A TALE OF SCALES

FERMION MASSES AND MIXING IN MINIMAL SUPERSYMMETRIC SO(10)
AND
RESUMMATION OF GLUINO CONTRIBUTIONS TO THE MSSM HIGGS POTENTIAL

MÜNDLICHE DOKTORPRÜFUNG VON
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26. APRIL 2019

PHYSIK JENSEITS DES STANDARDMODELLS

DAS STANDARDMODELL

$$SU(3)_C \times SU(2)_L \times U(1)_Y$$

+ Higgsmechanismus

✔ Wechselwirkungen der bekannten Elementarteilchen

✘ Neutrinomassen?

✘ dunkle Materie?

SUPERSYMMETRIE (MSSM)

Symmetrie:
Fermionen ↔ Bosonen

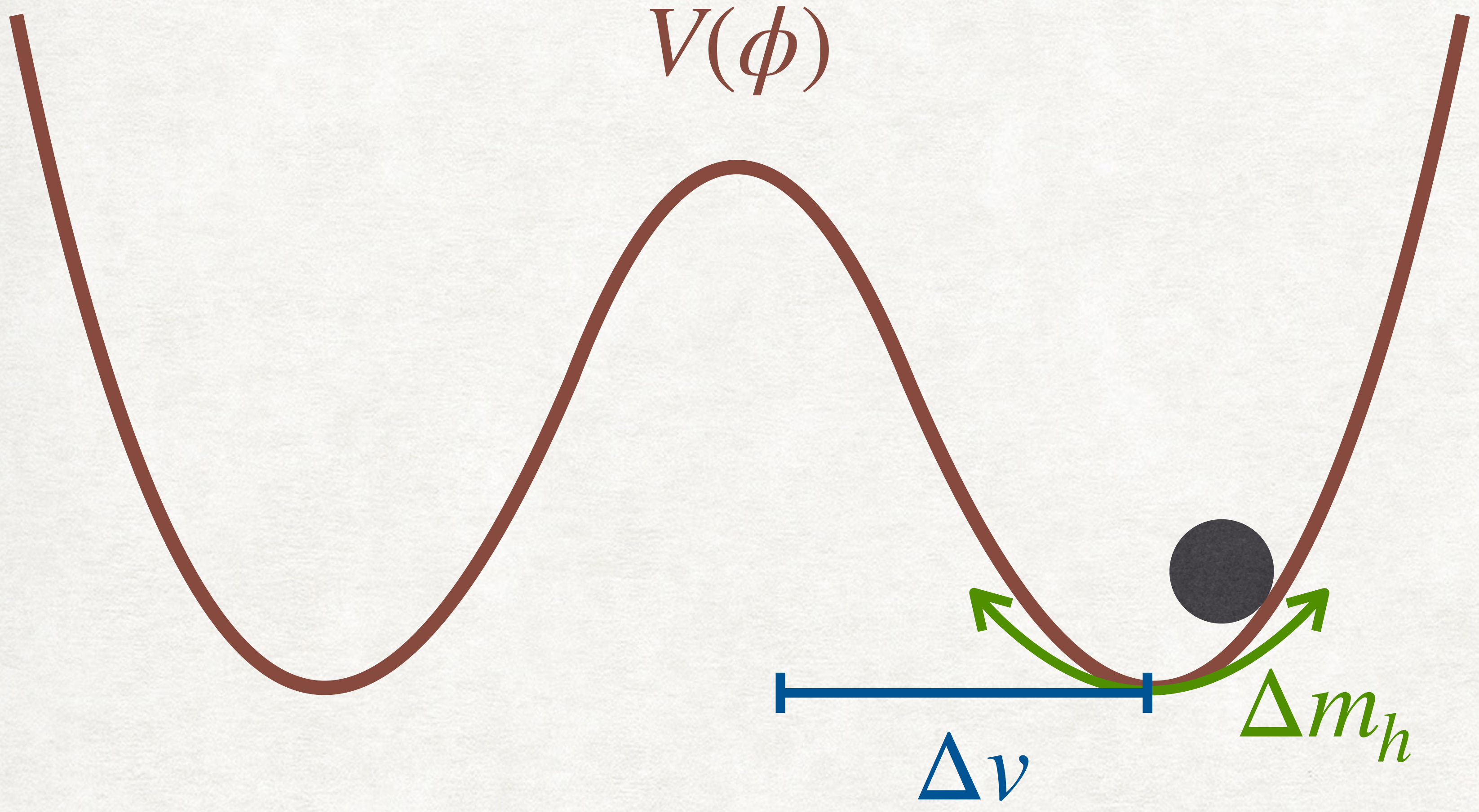
$$t_L \leftrightarrow \tilde{t}_L \qquad t_R \leftrightarrow \tilde{t}_R \qquad G^a_\mu \leftrightarrow \tilde{g}^a$$

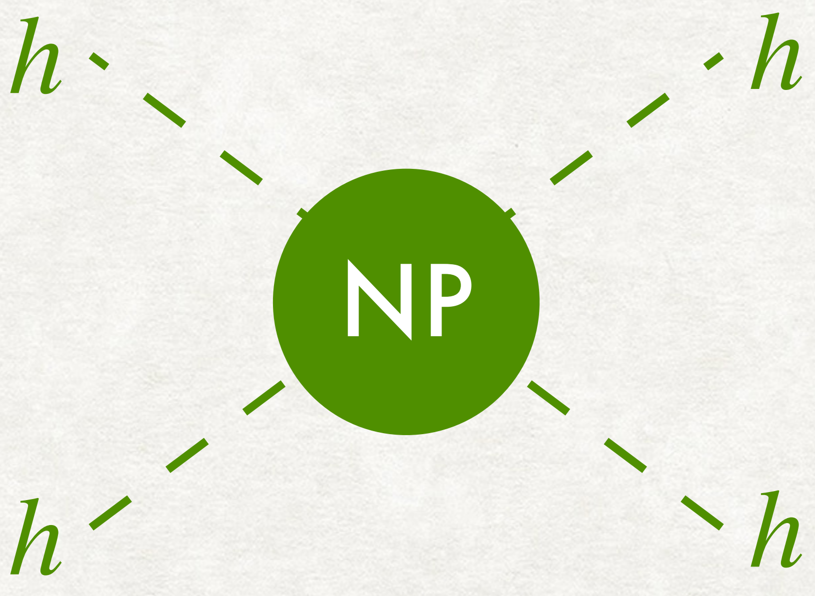
- Eichkopplungsvereinheitlichung (Thema 2)
- zwei Higgs-Dubletts ($\tan\beta = v_2/v_1$)
- R-Parität
- Hierarchieproblem (Thema 1)

Glashow, Weinberg, Salam, 1961-67
Higgs, 1964
Fritzsch, Gell-Mann, 1974

Wess, Zumino, 1974
Fayet, 1976
Nilles, 1984

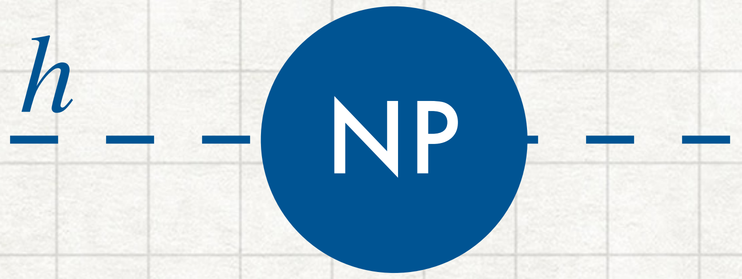
DAS HIERARCHIEPROBLEM





$\propto \log M_{NP}^2$

- Korrekturen zum Vakuumerwartungwert (VEV)



$\propto M_{NP}^2$ ~~SUSY~~ $\propto M_{SUSY}^2$

- fine-tuning der elektroschwachen Skala

$$v^2 \propto M_Z^2 = M_Z^{2,\text{tree}} + M_{SUSY}^2 + \delta M_Z^2$$

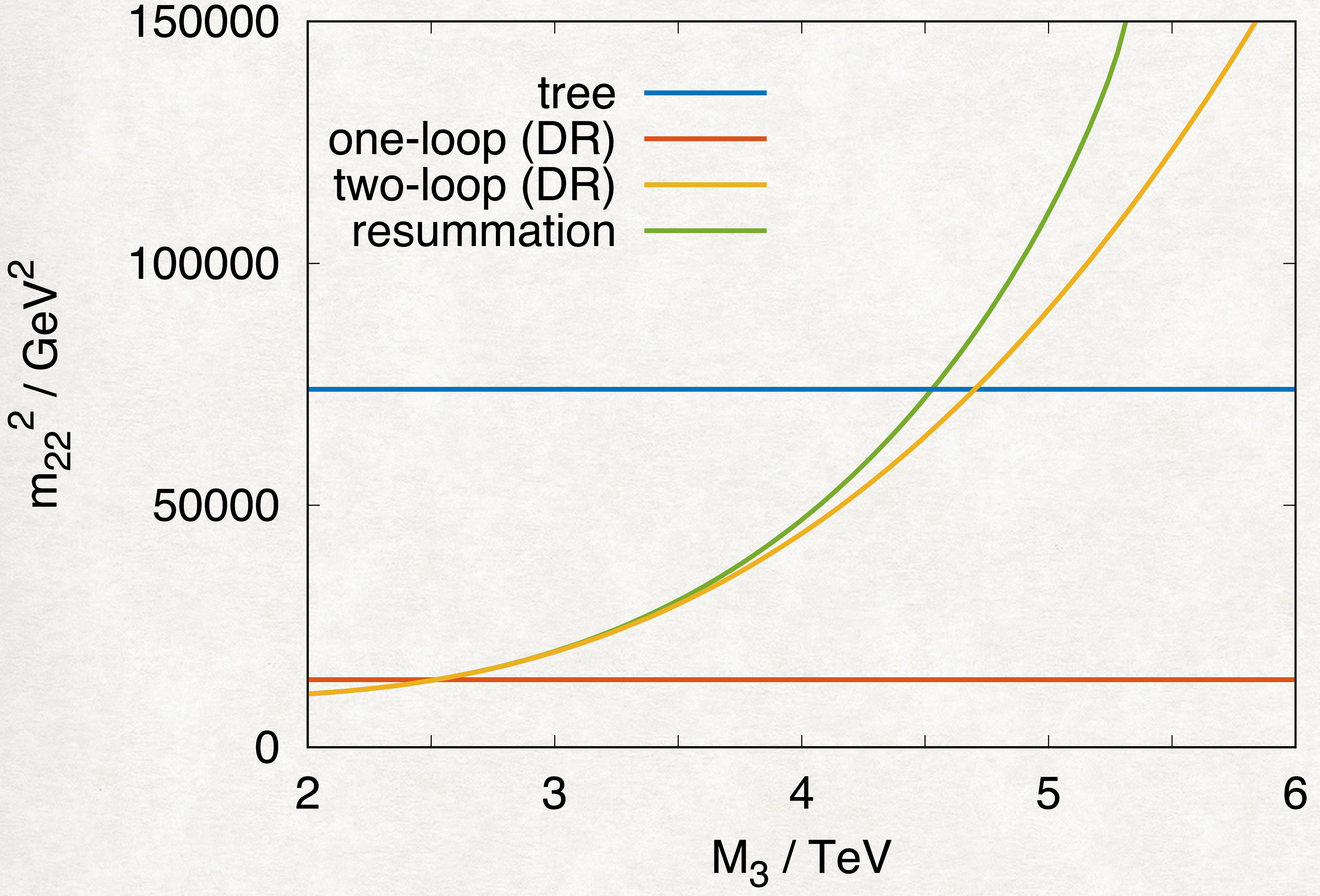
$$(100\,\text{GeV})^2 \overset{!}{=} (1\,\text{TeV})^2 - (1\,\text{TeV})^2$$

$$\Delta = \left| \frac{m_{\tilde{t}}}{M_Z(m_{\tilde{t}})} \frac{\partial M_Z(m_{\tilde{t}})}{\partial m_{\tilde{t}}} \right| \qquad 1:100$$

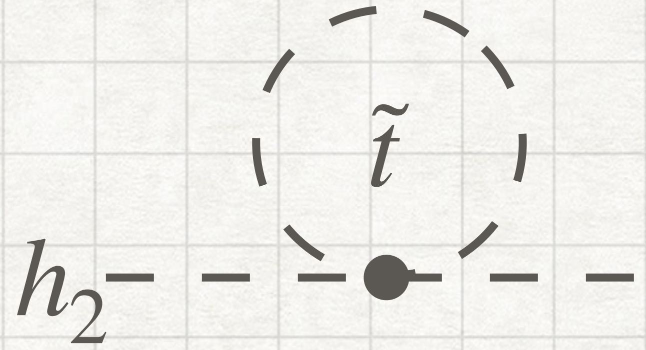
Ellis, 1986

Barbieri, Giudice, 1988

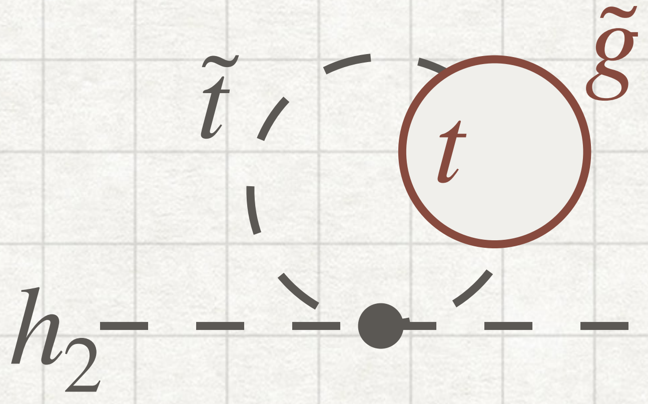
FINE-TUNING IM MSSM



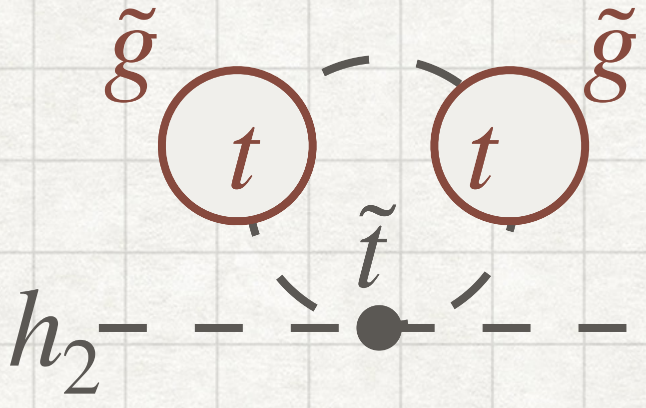
Grenzfall: $m_{\tilde t} \ll M_3 \quad (y_t, g_3, A_t)$



$$\propto \frac{y_t^2}{16\,\pi^2}\, m_{\tilde t}^2$$



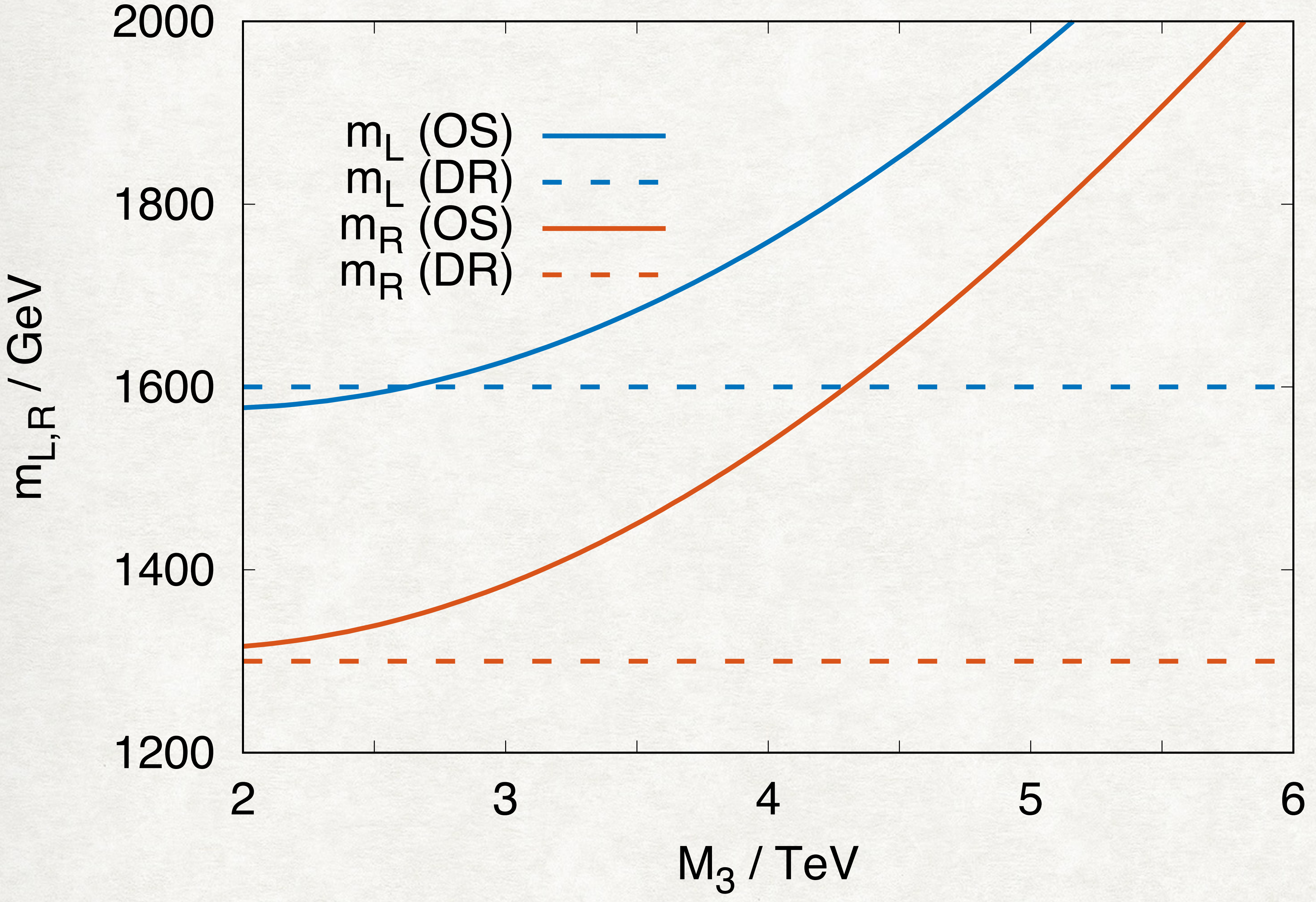
$$\propto \frac{y_t^2}{16\,\pi^2}\, m_{\tilde t}^2\, \frac{g_3^2}{16\,\pi^2}\frac{M_3^2}{m_{\tilde t}^2}$$



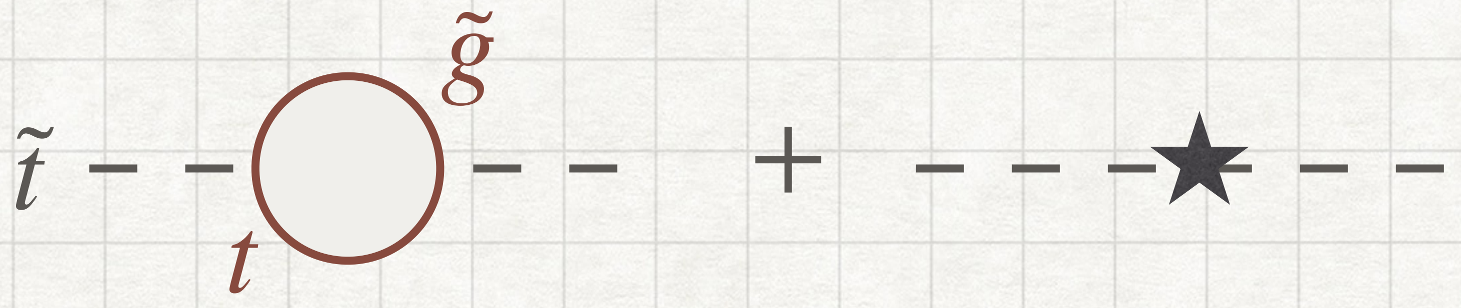
$$\propto \frac{y_t^2}{16\,\pi^2}\, m_{\tilde t}^2 \left(\frac{g_3^2}{16\,\pi^2}\frac{M_3^2}{m_{\tilde t}^2}\right)^2$$

Resummation: Neuordnung der Störungstheorie

RENORMIERUNGSSCHEMA DER STOPS



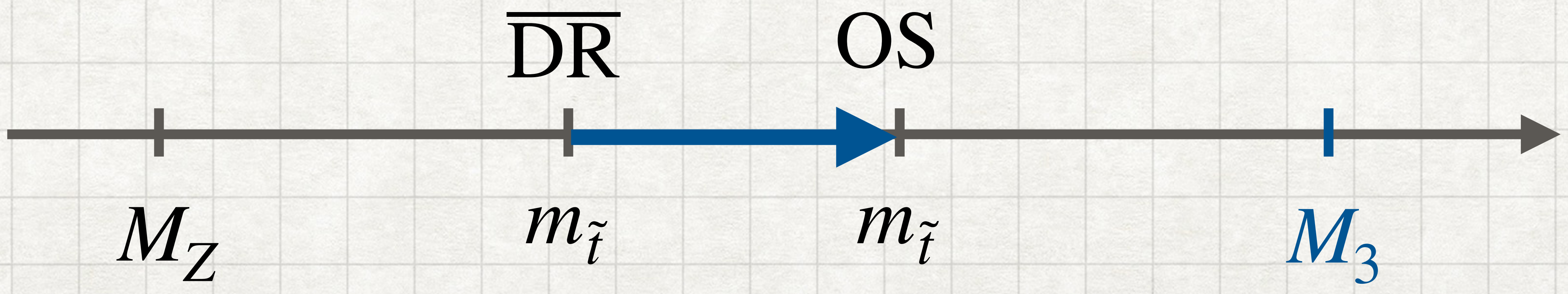
Renormierung der Stopmasse



$\overset{!}{=}$ UV endlich

Freiheit in der Wahl des Counterterms:

- $\overline{\mathrm{DR}}$: Resummation nötig
- on-shell (OS): keine Resummation nötig



FINE-TUNING IM MSSM

Parameterscan:

$$m_{11}^{2,tree} = 10\ldots600\,\text{GeV} = m_{22}^{2,tree}$$

$$m_{\tilde{t},R}^{2,\overline{\text{DR}}} = 400\,\text{GeV}\ldots M_{SUSY}$$

$$A_t = 10\,\text{GeV}\ldots3\,M_{SUSY}$$

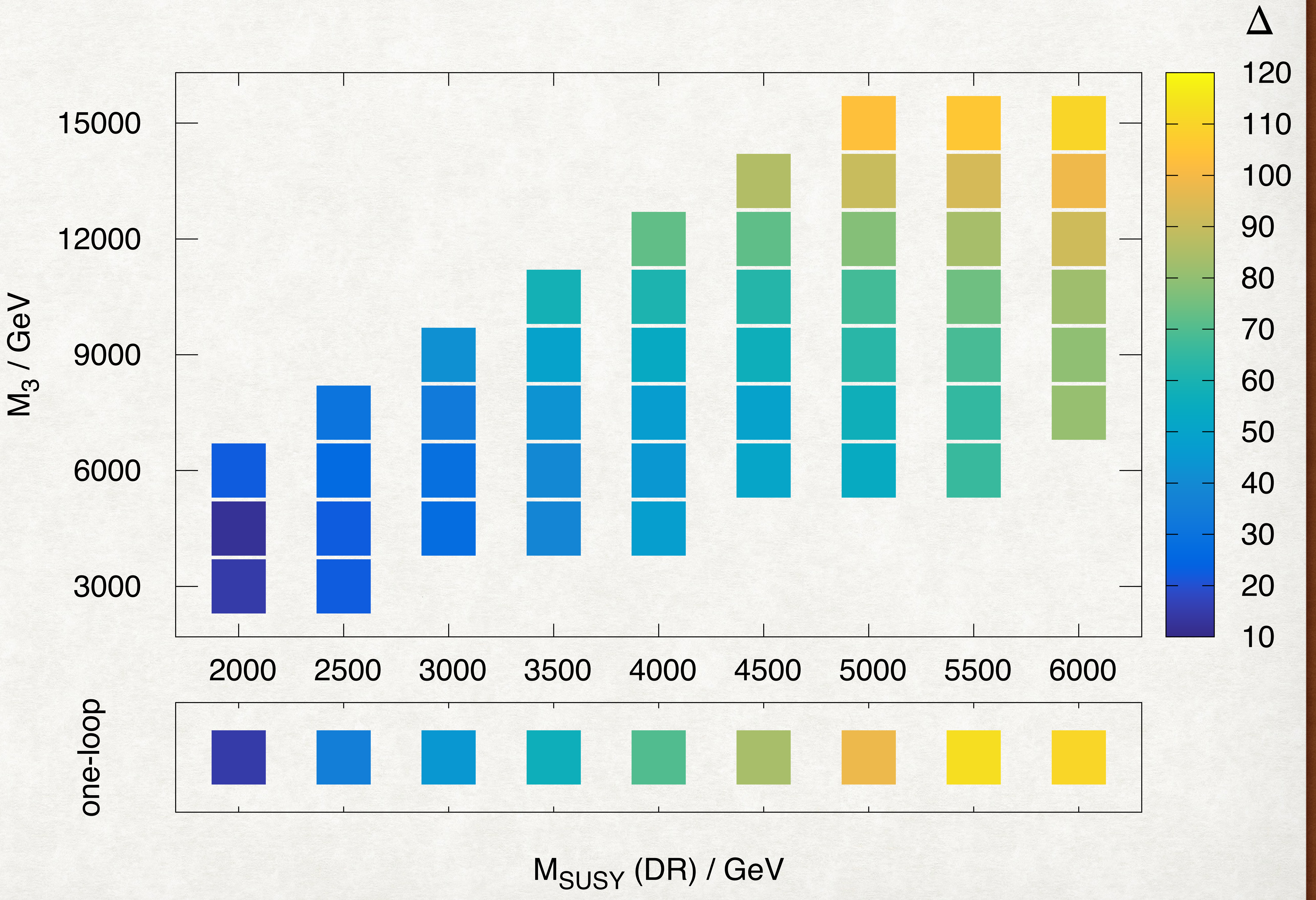
$$\tan\beta = 5 \qquad |\mu| = 400\,\text{GeV}$$

$$M_{SUSY} = \sqrt{m_{\tilde{t},L}\, m_{\tilde{t},R}}$$

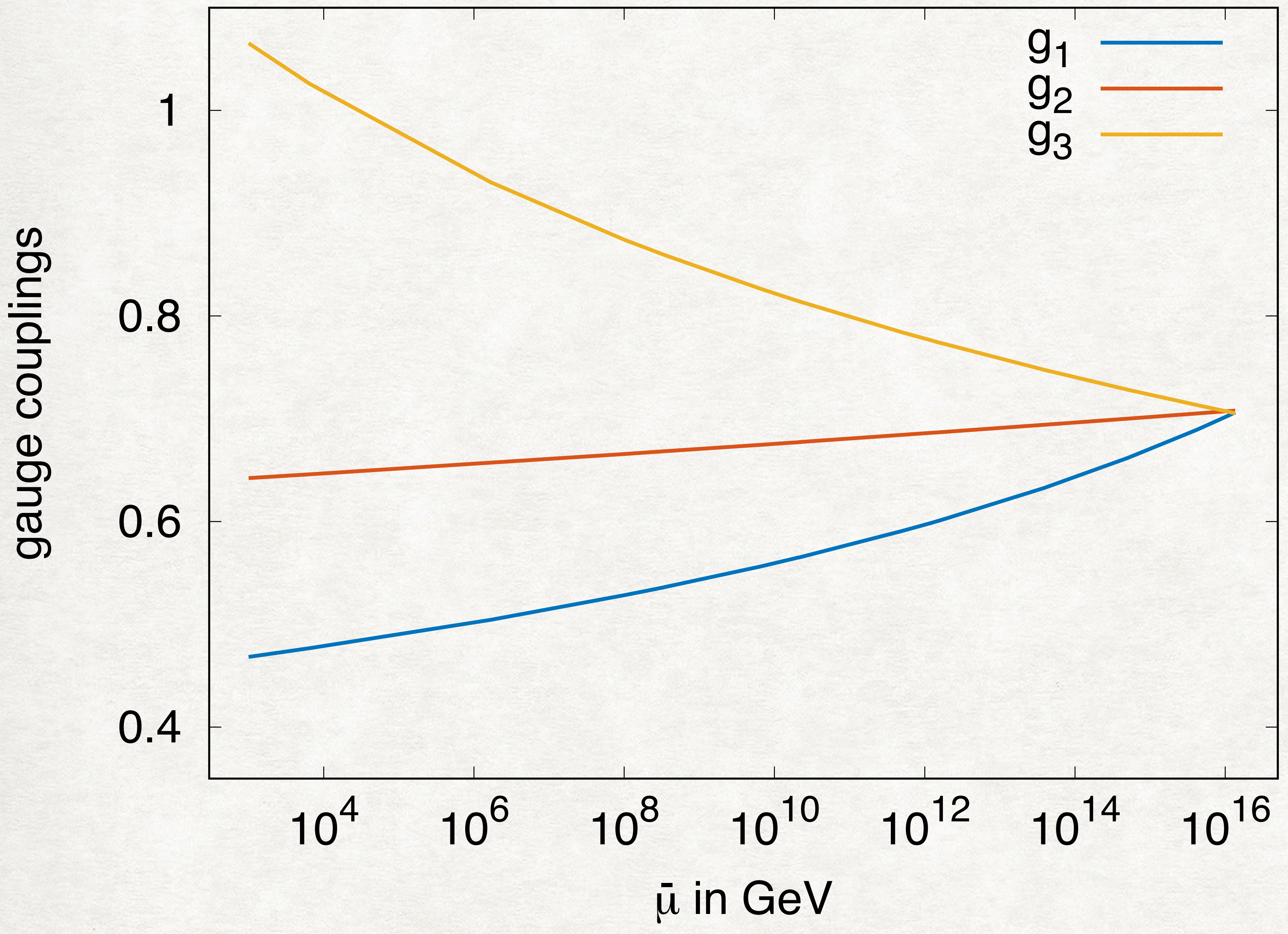
Bedingung:

$$m_h = 125.18 \pm 0.61\ \text{GeV}$$

$$m_Z = 91.1876 \pm 0.0021\ \text{GeV}$$



GROSSVEREINHEITLICHTE THEORIE (GUT): SO(10)



$$\begin{pmatrix} u_L & u_L & u_L & \nu_L \\ d_L & d_L & d_L & e_L \\ u^c & u^c & u^c & \nu^c \\ d^c & d^c & d^c & e^c \end{pmatrix}$$

- Eichtheorie:

$$SO(10) \supset SU(3)_C \times SU(2)_L \times U(1)_Y$$

- Yukawasektor: minimale SO(10)

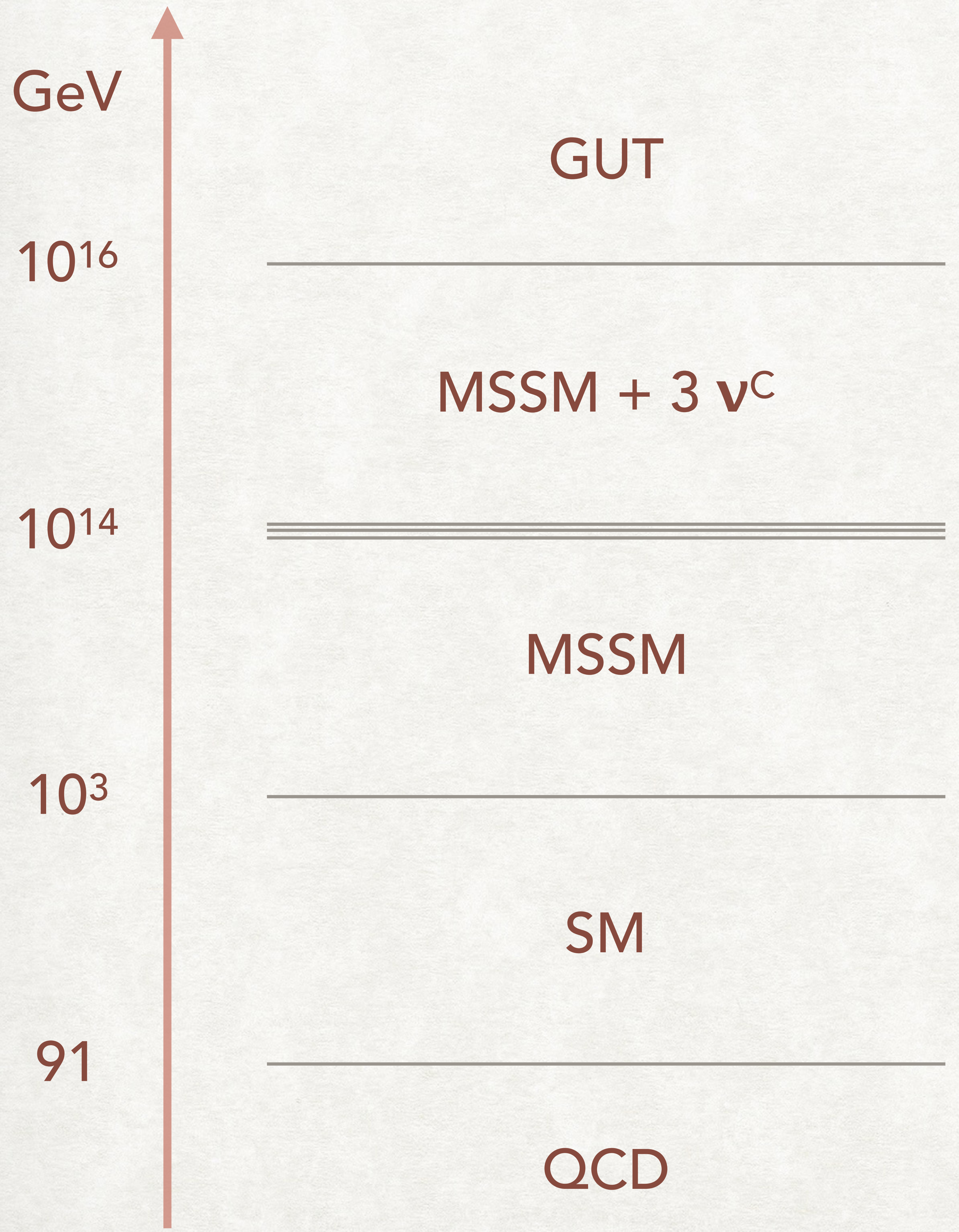
$$\mathscr{L}_{\mathrm{Yukawa}} = \mathbf{Y}^{10}_{ij}\, \overline{\psi}_i \phi^{10} \psi_j + \mathbf{Y}^{126}_{ij}\, \overline{\psi}_i \phi^{126} \psi_j$$

- SO(10) → MSSM

$$\mathbf{Y}^{10},\, \mathbf{Y}^{126} \to \mathbf{Y}_u,\, \mathbf{Y}_d,\, \mathbf{Y}_e,\, \mathbf{Y}_\nu,\, \mathbf{M}_{\nu^c}$$

Amaldi, de Boer, Fürstenau, 1991
Fritzsch, Minkowski, 1975

PARAMETERANPASSUNG



19 GUT Parameter im Yukawasektor

Renormierungsgruppengleichungen (2-loop)

Entkoppeln der rechtshändige Neutrinos

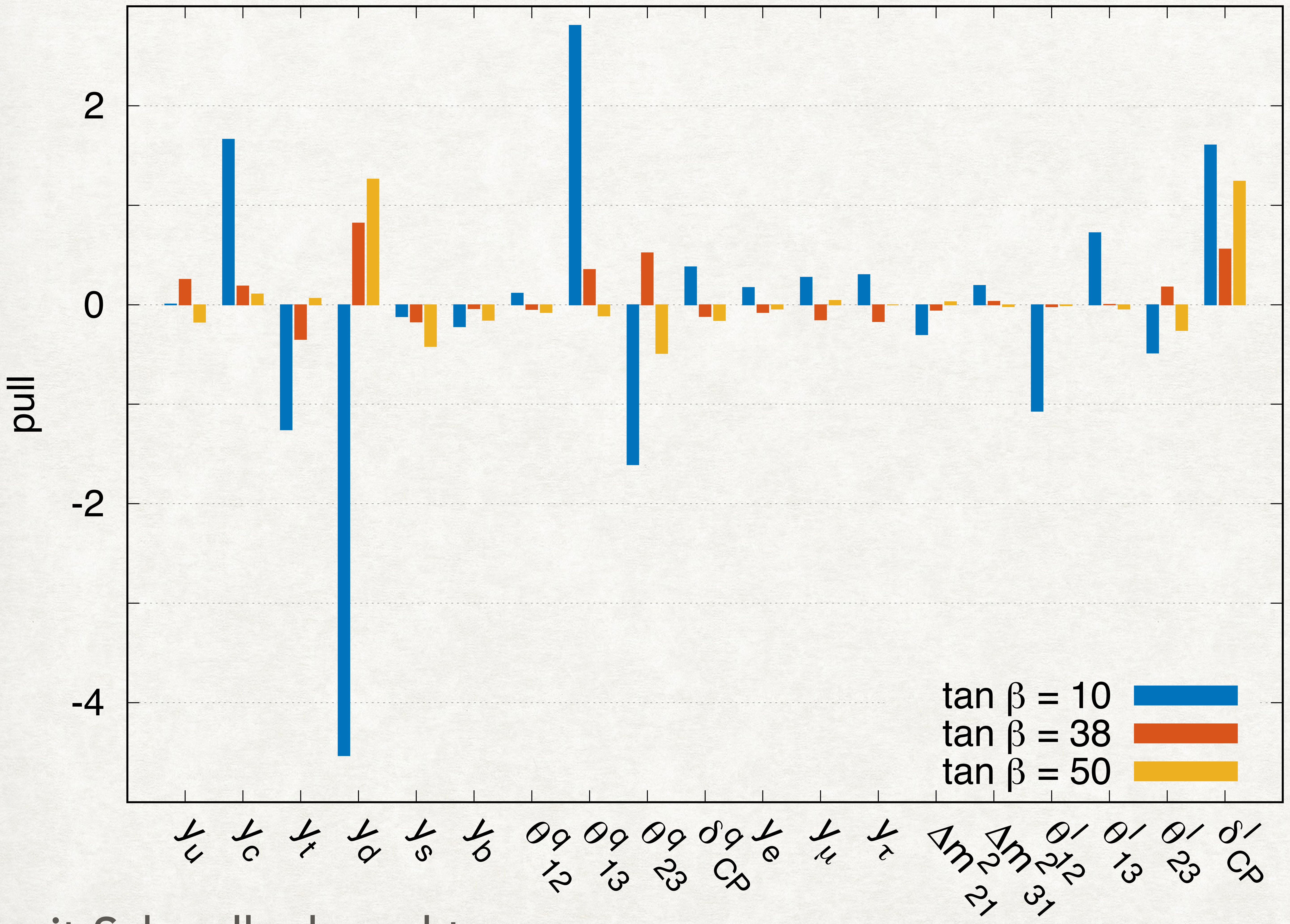
$$\chi^2 = \sum \left(\frac{\mathcal{O}_{\text{theo}} - \mathcal{O}_{\text{exp}}}{\sigma_{\text{exp}}} \right)^2$$

+ 3 SUSY Parameter $\epsilon_b, \epsilon_q, \epsilon_l$

19 Observablen:
Fermionmassen und -mischung

FLAG 2016
CKMfitter 2016
NuFIT 2016
PDG 2016

ERGEBNISSE

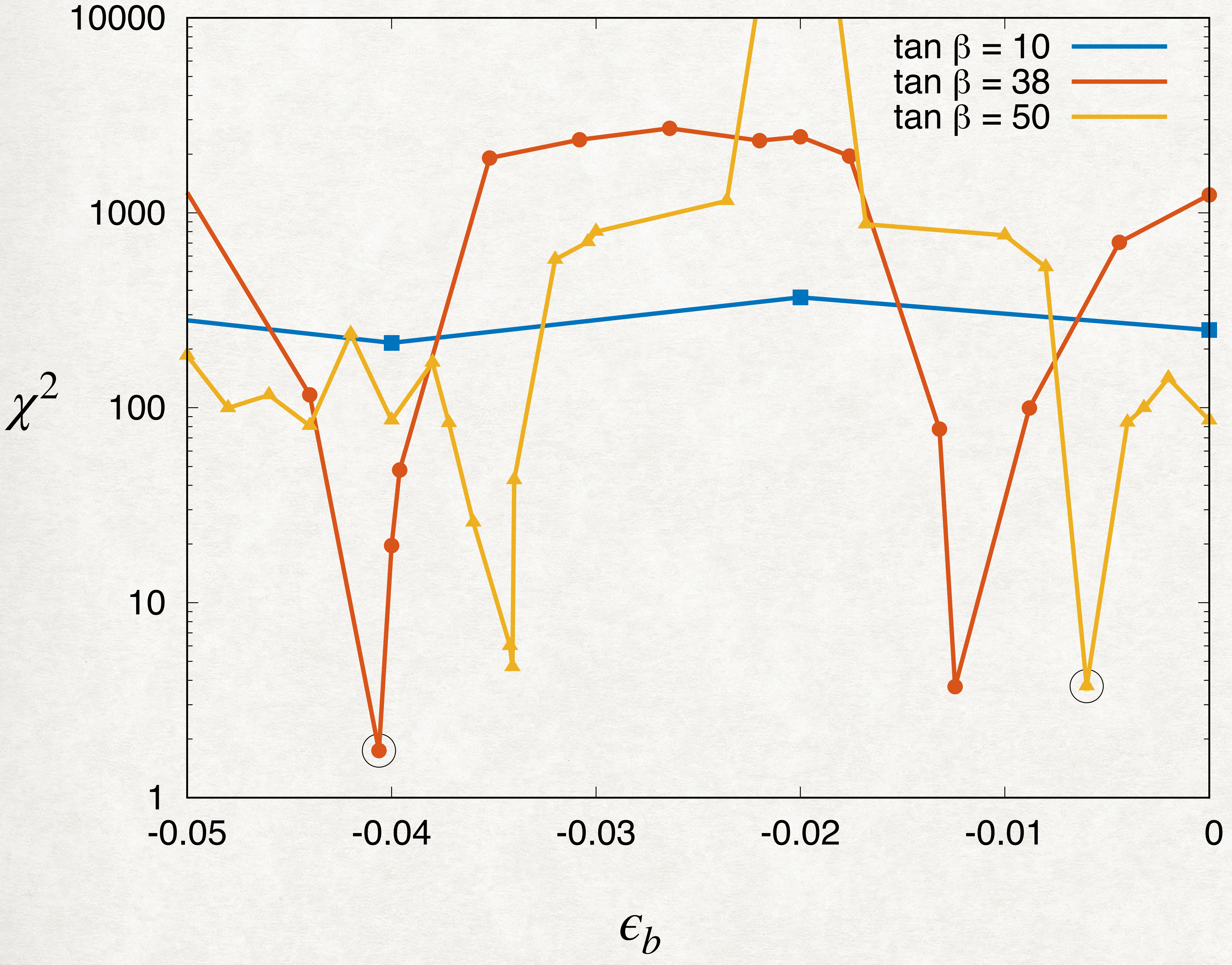


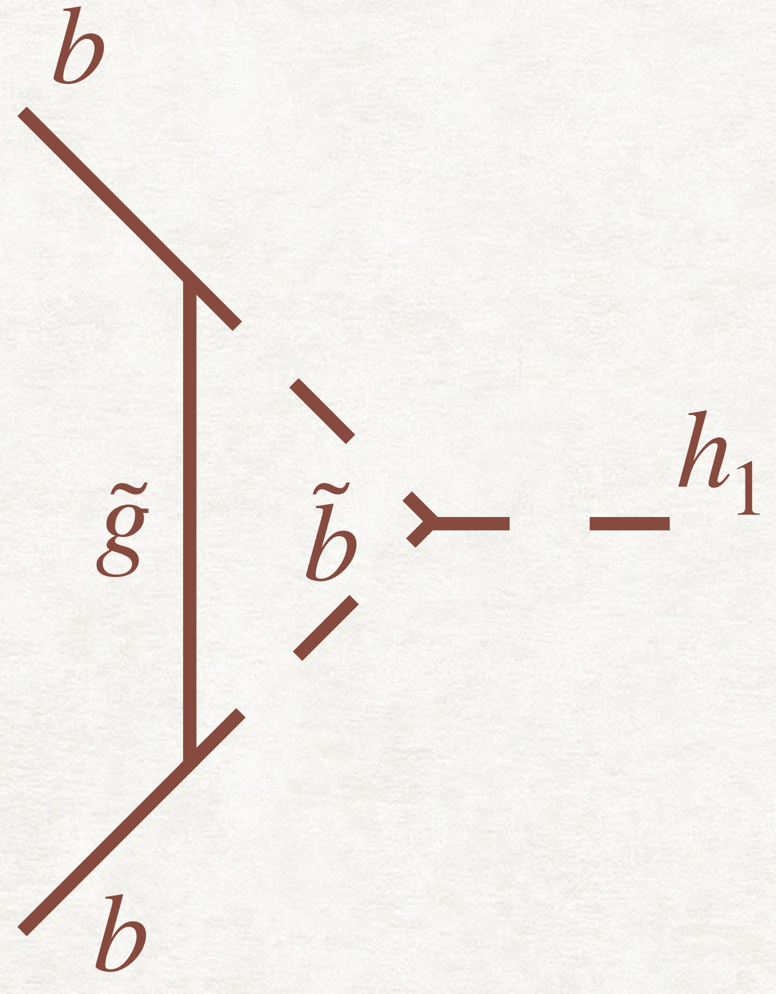
mit Schwellenkorrekturen

tan β	mit (ohne) Schwellenkorrekturen
10	40.37 (127.0)
38	1.74 (94.69)
50	3.71 (75.43)

Deppisch, Schacht, Spinrath, 2018

SCHWELLENKORREKTUREN



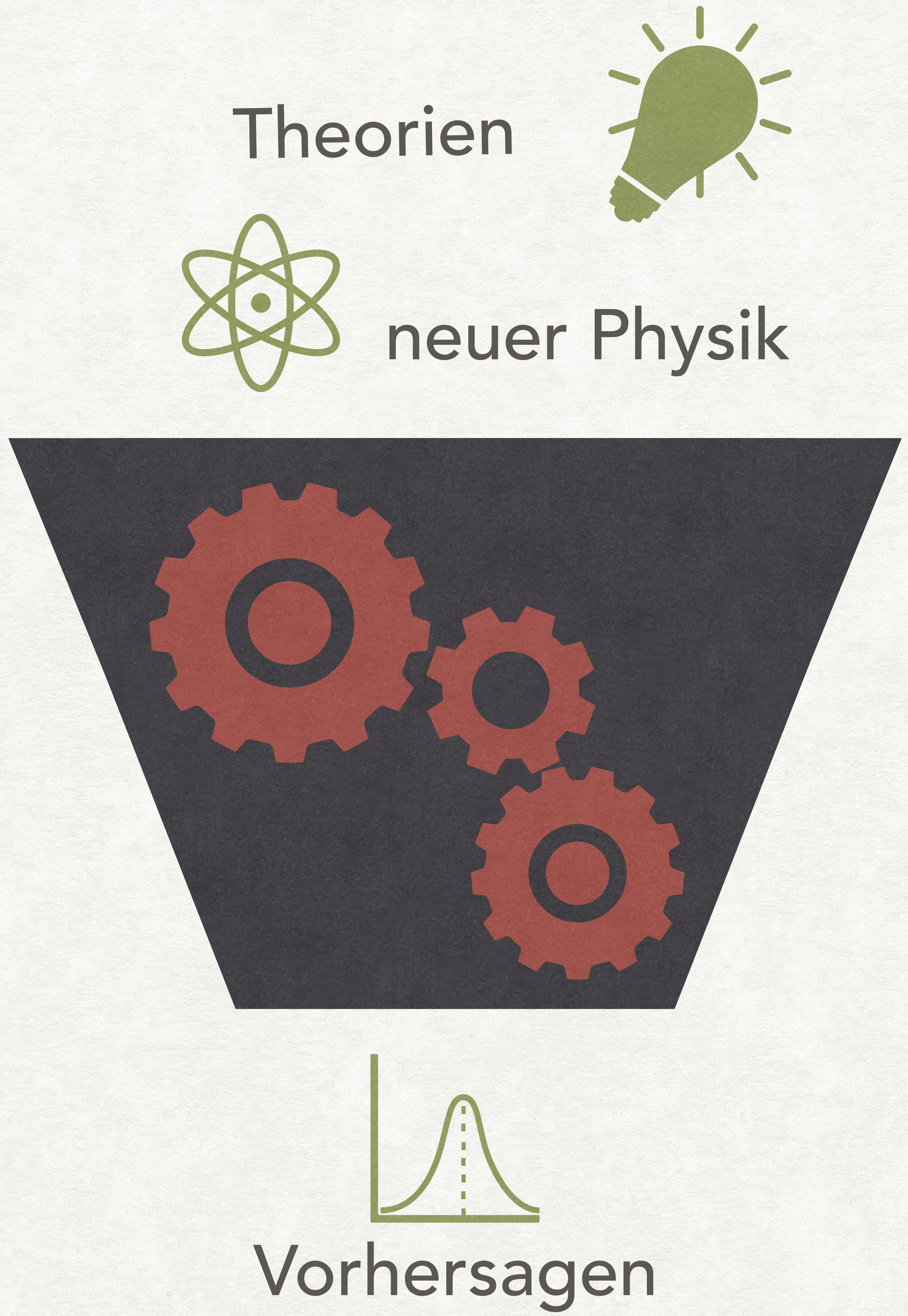


$\propto \epsilon_b \tan\beta$

Bereiche:

$$-0.1 \le \epsilon_b \le 0.1$$
$$-0.05 \le \epsilon_q \le 0.05$$
$$-0.03 \le \epsilon_l \le 0.03$$

FAZIT



- hierarchische Supersymmetrie
    - schweres Gluino relevant für das Hierarchieproblem
    - on-shell-Schema
- großvereinheitlichte Theorien
    - Quarkmassen und Neutrinodaten
    - Schwellenkorrekturen wichtig