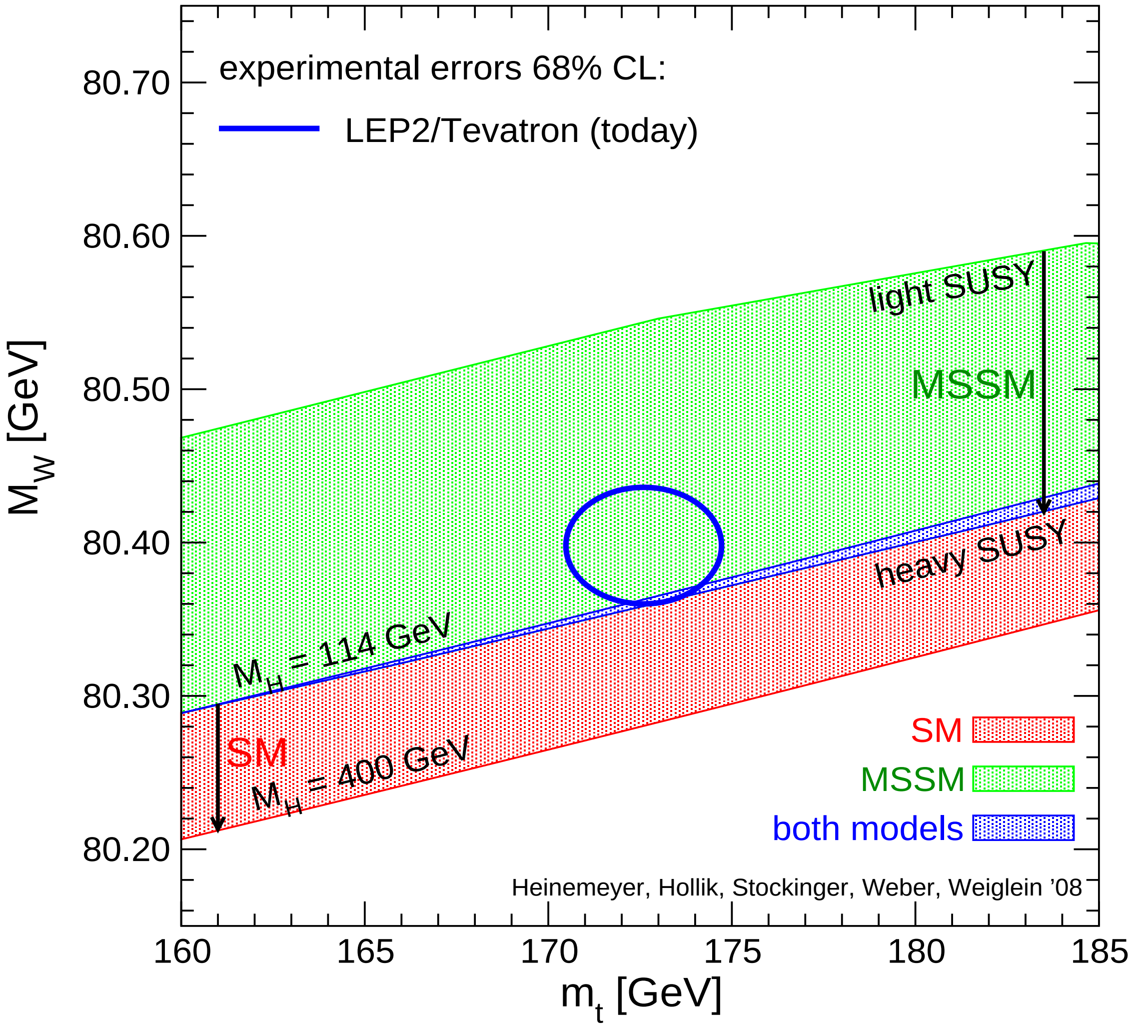


[*S. Heinemeyer, W. Hollik, A.M. Weber, G. W. '08*]

MSSM: SUSY parameters varied

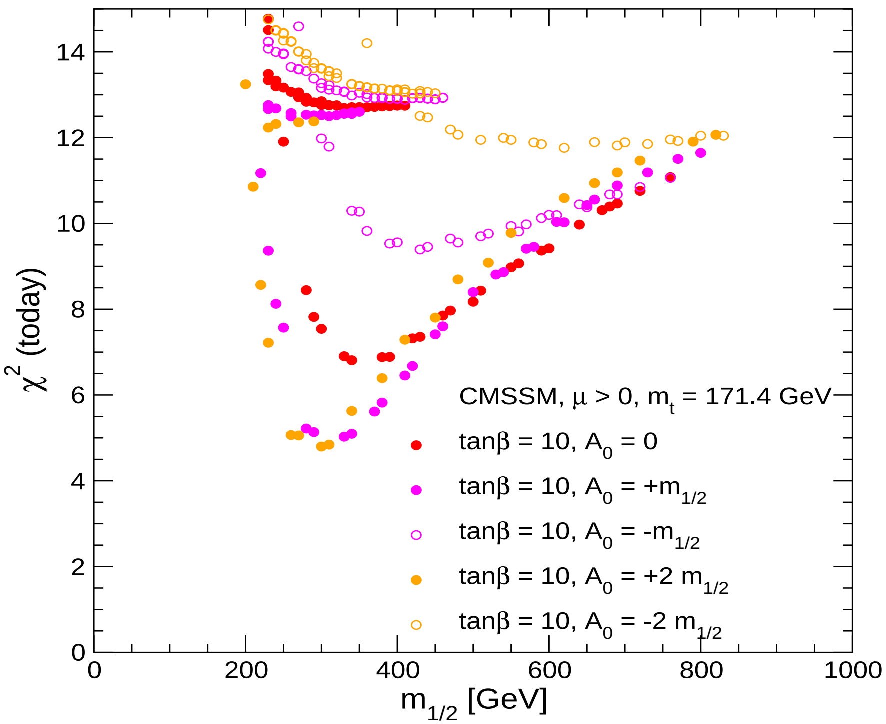
SM: M_H varied

$\Rightarrow$ Slight preference for MSSM over SM

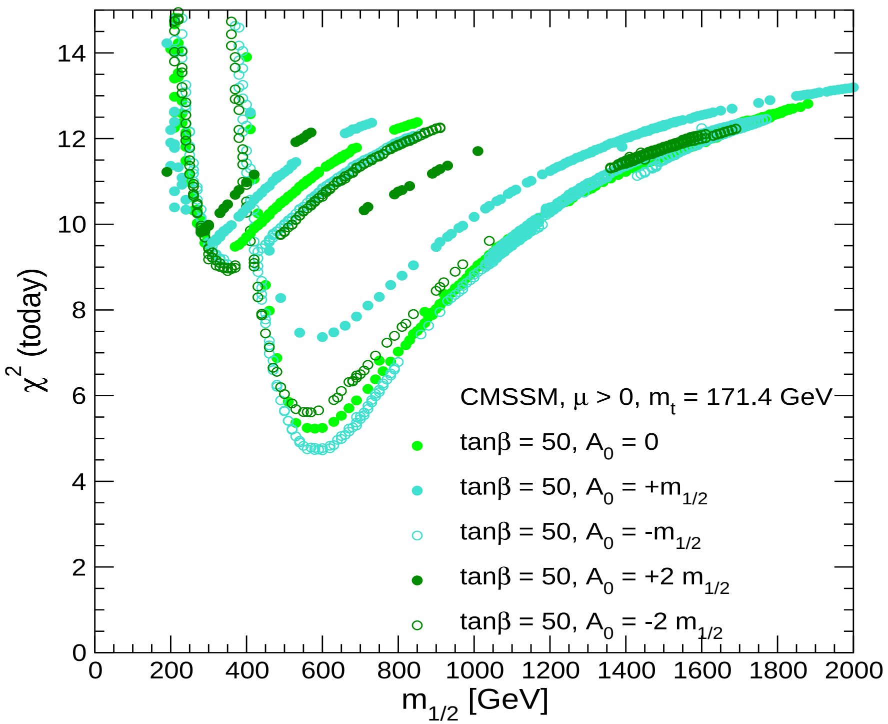
χ^2 *fit for the fermion mass scale,* $m_{1/2}$*, in the constrained MSSM (CMSSM) with dark matter constraints*

M_W, $\sin^2\theta_{\rm eff}$, Γ_Z, $(g-2)_\mu$, M_h, $\mathrm{BR}(b \to s\gamma)$, $\mathrm{BR}(B_s \to \mu^+\mu^-)$, $\mathrm{BR}(B_u \to \tau\nu_\tau)$, ΔM_{B_s}: [*J. Ellis, S. Heinemeyer, K. Olive, A. Weber, G. W. '07*]

$\tan\beta = 10$:



$\tan\beta = 50$:



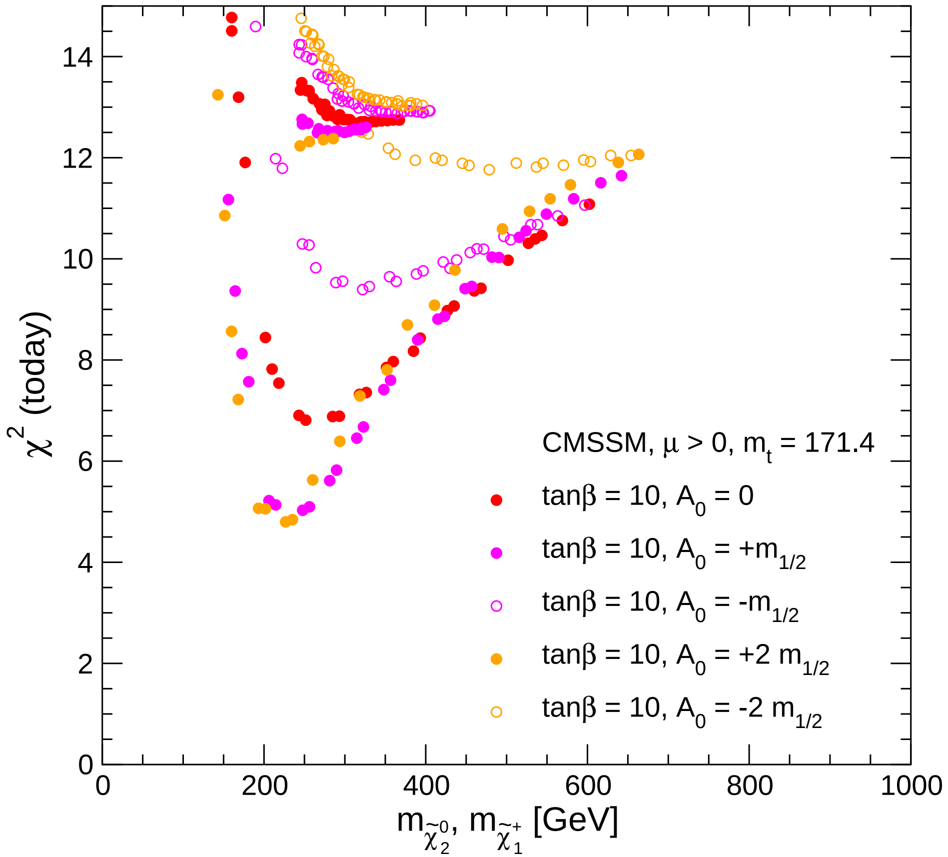
$\Rightarrow$ Very good description of the data

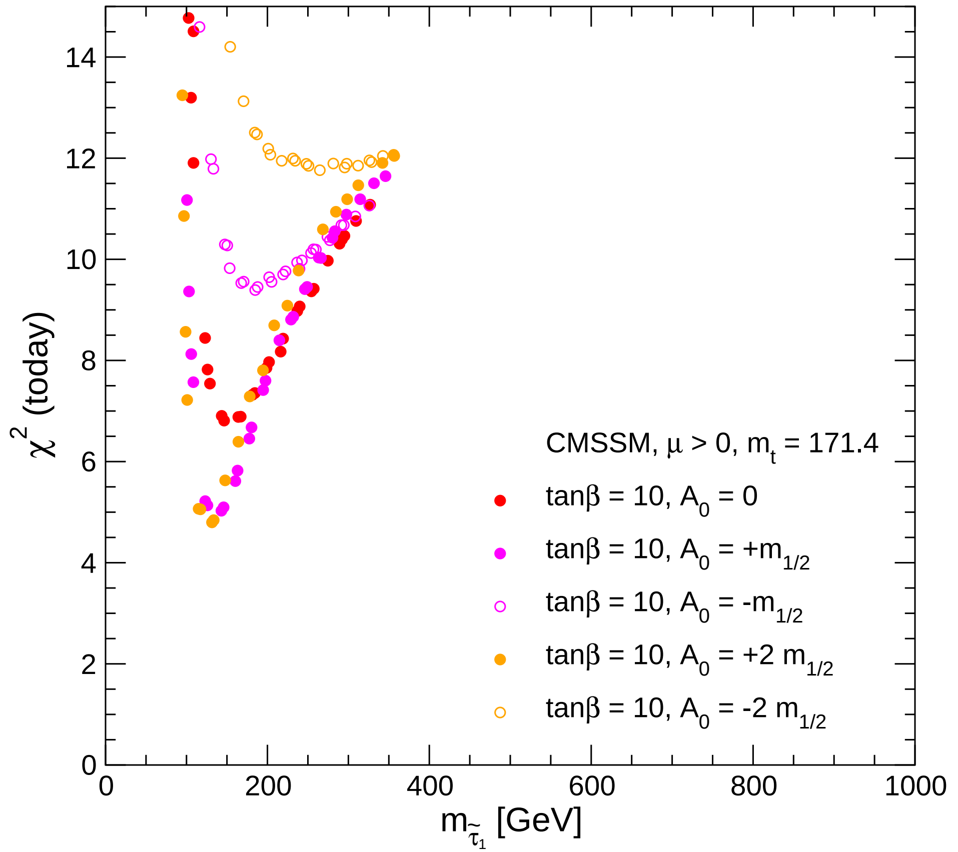
Preference for relatively light SUSY scale

Fit results for particle masses, $\tan\beta = 10$*:*

$m_{\tilde{\chi}_1^+} \approx m_{\tilde{\chi}_2^0}$, $m_{\tilde{\tau}_1}$

[*J. Ellis, S. Heinemeyer, K. Olive, A. Weber, G. W. '07*]

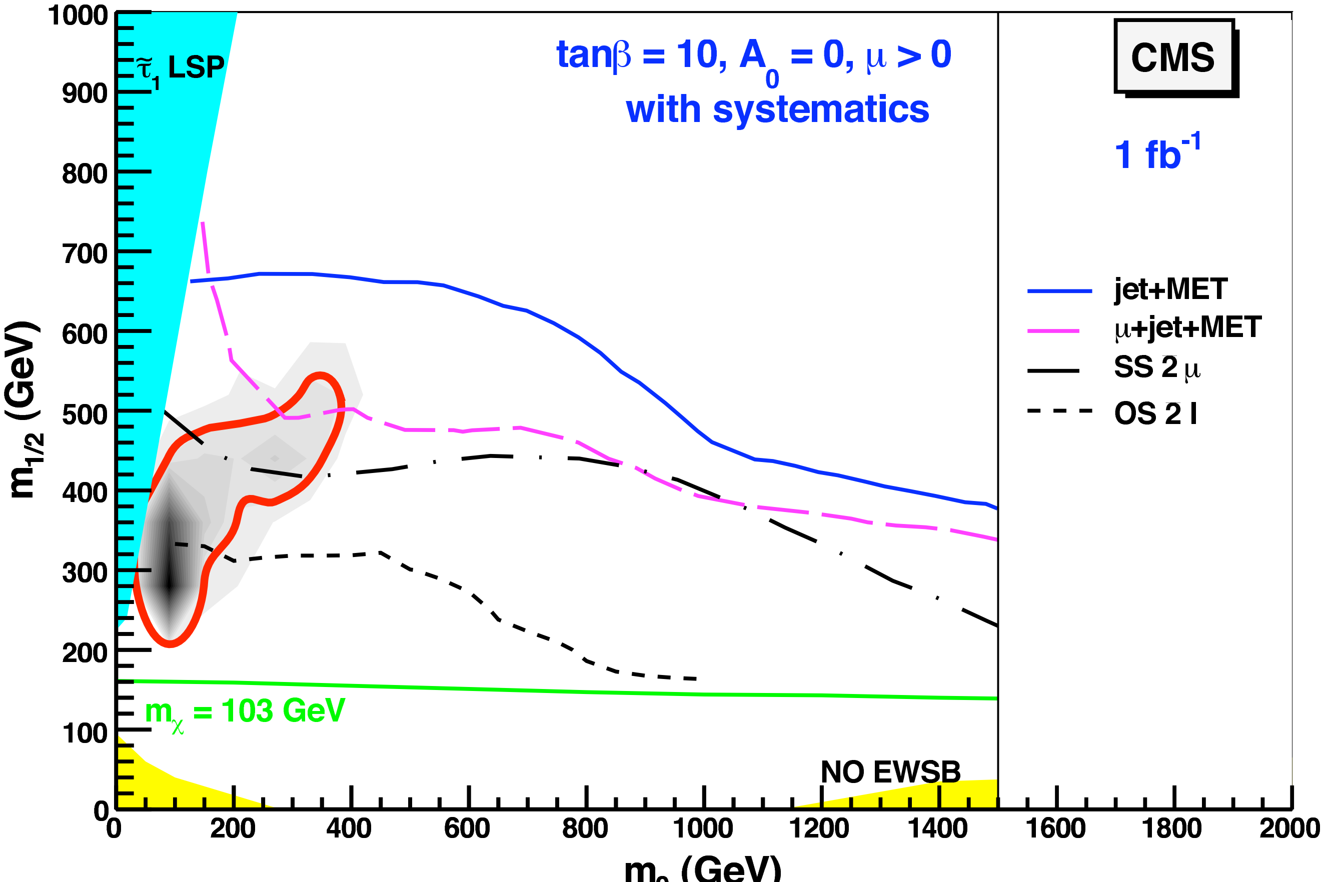




$\Rightarrow$ Good prospects for the LHC and ILC

Comparison: preferred region in m_0–$m_{1/2}$ plane, LHC discovery reach for $1\ \mathrm{fb}^{-1}$ of understood data

[*O. Buchmueller, R. Cavanaugh, A. De Roeck, S. Heinemeyer, G. Isidori, P. Paradisi, F. Ronga, A. Weber, G. W. '07*]

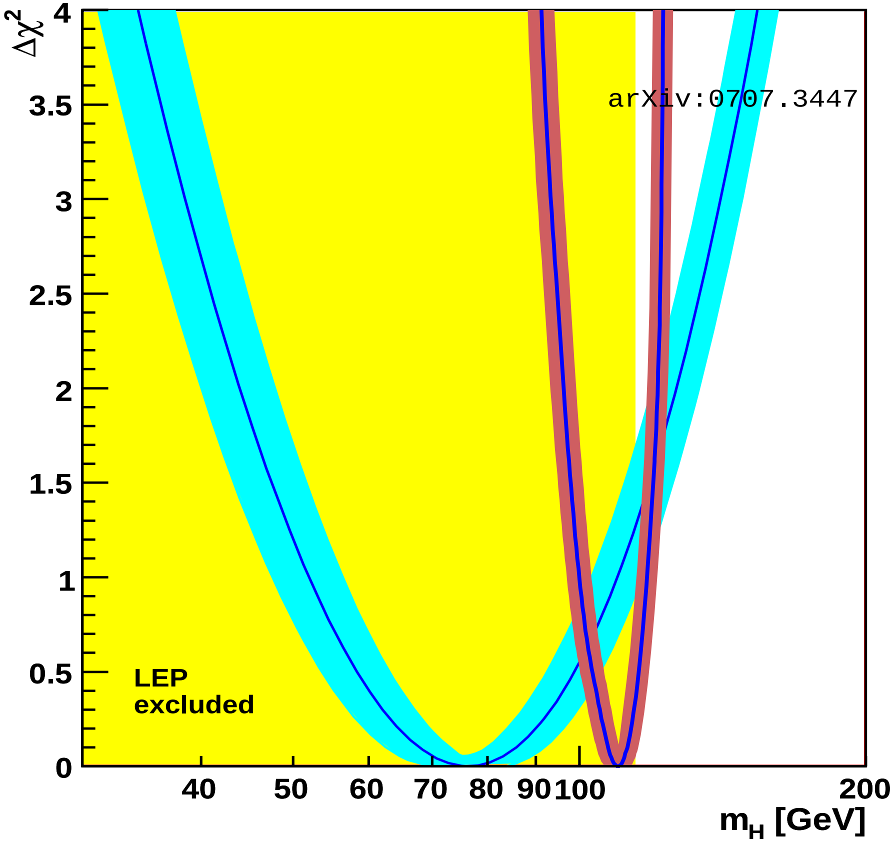


$\Rightarrow$ Preferred region would lead to early discovery

Indirect limits on the light Higgs mass in the CMSSM: EWPO + BPO + dark matter constraints

χ^2 fit for M_h, without imposing direct search limit [*O. Buchmueller, R. Cavanaugh, A. De Roeck, S. Heinemeyer, G. Isidori, P. Paradisi, F. Ronga, A. Weber, G. W. '07*]

SM CMSSM



$\Rightarrow$ Accurate indirect prediction; Higgs "just around the corner"?

What makes $\sin^2\theta_{\rm eff}$ special for the ILC?

In current analyses of EWPO: effective leptonic weak mixing angle at the Z resonance, $\sin^2\theta_{\rm eff}$, plays an important role

$$\sin^2\theta_{\rm eff} = \frac{1}{4}\left(1 - \mathrm{Re}\,\frac{g_V}{g_A}\right)$$

Current experimental value from LEP and SLD:

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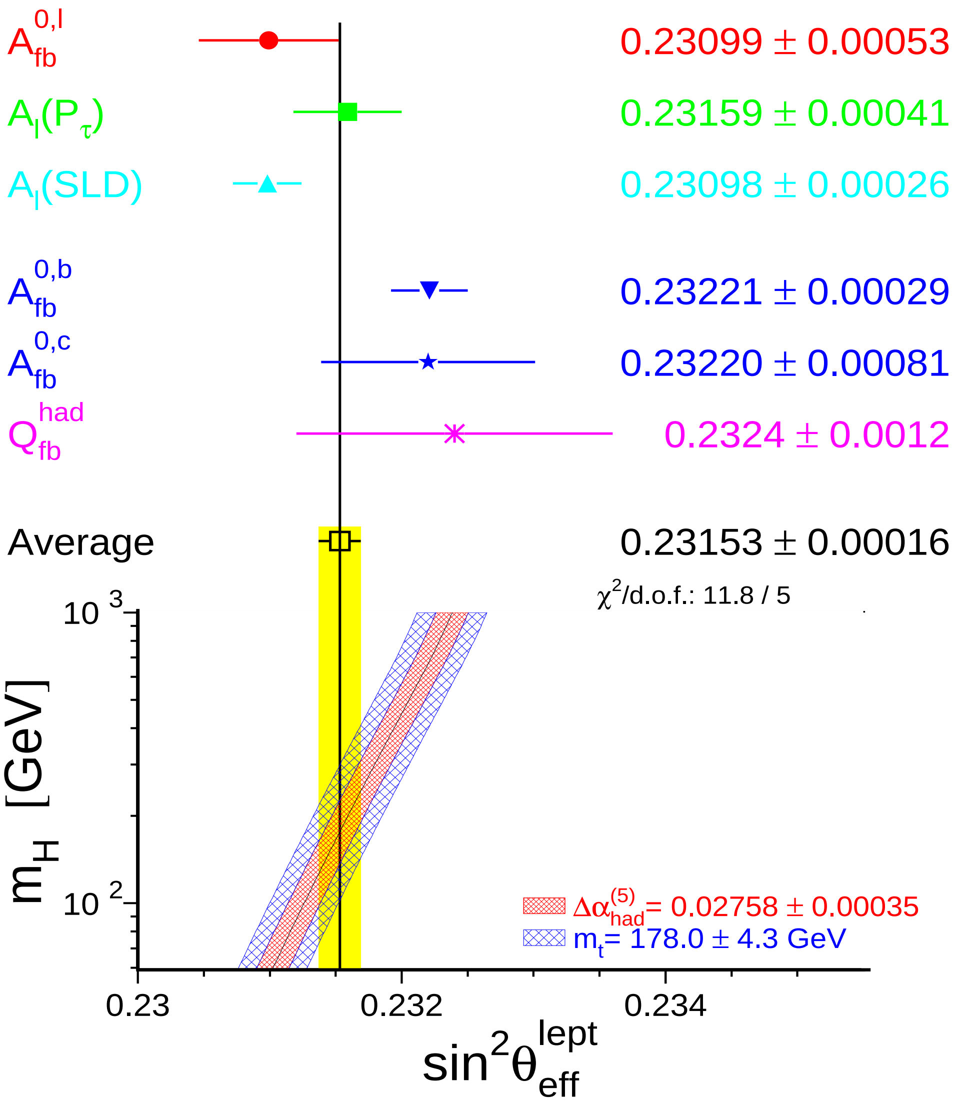
However: the small experimental error of the world-average is driven by two measurements that are not well compatible with each other

Effective weak mixing angle $\sin^2\theta_{\rm eff}$*: current situation*



[*LEPEWWG '05*]

$\sin^2\theta_{\rm eff}$ 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 indirect determination of $M_{\rm H}$

Effective weak mixing angle $\sin^2\theta_{\rm eff}$: future prospects

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$\Rightarrow$ Need the ILC to resolve the discrepancy

The ILC with polarised beams will have a unique opportunity for a high-precision measurement of $\sin^2\theta_{\mathrm{eff}}$

- ILC running at the Z resonance and the WW threshold: "GigaZ" ("MegaW") running; "option" to the ILC baseline

- 10^9 Z bosons can be produced within a few months of running (at $\mathcal{L} = 5 \times 10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$)

- $\sin^2\theta_{\mathrm{eff}}$ obtained from left–right polarisation asymmetry

$$A_{\mathrm{LR}} = \frac{1}{\mathcal{P}} \frac{\sigma_{\mathrm{L}} - \sigma_{\mathrm{R}}}{\sigma_{\mathrm{L}} + \sigma_{\mathrm{R}}} = 2\frac{g_V g_A}{g_V^2 + g_A^2}$$

- With polarisation of both beams: cross section for a certain beam polarisation is given by

$$\sigma = \sigma_u \left[1 - \mathcal{P}_{e^-}\mathcal{P}_{e^+} + A_{\mathrm{LR}}\left(\mathcal{P}_{e^+} - \mathcal{P}_{e^-}\right)\right]$$

High-precision measurement of $\sin^2\theta_{\rm eff}$ at the ILC with polarised beams

Flip (needs to be sufficiently quick) of e^- and e^+ polarisation

$\Rightarrow$ four measurements for four unknowns

$\Rightarrow$ can measure $A_{\rm LR}$ without the need for absolute polarimetry (still need polarimeters for polarisation differences, etc.)

$\Rightarrow$ can reach experimental error of $\Delta\sin^2\theta_{\rm eff} = 1.3 \times 10^{-5}$ (based on: 80%, 60% polarisations, $\Delta\mathcal{P}/\mathcal{P} = 0.5\%$)

$\Rightarrow$ improvement by more than factor 10 over present situation

Note:

Positron polarisation is crucial for achieving this accuracy; experimental error increases by about a factor of five if only the electron beam is polarised

Electroweak precision observables (EWPO): present status vs. LHC vs. ILC precision

obs.	exp. cent. value	σ^{today}	σ^{LHC}	σ^{ILC}
M_W [GeV]	80.398	0.025	0.015	0.007
$\sin^2\theta_\text{eff}$	0.23153	0.00016	20–14 $\times 10^{-5}$	1.3×10^{-5}
Γ_Z [GeV]	2.4952	0.0023	—	0.001
R_l	20.767	0.025	—	0.01
R_b	0.21629	0.00066	—	0.00014
σ^0_had	41.540	0.037	—	0.025

$\Rightarrow$ The crucial measurement at the ILC is the high-precision determination of $\sin^2\theta_\text{eff}$

moderate improvement in other Z-pole observables, M_W

(note: latest LHC number is $\Delta M_\text{W} = 7$ MeV [*N. Besson, DIS08*])

Physics gain from a high-precision measurement of $\sin^2\theta_{\rm eff}$

For comparison with theory predictions: need to have theoretical uncertainties under control

Sources of theoretical uncertainties:

- Unknown higher-order corrections
- Parametric uncertainty induced by the experimental errors of the input parameters: $m_{\rm t}$, $\Delta\alpha_{\rm had}$, ...

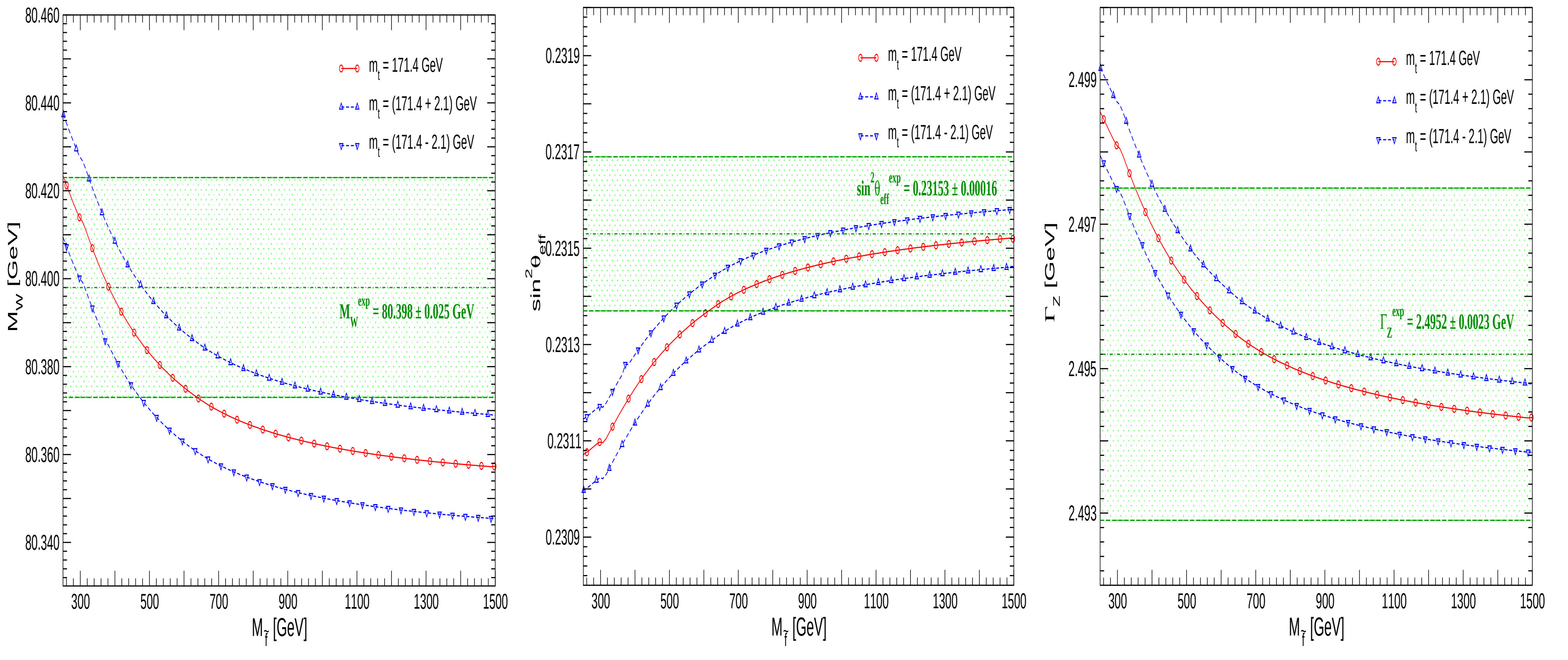
  $\Rightarrow$ ILC will yield improvement in $m_{\rm t}$ by an order of magnitude

  exp. error on $m_{\rm t}$: $\approx 1\ \mathrm{GeV} \xrightarrow{\text{ILC}} 0.1\ \mathrm{GeV}$

M_W, $\sin^2\theta_\mathrm{eff}$, Γ_Z: *MSSM predictions vs. current experimental errors*

Dependence on the sfermion mass scale

[*S. Heinemeyer, W. Hollik, A.M. Weber, G. W. '07*]



$\Rightarrow$ Sizable dependence on the sfermion mass scale

Drastic improvement with ILC precision on $\sin^2\theta_\mathrm{eff}$, m_t

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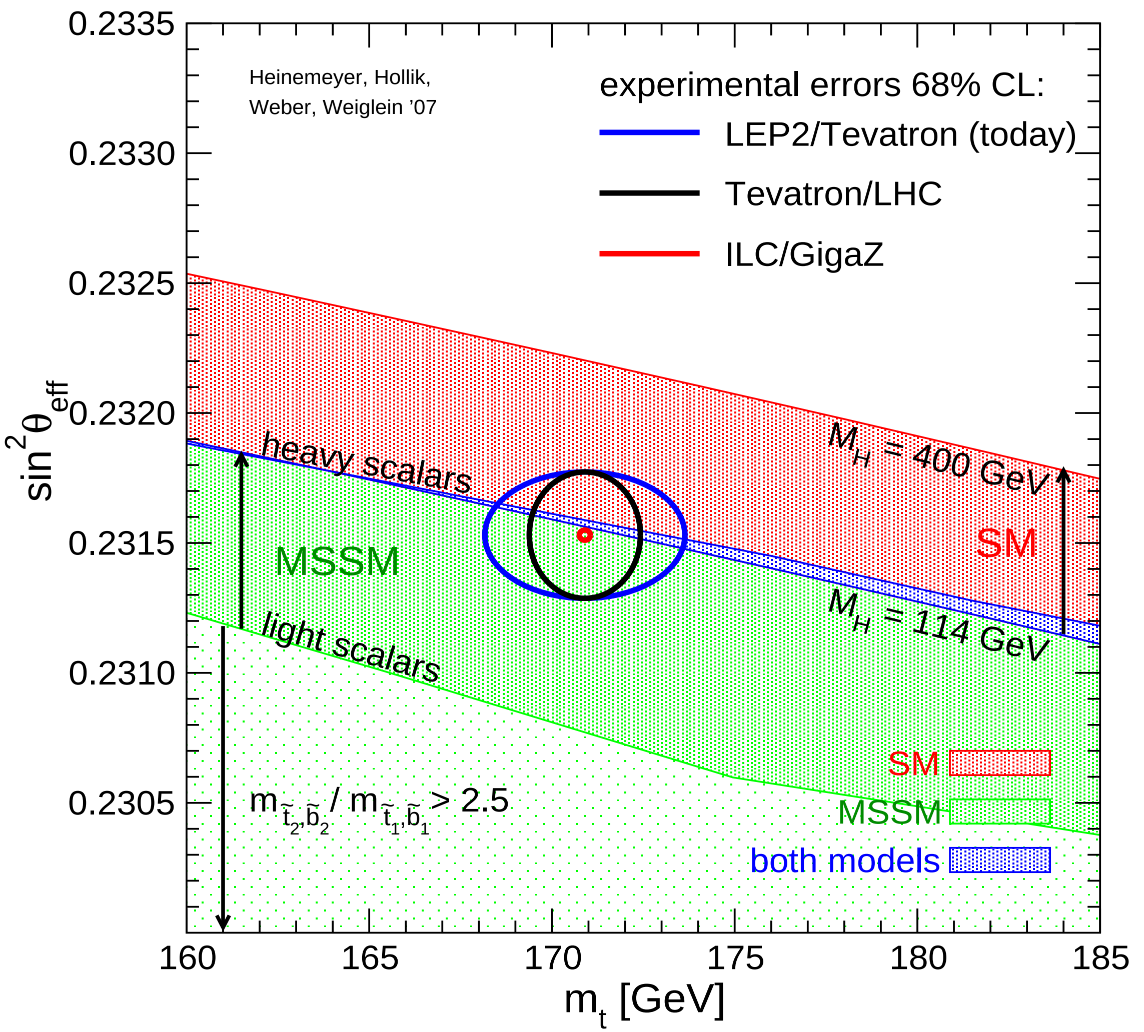
Prediction for $\sin^2\theta_{\rm eff}$ in the SM and the MSSM:



[S. Heinemeyer, W. Hollik, A.M. Weber, G. W. '07]

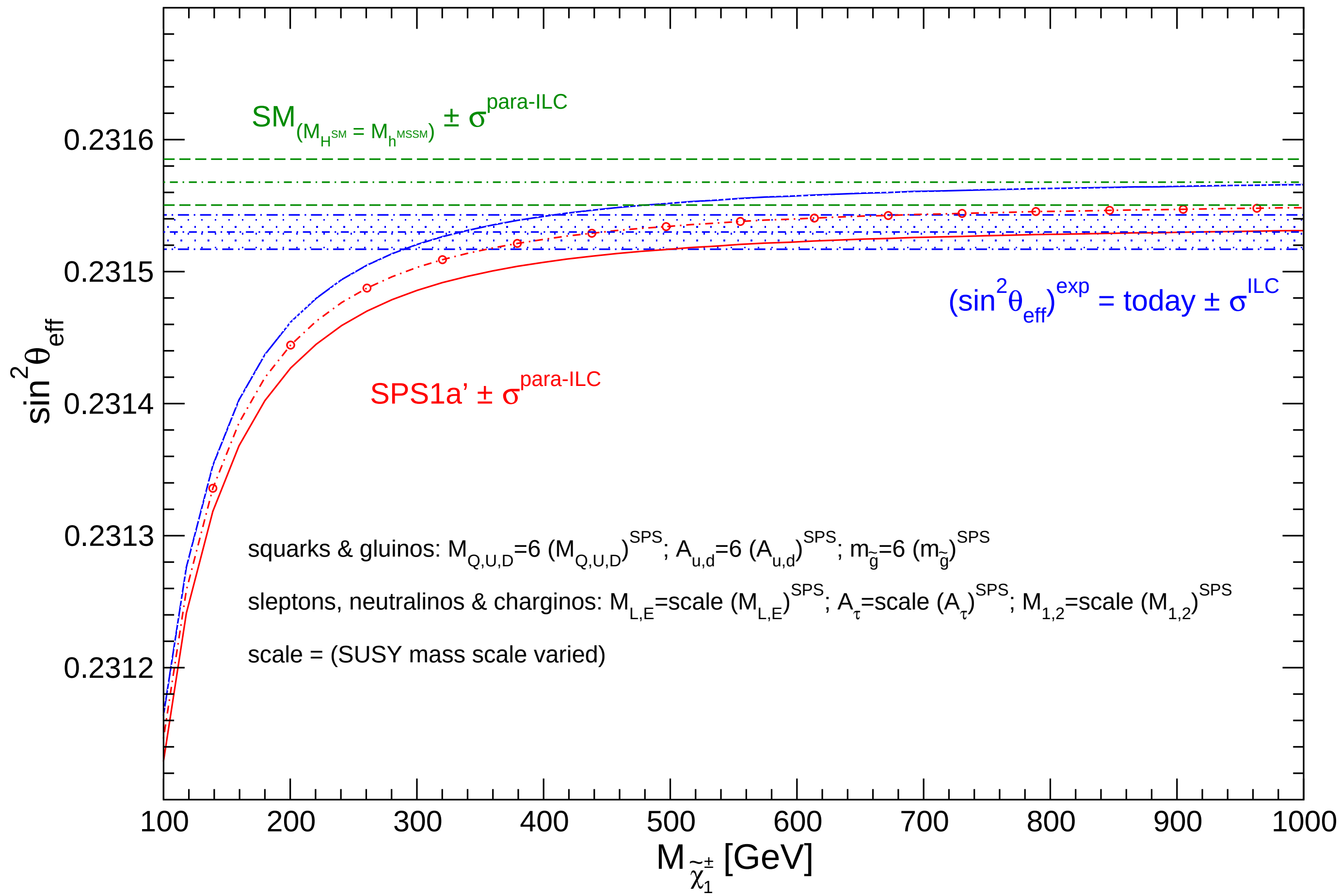
MSSM: SUSY parameters varied

SM: $M_{\rm H}$ varied

$\Rightarrow$ ILC precision on $\sin^2\theta_{\rm eff}$ and $m_{\rm t}$ yields drastic improvement

GigaZ: sensitivity to the scale of SUSY in a scenario where no SUSY particles are observed at the LHC

[*S. Heinemeyer, W. Hollik, A.M. Weber, G. W. '07*]



⇒ GigaZ measurement provides sensitivity to SUSY scale, extends the direct search reach of ILC(500)

Conclusions

- High-precision determination of $\sin^2\theta_{\mathrm{eff}}$: crucial measurement that only the ILC can do, improvement by more than an order of magnitude over present situation and LHC capabilities
  Positron polarisation will be crucial in order to achieve this

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It is evident that reducing the costs for the ILC is crucial
However, the most important criterion for actually getting the ILC will be a compelling physics case