MSSM PRECISION PHYSICS AT THE Z RESONANCE

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[based on a collaboration with: S.Heinemeyer, W.Hollik, G.Weiglein]

SUSY '07

Outline

1. What, why, how?
2. Status
3. Results
4. Conclusions

What, why, how?

Electroweak precision calculations, why bother?

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	central value	absolute error	relative error
$\sin^2\theta_{\text{eff}}$	0.23153	± 0.00016 ILC: ± 0.000013	$\pm 0.07\%$
Γ_Z[GeV]	2.4952[GeV]	± 0.0023 ILC: ± 0.001	$\pm 0.09\%$
M_W[GeV]	80.398	± 0.025 TEV/LHC: $\pm 0.020/0.015$ ILC:± 0.007	$\pm 0.03\%$

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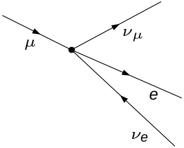
- Theory predictions sensitive to new physics via quantum corrections.

  $\Rightarrow$ New physics can already be observed.

W boson mass from μ-decay

Born level



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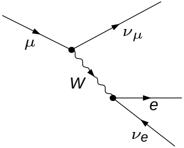

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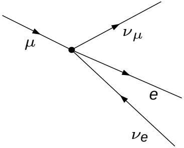

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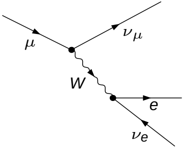

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- Summarise electroweak radiative corrections by Δr.
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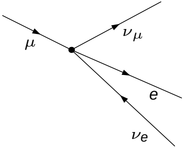

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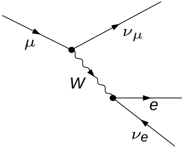

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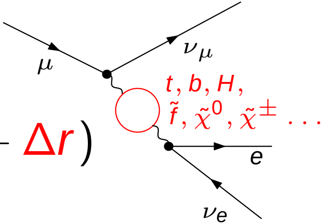

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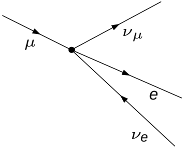

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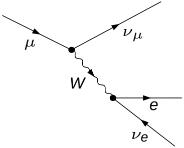

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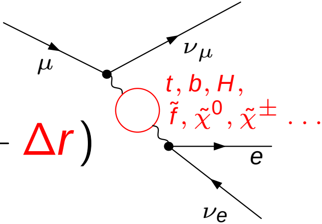

$$\Delta r = \Delta r\,(M_W, M_Z, m_t, \alpha, \alpha_s, M_h, M_A, m_{\tilde{f}}, m_{\tilde{\chi}^{0,\pm}} \ldots)$$

Z pole observables

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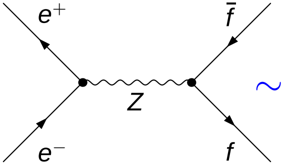

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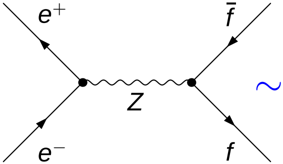

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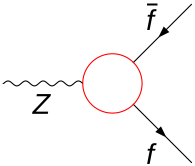

$$\Longrightarrow \mathcal{M}_{\text{eff}} = \bar{u}_f \gamma_\alpha [\mathcal{G}_V^{\text{eff}} - \gamma_5 \mathcal{G}_A^{\text{eff}}] v_f \epsilon_Z^\alpha$$

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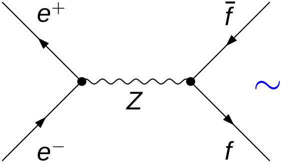

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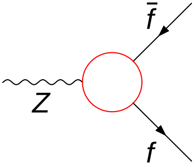

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- Total Z width Γ_Z, pole asymmetries $\mathcal{A}^0_{FB,LR}$, peak cross sections $\sigma^0_{had,l}$, ratios of partial widths $R_b, R_l \ldots$ determined by $\sin^2\theta^f_{\text{eff}}$ and Γ_f.

Status

Status of M_W & $\sin^2\theta_{\text{eff}}$ calculation

Standard Model:

- Full electroweak calculation up to two-loop order, full $\mathcal{O}(\alpha\alpha_s)$, $\mathcal{O}(\alpha\alpha_s^2)$ result.
- Leading universal terms in the relevant parameters at $\mathcal{O}(\alpha_s G_F^2 m_t^4)$,$\mathcal{O}(G_F^3 m_t^6)$, $\mathcal{O}(\alpha\alpha_s^3)$.

[Freitas, Hollik, Walter, Weiglein], [Awramik, Czakon], [Onishchenko, Veretin],

[Awramik, Czakon, Freitas, Weiglein],[Hollik, Meier, Uccirati],[Chetyrkin, Kühn, Steinhauser],

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MSSM in previous analyses:

- One-loop with assumptions (real parameters,. . .).
  [Dabelstein, Hollik, Mösle]
- Leading SM and universal SUSY $O(\alpha\alpha_s)$ terms.
  [Dabelstein, Hollik] & [Heinemeyer, Weiglein]

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[Heinemeyer, Hollik, Stöckinger, Weiglein, AMW] – JHEP08(2006)052 & forthcoming pub.

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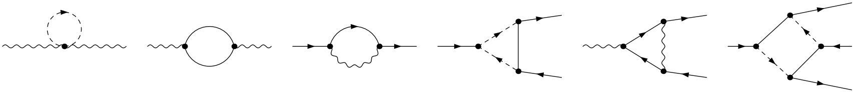

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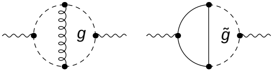

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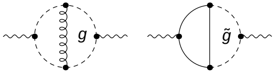

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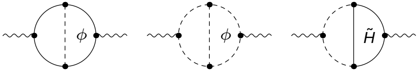

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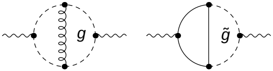

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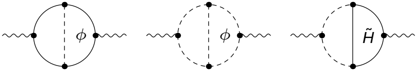

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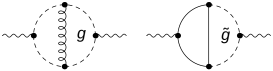

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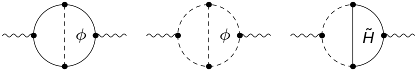

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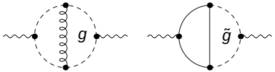

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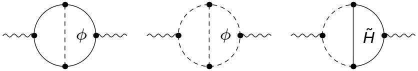

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$\Rightarrow$ Most precise & most general MSSM prediction for W boson mass and Z observables!

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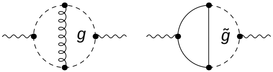
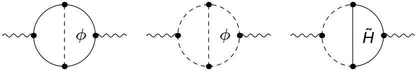
  - Leading universal $\mathcal{O}(\alpha\alpha_s)$ terms.
    [Djouadi, Gambino, Heinemeyer, Hollik, Jünger, Weiglein]



  - Yukawa enhanced universal $\mathcal{O}(\alpha_t^2, \alpha_t\alpha_b, \alpha_b^2)$ terms.
    [Haestier, Heinemeyer, Stöckinger, Weiglein]



  - Resummation of reducible one-loop contributions.
    [Consoli, Hollik, Jegerlehner]
  - Inclusion of full SM result.

$\Rightarrow$ Most precise & most general MSSM prediction for W boson mass and Z observables!

$\delta M_W^{\text{th}} \approx 4 \ldots 10$ MeV $\qquad \delta \sin^2\theta_{\text{eff}}^{\text{th}} \approx (4.9 \ldots 7.1) \times 10^{-5}$

Results

- $\mathcal{CP}$-phases, in particular ϕ_μ, strongly constrained by EDMs.
- However, $\phi_{A_{t,b}}$ almost unconstrained. *[Barger,Falk,Han,Jiang,Plehn]*

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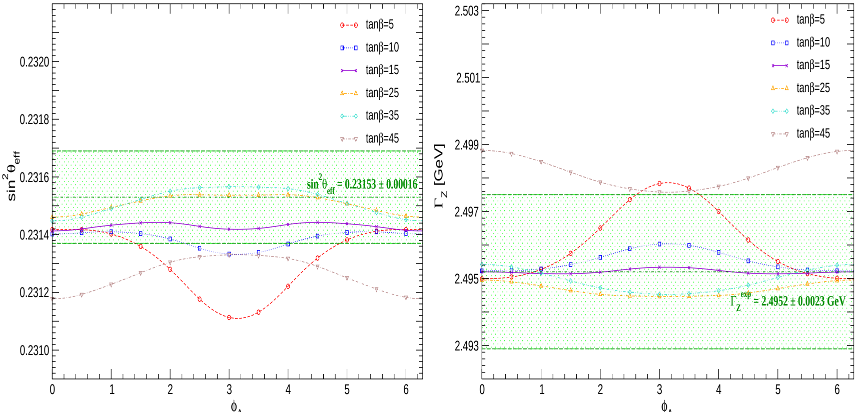
Effect of ϕ_{A_t} on $\sin^2\theta_{\rm eff}$ and Γ_Z



$M_{\tilde f} = M_{H\pm} = M_2 = m_{\tilde g} = 500$ GeV, $A_{\tau,t,b} = \mu = 1000$ GeV, $\phi_{A_b,\mu,M_1} = 0$

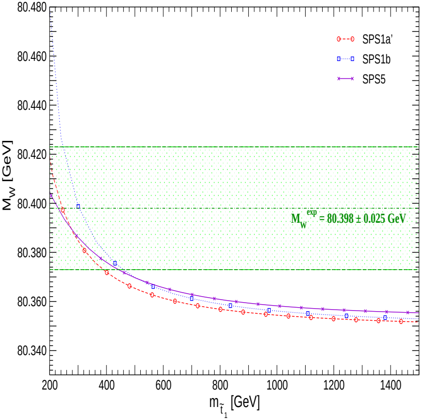
$\Rightarrow$ Large shifts can be induced by complex parameters.

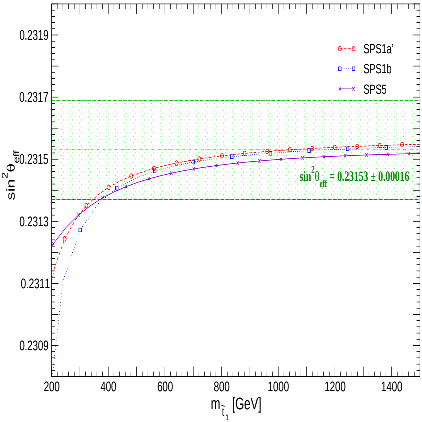
SPS benchmark scenarios

- Benchmark points within “typical” constrained MSSM scenarios.
- SPS scenarios fix low-energy MSSM parameters.
- *here:*

$$M_{A^0} = \text{scalefactor} \cdot M_{A^0}^{\text{SPS}},\ M_{\tilde{F},\tilde{F}'} = \text{scalefactor} \cdot M_{\tilde{F},\tilde{F}'}^{\text{SPS}},$$
$$A_{t,b} = \text{scalefactor} \cdot A_{t,b}^{\text{SPS}},\ \mu = \text{scalefactor} \cdot \mu^{\text{SPS}},$$
$$M_{1,2,3} = \text{scalefactor} \cdot M_{1,2,3}^{\text{SPS}}.$$

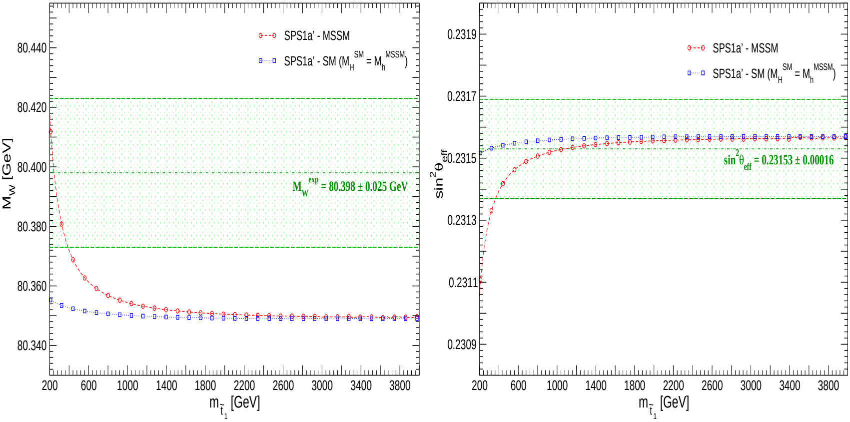
M_W and $\sin^2\theta_{\text{eff}}$ for varied SUSY-scale





⇒ Slight preference for light SUSY from M_W.
⇒ No clear preference for light SUSY from $\sin^2\theta_{\text{eff}}$.

M_W and $\sin^2\theta_{\text{eff}}$ for varied SUSY-scale



⇒ MSSM slightly favoured over Standard Model from M_W.

⇒ No preference for MSSM from $\sin^2\theta_{\text{eff}}$.

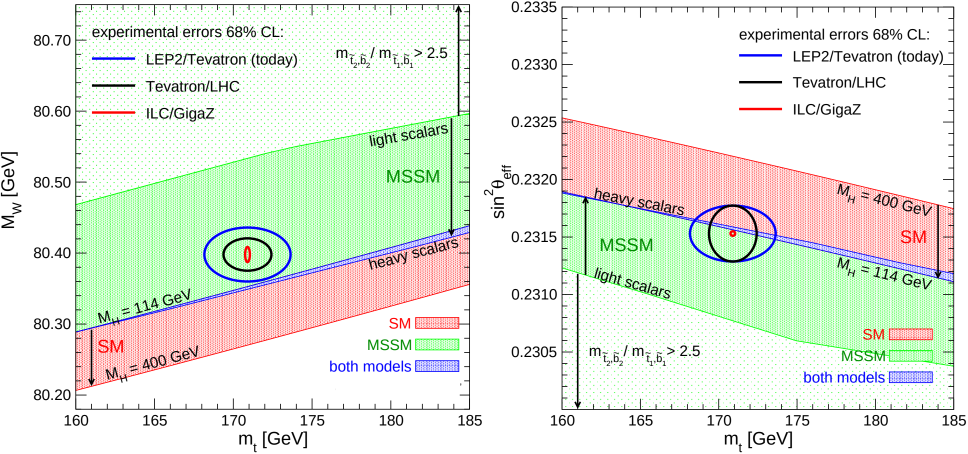
Scatter plots for M_W *&* $\sin^2\theta_{\text{eff}}$

- SUSY parameters:

$$\begin{aligned}
\text{sleptons} &: \quad M_{\tilde{F},\tilde{F}'} = 100\ldots2000 \text{ GeV}\\
\text{light squarks} &: \quad M_{\tilde{F},\tilde{F}'_{\text{up/down}}} = 100\ldots2000 \text{ GeV}\\
\tilde{t}/\tilde{b}\ \text{doublet} &: \quad M_{\tilde{F},\tilde{F}'_{\text{up/down}}} = 100\ldots2000 \text{ GeV}\\
& \quad\ A_{t,b} = -2000\ldots2000 \text{ GeV}\\
\text{gauginos} &: \quad M_{1,2} = 100\ldots2000 \text{ GeV}\\
& \quad\ m_{\tilde{g}} = 195\ldots1500 \text{ GeV}\\
& \quad\ \mu = -2000\ldots2000 \text{ GeV}\\
\text{Higgs} &: \quad M_A = 90 - 1000 \text{ GeV}\\
& \quad\ \tan\beta = 1.1\ldots60
\end{aligned}$$

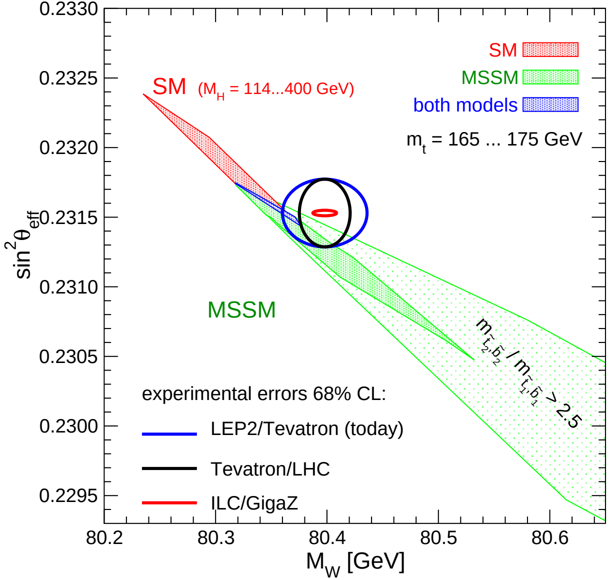
- Unconstrained scan, only Higgs mass required to be in agreement with LEP data.

$M_W(m_t)$ and $\sin^2\theta_{\text{eff}}(m_t)$ in the MSSM



⇒ Preference of MSSM over SM from M_W.

⇒ MSSM and SM equally good for $\sin^2\theta_{\text{eff}}$.



⇒ Combination of M_W and $\sin^2\theta_{\rm eff}$ slightliy favours MSSM.

Conclusions

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  - Match experimental accuracy.
  - Test Standard Model and its extensions.

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    [Ellis, Heinemeyer, Olive, AMW, Weiglein]

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- Global mSUGRA fits:
  - Preference for light SUSY for “natural" priors.
    [Allanach, Cranmer, Lester, AMW]

$\Rightarrow$ *B.C. Allanach, SUSY 07*

Outlook & current projects

- Extend computation and analysis to non-minimal models.
- Preparation of public computer code "`SUSY-POPE`".
- LHC precision analysis projects:
  - "KISMET"
    [Allanach, Cranmer, Lester, AMW], see B.C. Allanach SUSY '07
  - "Mastercode"
    [Buchmüller, Cavanaugh, Heinemeyer, Isidori, Paradisi, Ronga, AMW, Weiglein], see O. Buchmüller/F. Ronga SUSY '07