Precision Calculations in a Gauged Singlet Extension of the Standard Model

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Abstract

Since the discovery of a Higgs boson at the LHC in 2012 no additional truly elementary particles have been found in experiments. Therefore, the search for small deviations of experimental results from Standard Model predictions is currently the most promising way to obtain hints on the structure of potential new physics, needed to explain unanswered questions like the origin of dark matter or the baryon asymmetry. For a well-founded interpretation of high-precision measurements it is of uttermost importance to have precise theoretical predictions within the Standard Model and its possible extensions. In the presented work the Gauged Singlet Extension of the Standard Model [1] (GSESM) is considered. It extends the Standard Model gauge sector by an additional $U(1)_\mathrm{d}$ gauge group of a possible hidden sector, leading to kinetic mixing between the two $U(1)$ gauge groups of the theory. Further, the Higgs sector is extended by an additional scalar, complex Higgs field with non-vanishing vacuum expectation value. This Higgs field is a singlet under the Standard Model gauge group, but charged under the new $U(1)_\mathrm{d}$ gauge group. Furthermore, right-handed neutrino fields as well as a fermion field that is only charged under the $U(1)_\mathrm{d}$ gauge group are introduced. The GSESM predicts an additional massive Higgs boson H, an additional massive, neutral gauge boson Z', massive neutrinos as well as an additional massive Dirac fermion.

The Gauged Singlet Extension of the Standard Model

- GSESM has a richer gauge group than the SM:

$$SU(3)_\mathrm{C} \times SU(2)_\mathrm{W} \times U(1)_\mathrm{Y} \times U(1)_\mathrm{d}$$

- Higgs sector extended by additional complex, SM-singlet Higgs field which carries $U(1)_\mathrm{d}$ charge

$$\Phi = \begin{pmatrix} \phi^+ \\ \frac{1}{\sqrt{2}}(h_2 + v_2 + \mathrm{i}\chi_2) \end{pmatrix}, \qquad \rho = \frac{1}{\sqrt{2}}(h_1 + v_1 + \mathrm{i}\chi_1)$$

- two generic portals to a possible hidden sector:
  - in the gauge sector via kinetic mixing of the two $U(1)$ field-strength tensors

$$\mathcal{L}_\mathrm{kin,mix} = -\tfrac{a}{2} F_{\mathrm{Y},\mu\nu} F_\mathrm{d}^{\mu\nu}$$

  - in the Higgs potential

$$\mathcal{L}_\mathrm{pot,mix} = -\lambda_{12} \Phi^\dagger \Phi \rho^\dagger \rho$$

- GSESM has enriched particle content:
  - two physical Higgs bosons

$$\begin{pmatrix} h \\ H \end{pmatrix} = \begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} h_2 \\ h_1 \end{pmatrix}$$

  - three physical, neutral gauge bosons

$$\begin{pmatrix} B'_{\mathrm{Y},\mu} \\ W^3_\mu \\ B'_{\mathrm{d},\mu} \end{pmatrix} = \begin{pmatrix} \cos\theta_\mathrm{w} & \sin\theta_\mathrm{w}\cos\gamma & -\sin\theta_\mathrm{w}\sin\gamma \\ -\sin\theta_\mathrm{w} & \cos\theta_\mathrm{w}\cos\gamma & -\cos\theta_\mathrm{w}\sin\gamma \\ 0 & \sin\gamma & \cos\gamma \end{pmatrix} \begin{pmatrix} A_\mu \\ Z_\mu \\ Z'_\mu \end{pmatrix}$$

  - various modifications in the gauge-fixing and ghost parts of the Lagrangian

→ leads to additional Feynman diagrams and modified coupling structures

Calculation of Precision Observables

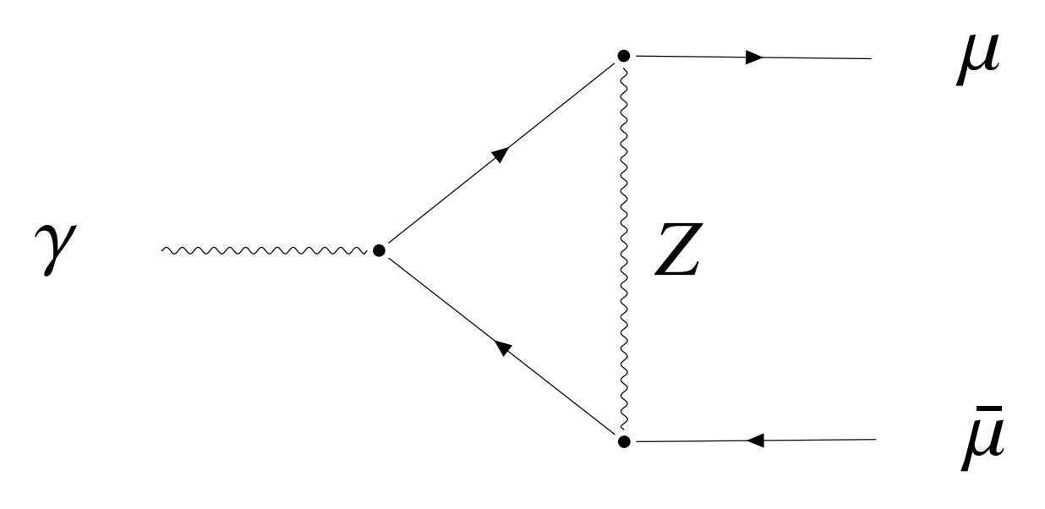
- renormalization of GSESM needed for NLO calculations
  - further development of established renormalization schemes needed
  - e.g. newly developed methods for phenomenologically sound renormalization of mixing angles needed [2]
- probe influence of the various generic extensions included in the GSESM by calculating predictions for precision observables

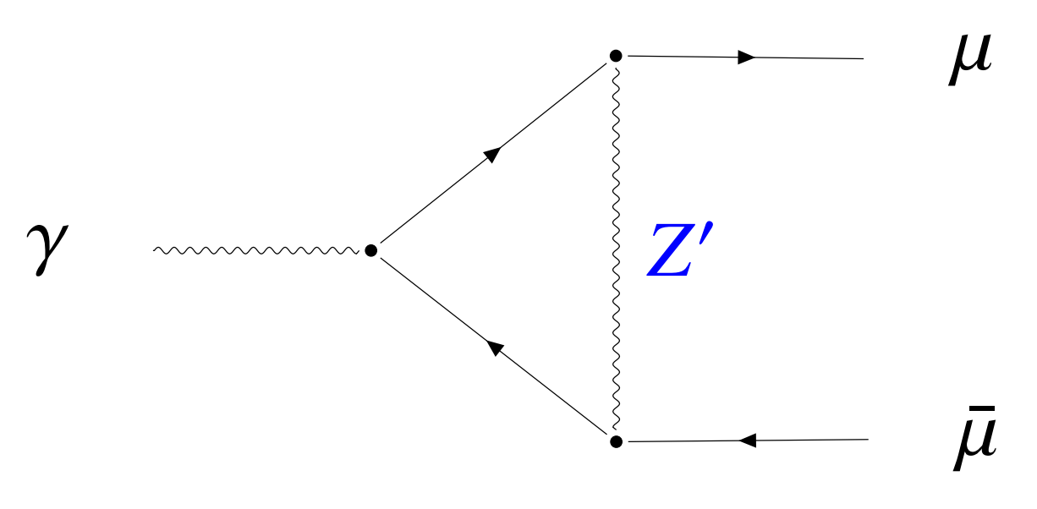
→ study influence of generic BSM model-building blocks on theoretical predictions

- calculation of precision observables in GSESM used to determine limits from data on new parameters
- influence of various Higgs sector extensions known (e.g. Singlet Extension, THDM)

→ focus on influence of gauge-sector extension

- precision observables:
  - the anomalous magnetic moment of the muon, g-2: diagrams sensitive to mixing angle γ

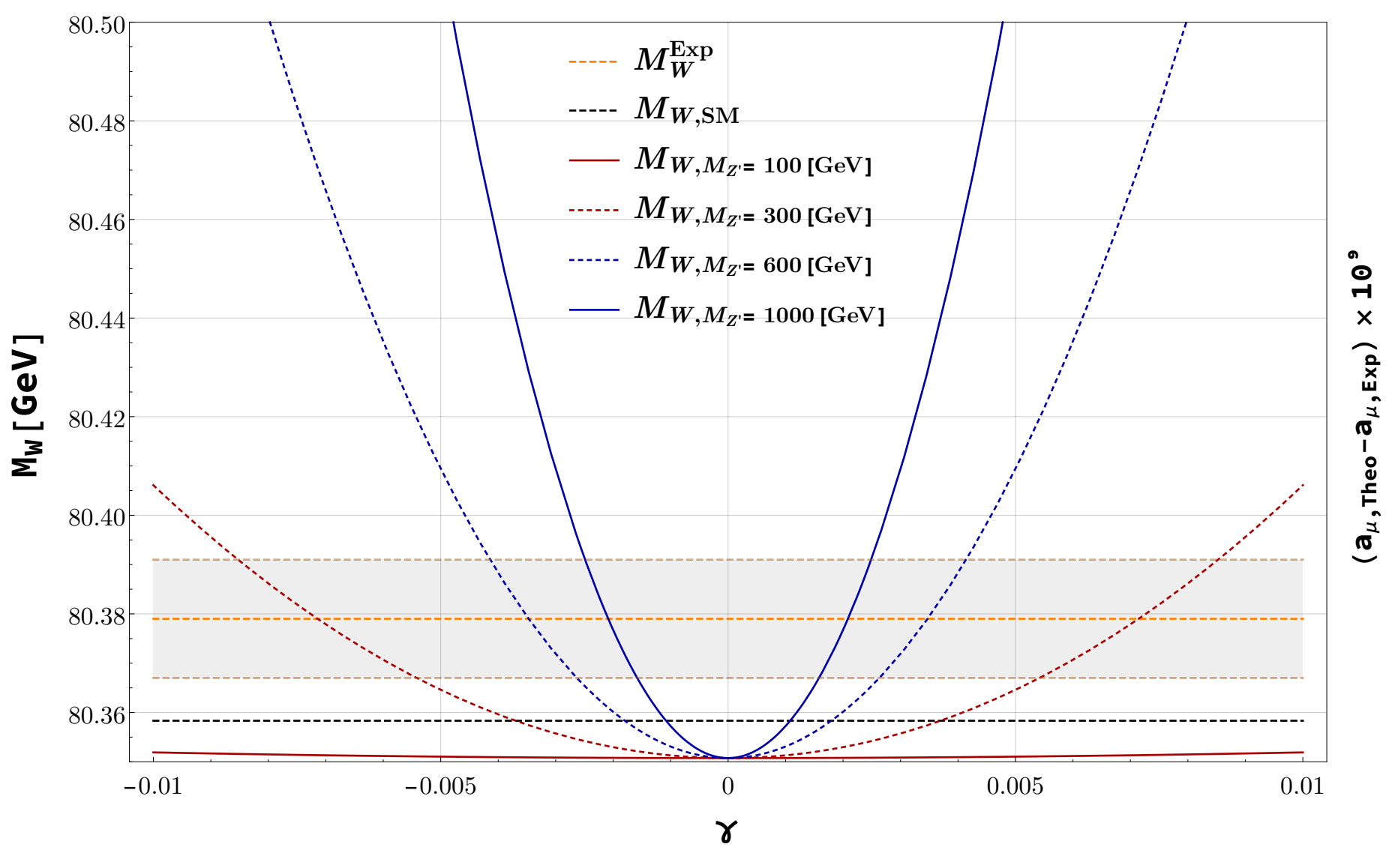




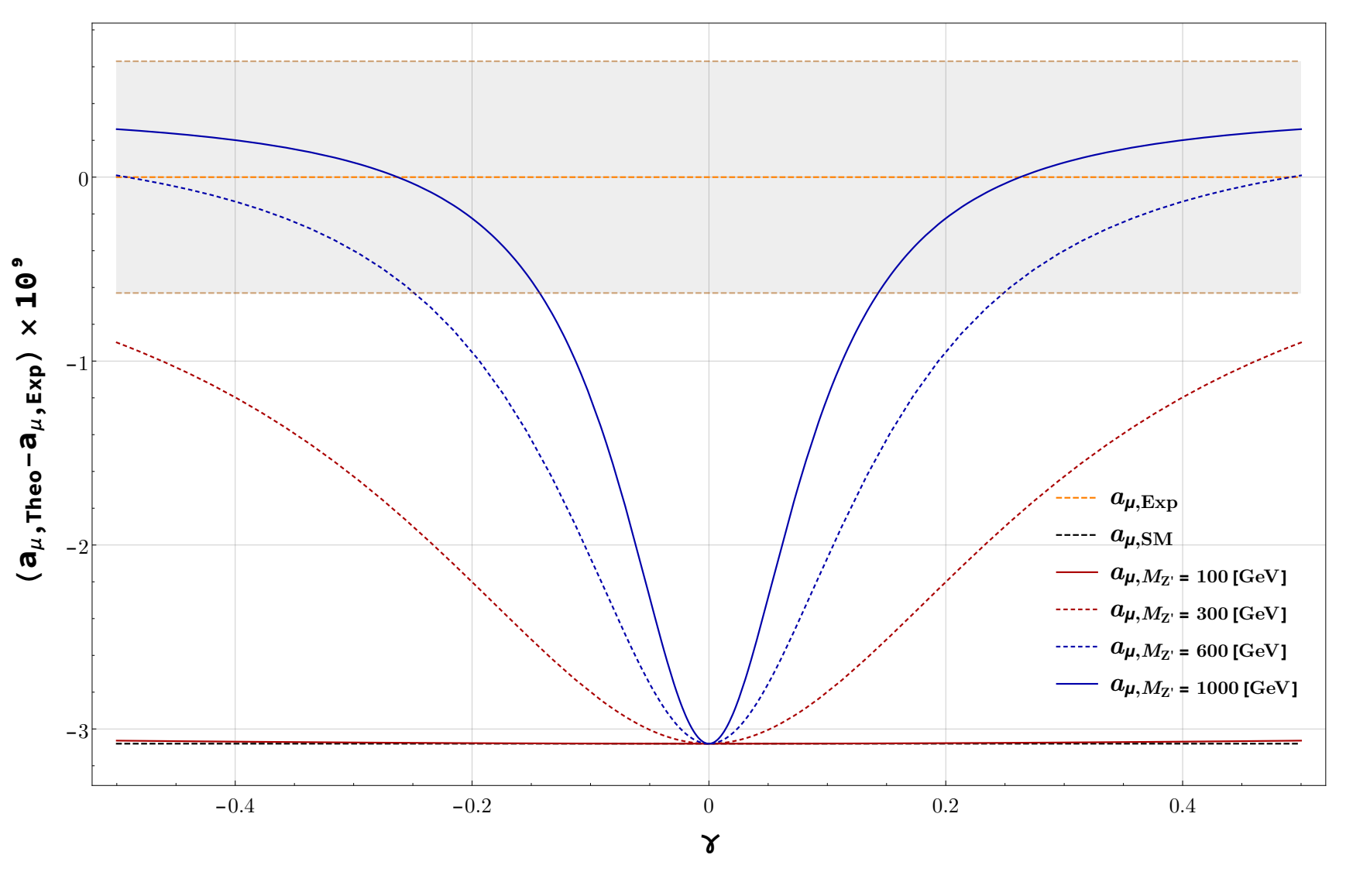
  - the W-boson mass, M_W via the muon-decay at NLO
  - effective weak-mixing angle, $s_\mathrm{w,eff}$

Results and Exclusion Limits

- all three newly introduced parameters (M_H, α, λ_{12}) of the Higgs sector fixed
- focus on new parameters in gauge sector $M_{Z'}$, γ



M_W



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- confronting predictions with experimental results leads to exclusion limits for parameters
- GSESM predictions have a higher level of agreement with measurements than SM predictions for each precision observable separately

$M_{Z'}$ [GeV]	100	300	600	1000
$\lvert\gamma\rvert_{M_\mathrm{W},\max}$	0.0591	0.0085	0.0041	0.0025
$\lvert\gamma\rvert_{a_\mu,\min}$	−	0.641	0.249	0.143
$\lvert\gamma\rvert_{s_\mathrm{w,eff},\max}$	0.107	0.220	0.042	0.017

- parameter regions providing higher level of agreement do not overlap

→ GSESM does not provide better results overall

Outlook

- expand fermion sector of the SM
  - include right-handed SM-like neutrino fields $\nu_{\mathrm{R},e}$, $\nu_{\mathrm{R},\mu}$, $\nu_{\mathrm{R},\tau}$
  - introduce additional, heavy, dark fermion field f_d
- introduces mixing between right-handed neutrino fields and dark fermion via Higgs field ρ

$$\mathcal{L}_\mathrm{ferm,mix} = -\sum_{i=e,\mu,\tau} y_i \rho \bar{f}_{\mathrm{d,L}} \nu_{\mathrm{R},i} \tag{1}$$

- leads to massive neutrinos and an additional massive fermion
- mixing influences all considered precision observables non-trivially
- might lead to better agreement between obtained limits on the newly introduced parameters
- predictions for further precision observables

→ obtain even better picture of the influences of the various extensions included in GSESM

References

[1] R. Schabinger and J.D. Wells. Minimal spontaneously broken hidden sector and its impact on Higgs boson physics at the CERN Large Hadron Collider. *Phys. Rev. D 72 (2005) 093007.*

[2] A. Denner, S. Dittmaier, and JN. Lang. Renormalization of mixing angles. *Journal of High Energy Physics*, 2018(11), 2018.

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