$g-2$ and low-mass new physics

Dominik Stöckinger, TU Dresden

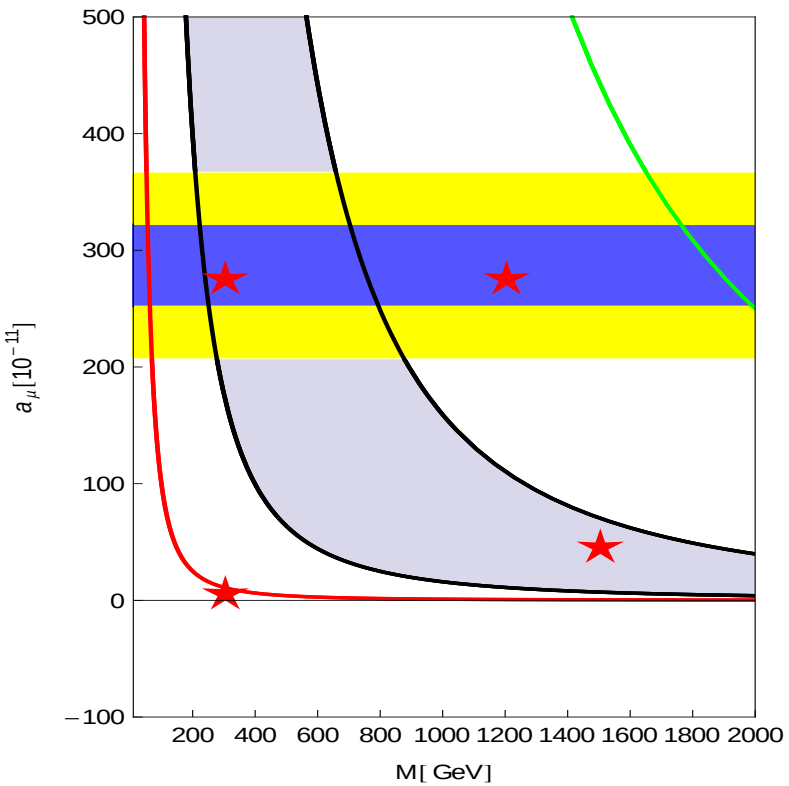
Matter to the Deepest, September 2017

Outline

Overview on $g-2$

Now: $$a_\mu^{\rm exp} - a_\mu^{\rm SM} = (28.1 \pm 6.3^{\rm Exp} \pm 3.6^{\rm Th(KNT17)}) \times 10^{-10}$$

Keshavarzi,Nomura,Teubner'17; Jegerlehner'17:$\pm 4.4^{\rm Th}$



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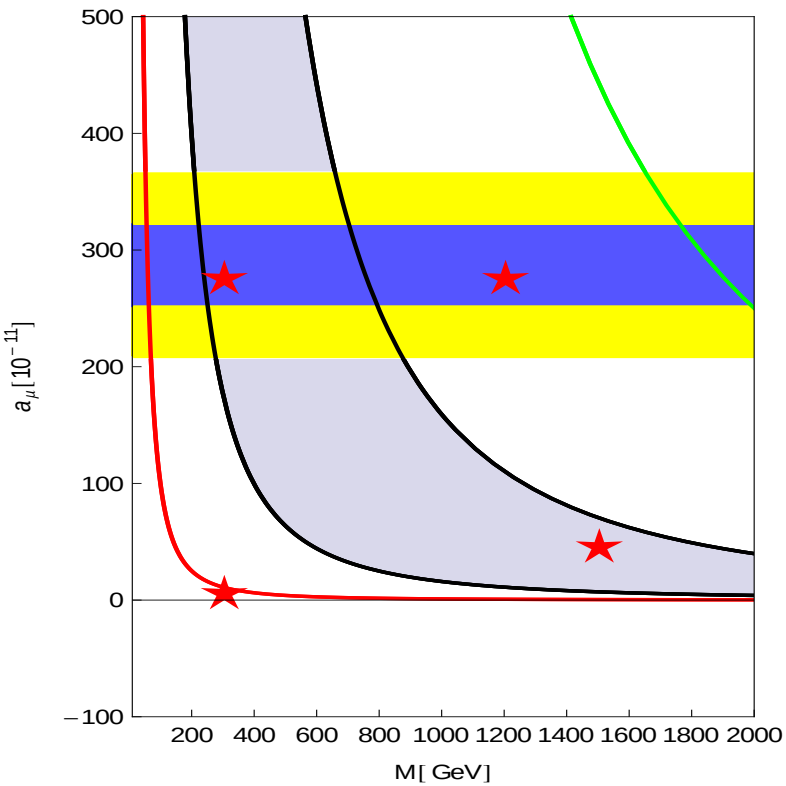

Outline

Two-Higgs Doublet Model

- Second Higgs doublet well motivated in theory
  $\rightsquigarrow h, H, H^{\pm}, A^0$

$$h^{\text{SM-like}} = (c_{\beta-\alpha} H + s_{\beta-\alpha} h) \qquad (\text{LHC-data} \Rightarrow c_{\beta-\alpha}=\text{small !})$$

- Yukawas: type 1, 2 ($\leftarrow$ MSSM), X (lepton-specific), Y (flipped)
- consider general model without FCNC $\rightsquigarrow$ "aligned" [Pich, Tuzon]
- recently: full two-loop calculation of $g-2$ in this model
  [Cherchiglia,Kneschke,DS,Stöckinger-Kim'16] $\rightsquigarrow$ now apply! [ongoing, Cherchiglia,DS,Stöckinger-Kim]

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Two-Higgs Doublet Model couplings

- Yukawa couplings in general "aligned" model

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\begin{aligned}
Y^A_{d,l;u} &= \mp \zeta_{d,l;u} \\
Y^h_f &= s_{\beta-\alpha} + c_{\beta-\alpha}\zeta_f \\
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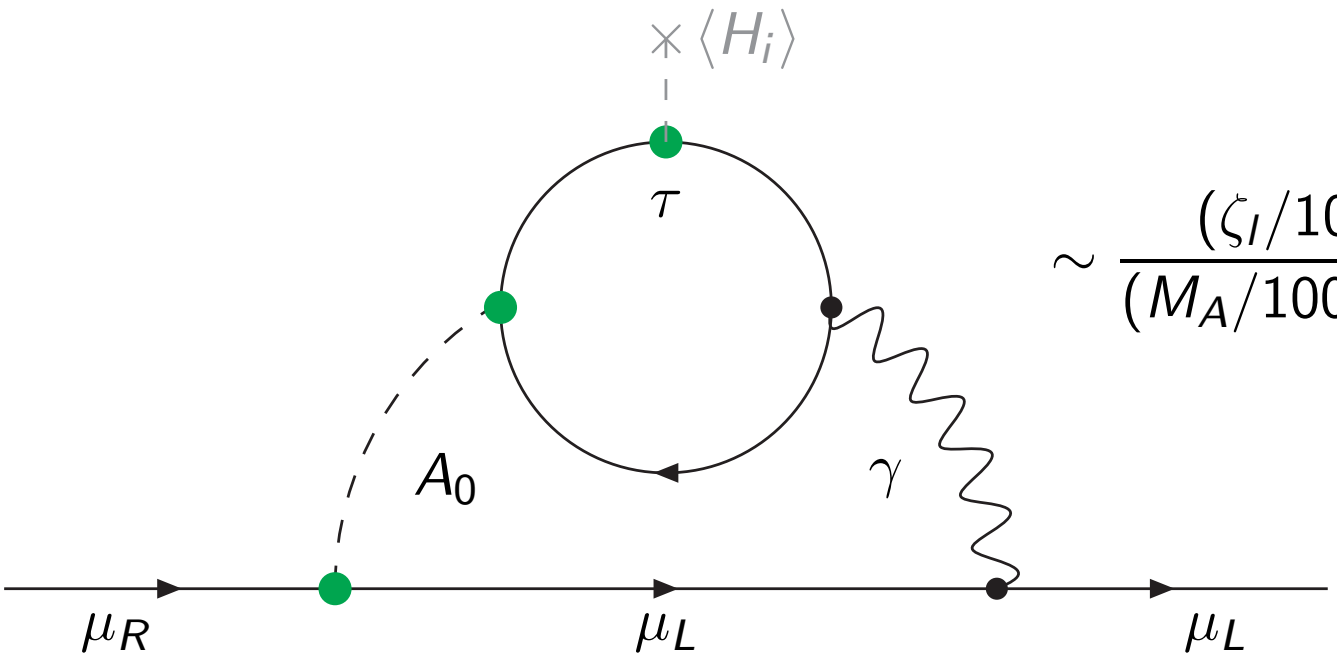
$$

MSSM/Type 2:	$\zeta_{d,l} = -\tan\beta,$	$\zeta_u = 1/\tan\beta$	
Type X (lepton-specific):	$\zeta_l = -\tan\beta,$	$\zeta_{d,u} = 1/\tan\beta$	
General: expect	$\zeta_l \sim 50,$	$\zeta_{d,u} \sim 1,$	$M_A < M_h$

Two-Higgs Doublet Model: τ-loop



$$\sim \frac{(\zeta_l/100)^2}{(M_A/100\text{GeV})^2} \times 10^{-9}$$

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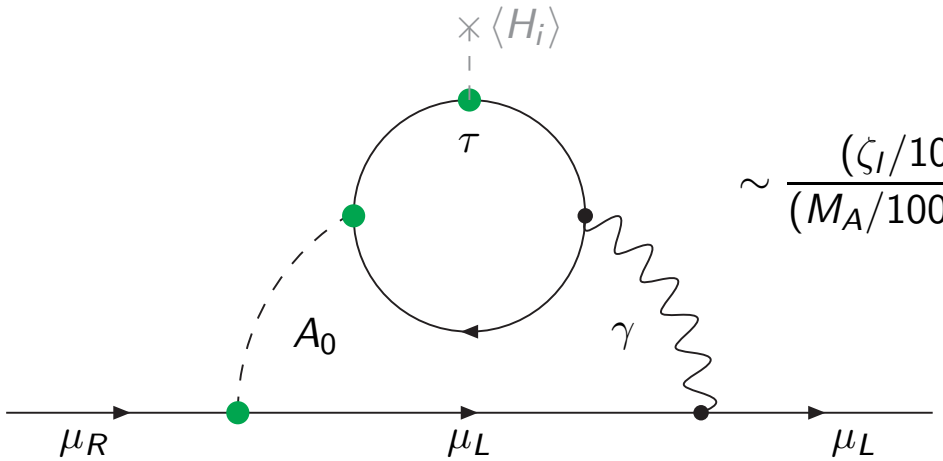
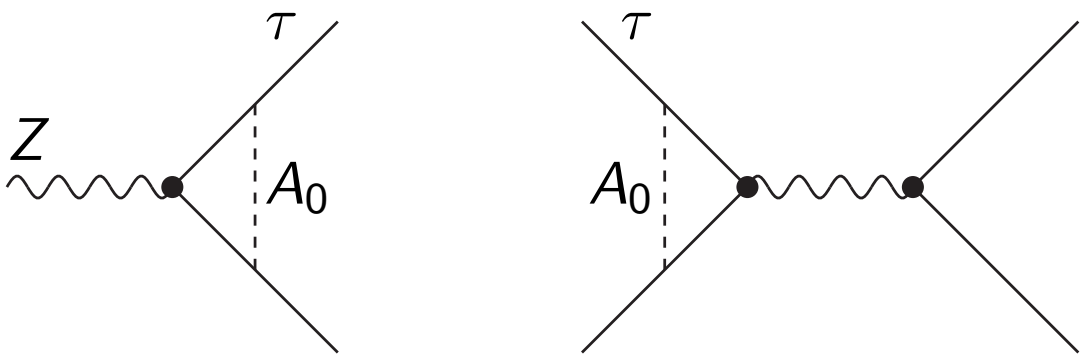
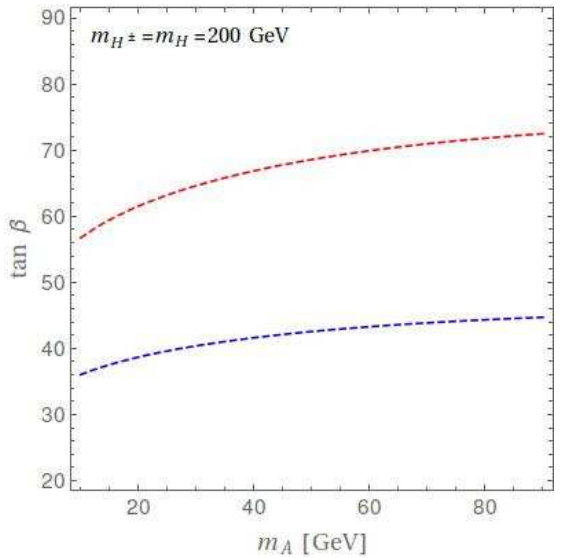


$$\sim \frac{(\zeta_l/100)^2}{(M_A/100\text{GeV})^2} \times 10^{-9}$$

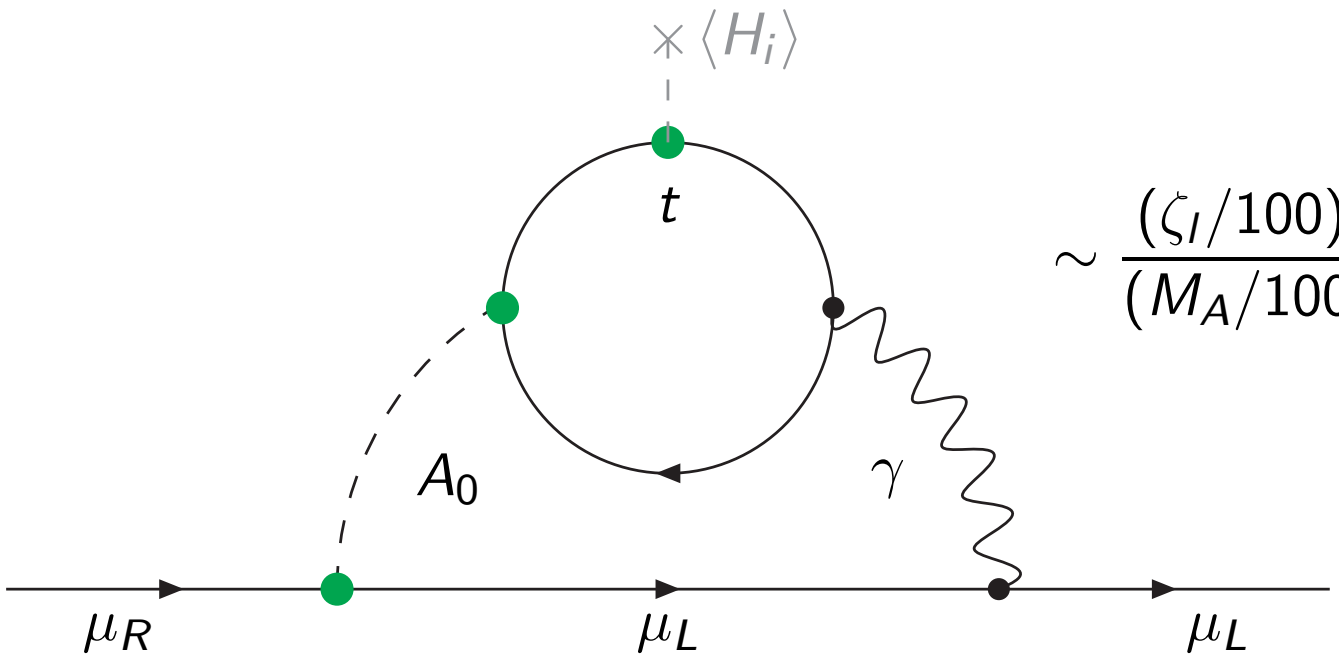
But: $Z \to \tau\tau$, τ-decay constraints on ζ_L!

[Chun,Kim'16; Abe et al '15; Han et al '15]





Two-Higgs Doublet Model: top-loop



$$\sim \frac{(\zeta_l/100)(-\zeta_u)}{(M_A/100\text{GeV})^2} \times 2 \cdot 10^{-9}$$

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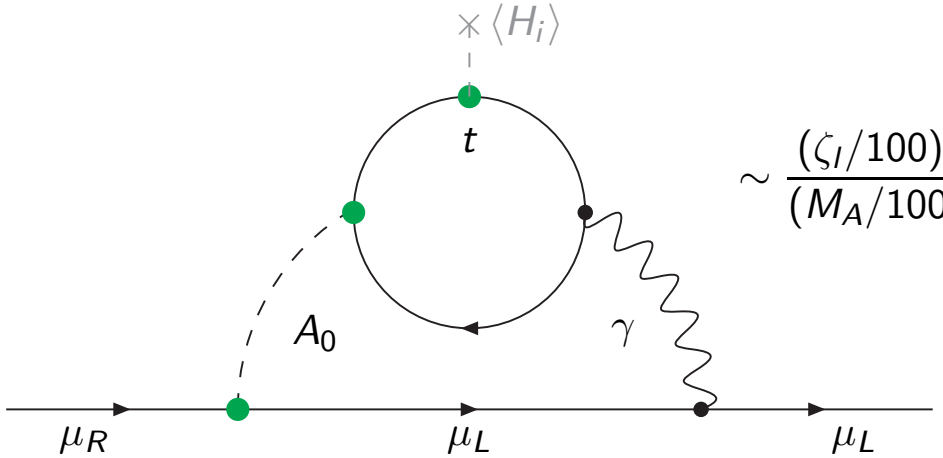
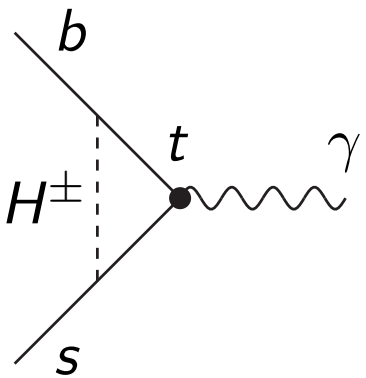
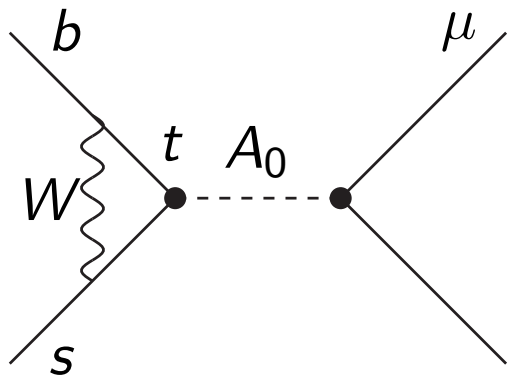
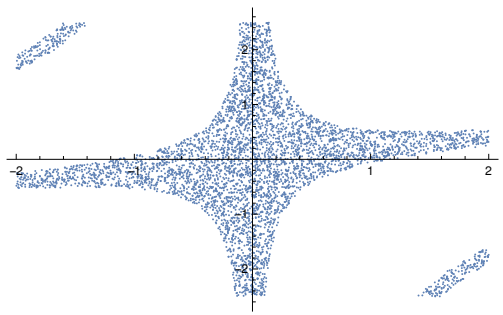


$$\sim \frac{(\zeta_l/100)(-\zeta_u)}{(M_A/100\text{GeV})^2} \times 2\cdot 10^{-9}$$

But: $b \to s\gamma$ and $B_s \to \mu\mu$ constraints! [Enomoto,Watanabe '15; Pich et al '14]





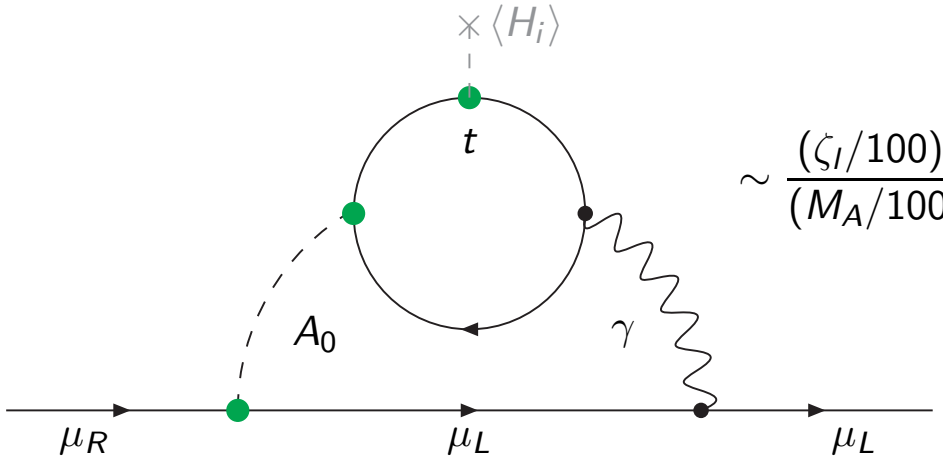


ζ_d/ζ_u vs. $b \to s\gamma$ ($M_{H^\pm} = 200$ GeV)

Note: type 2: $\zeta_d = -\tan\beta$, $\zeta_u = 1/\tan\beta$

$\rightsquigarrow$ excluded for $M_{H^\pm} <\sim 580$ GeV [Misiak, Steinhauser '17]

Two-Higgs Doublet Model: top-loop



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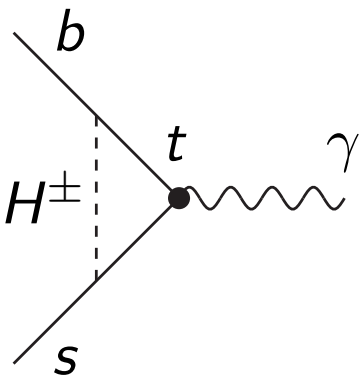
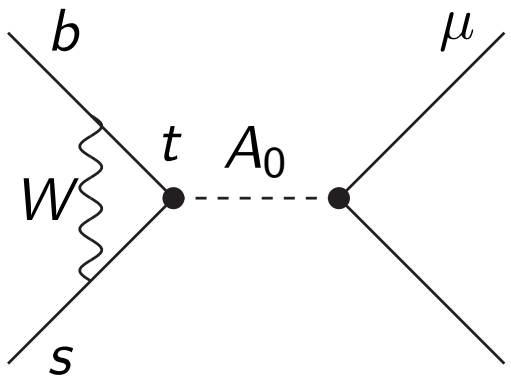
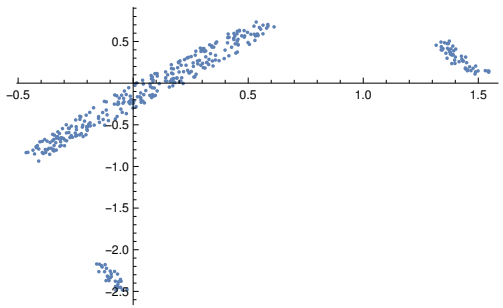
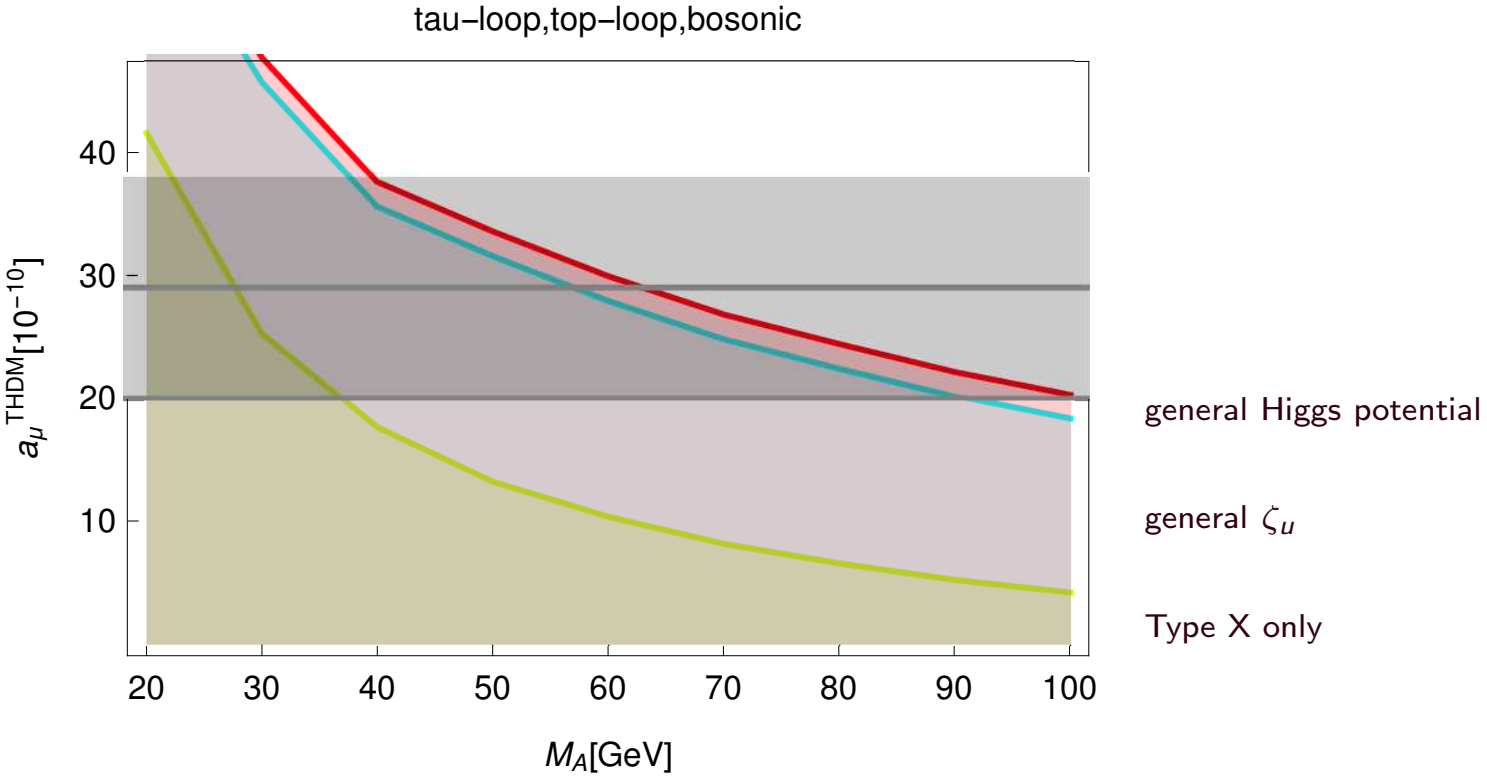






ζ_d/ζ_u also vs. $B_s \to \mu\mu$

Results and outlook



- Maximum contributions to $g-2$
- Interesting scenario: light A^0; $M_{H^\pm} \sim 200$ GeV,
  large couplings to tau/top, large Higgs self couplings preferred
- Constrained/testable by other measurements, e.g.: $gg \to A^0 \to \tau\tau$

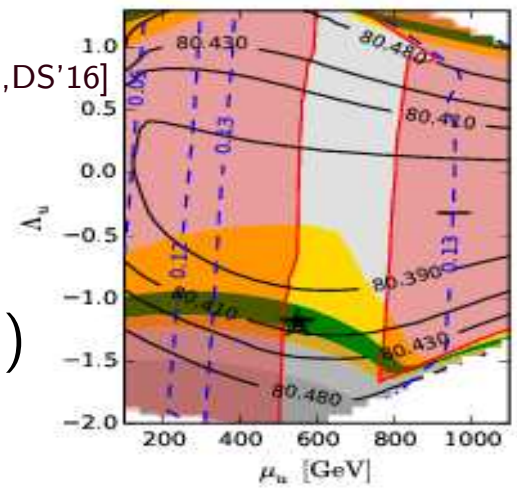
  [$\rightsquigarrow$ + Dresden ATLAS group]

Outline

R-symmetric model MRSSM [Kribs, Poppitz, Weiner]

- surprisingly promising:
  (LHC, EWPO, dark matter)
- beautiful/rigid: conserved R-charges
- Gauginos/Higgsinos must be Dirac (not Majorana!)

[Diessner,Kalinowski,Kotlarski,DS'16]
[→ talk Wojciech Kotlarski]



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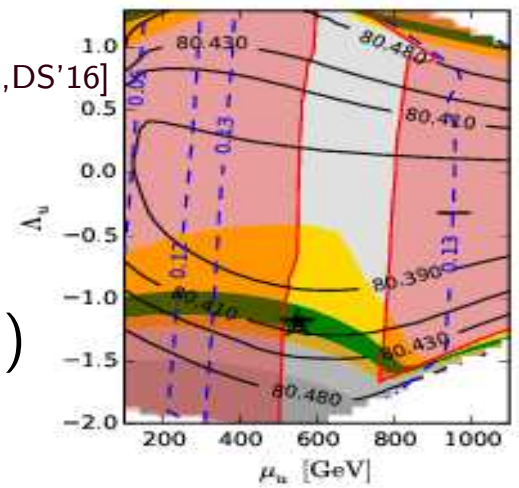
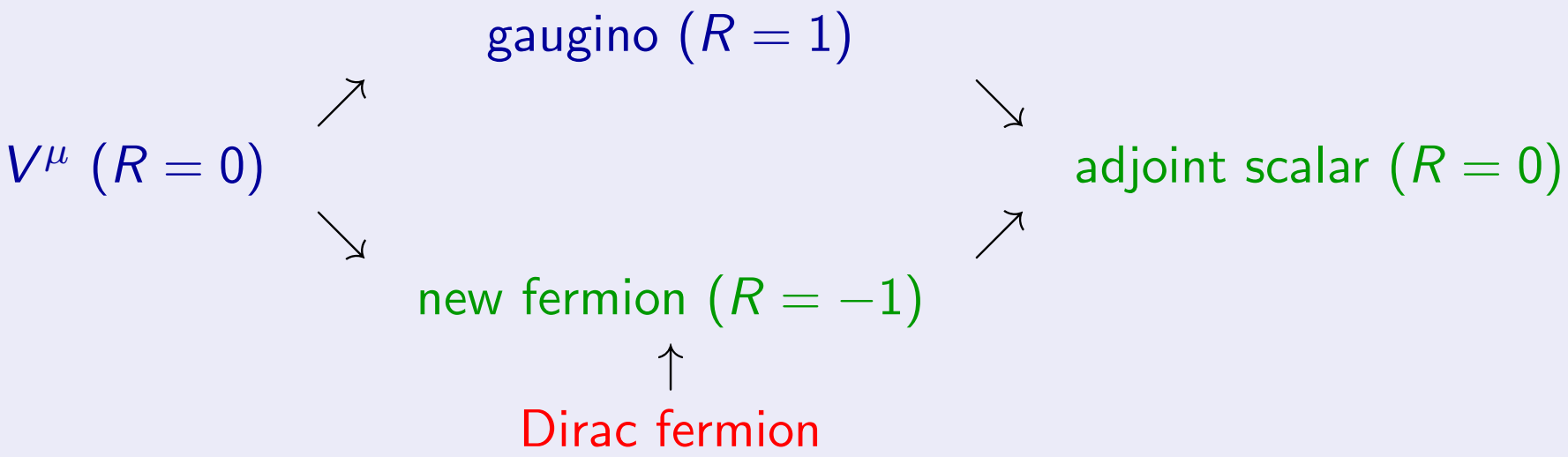


new SUSY multiplets with fixed properties



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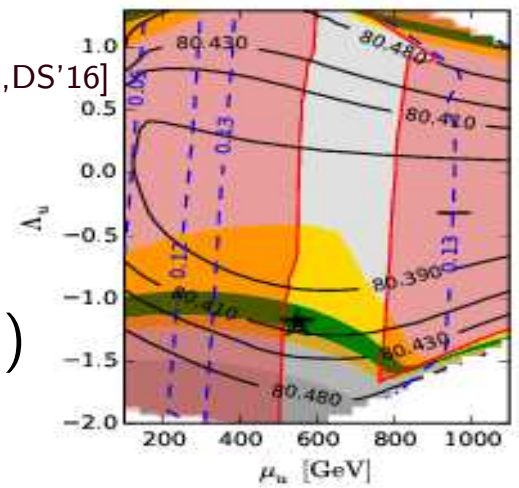
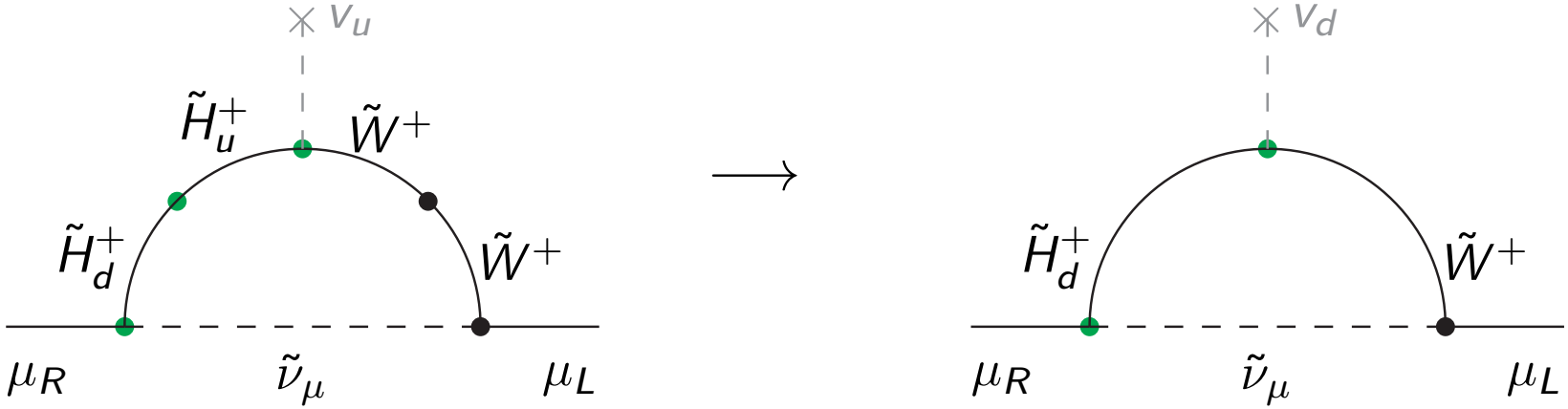


new Yukawa-like terms

$$W_{\text{MRSSM}} = \ldots + \Lambda_u \hat{H}_u \hat{T} \hat{R}_u + y_u \hat{Q} \hat{H}_u \hat{U}$$

Compare standard/R-symmetric SUSY



No enhancement by v_u any more!

$$a_\mu^{\mathrm{SUSY}} \propto \frac{\alpha}{4\pi}\frac{m_\mu^2\ \mu}{M_{\mathrm{SUSY}}^3}\underbrace{\frac{y_\mu\langle H_u\rangle}{m_\mu}}_{\tan\beta\ !} \longrightarrow \frac{\alpha}{4\pi}\frac{m_\mu^2}{M_{\mathrm{SUSY}}^2}\underbrace{\frac{y_\mu\langle H_d\rangle}{m_\mu}}_{1\ !}$$

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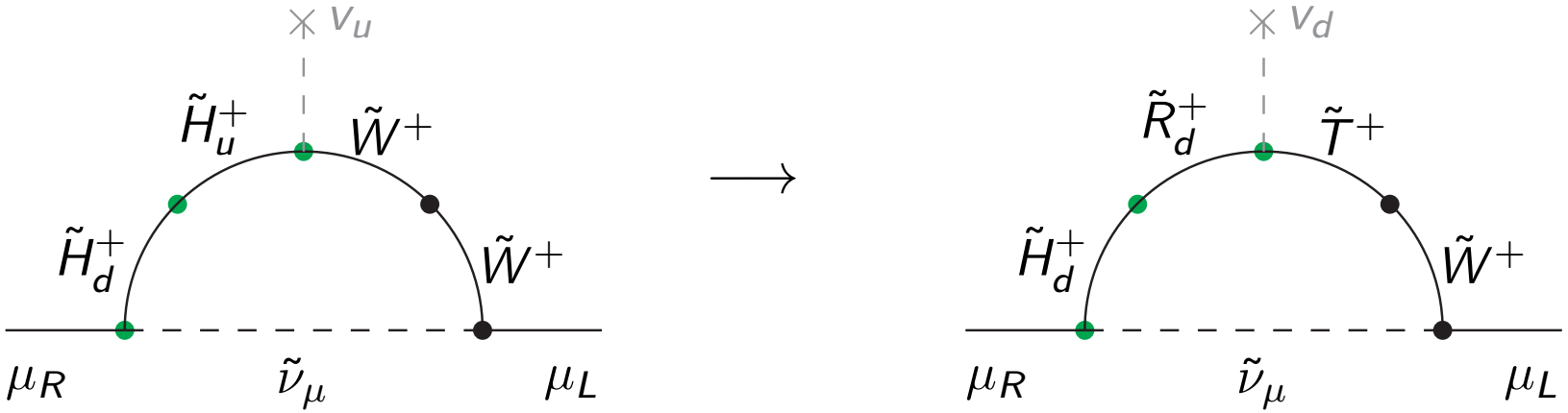

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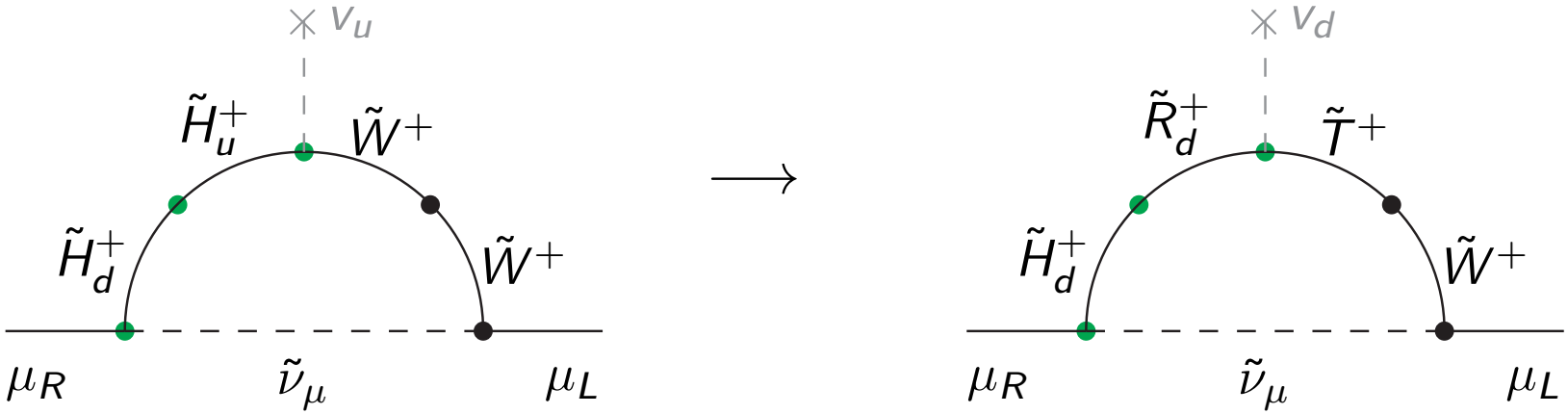

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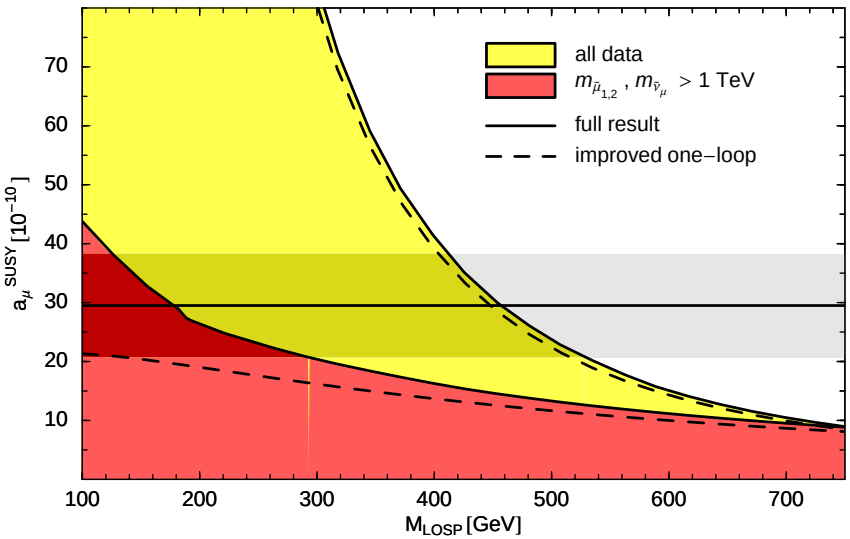
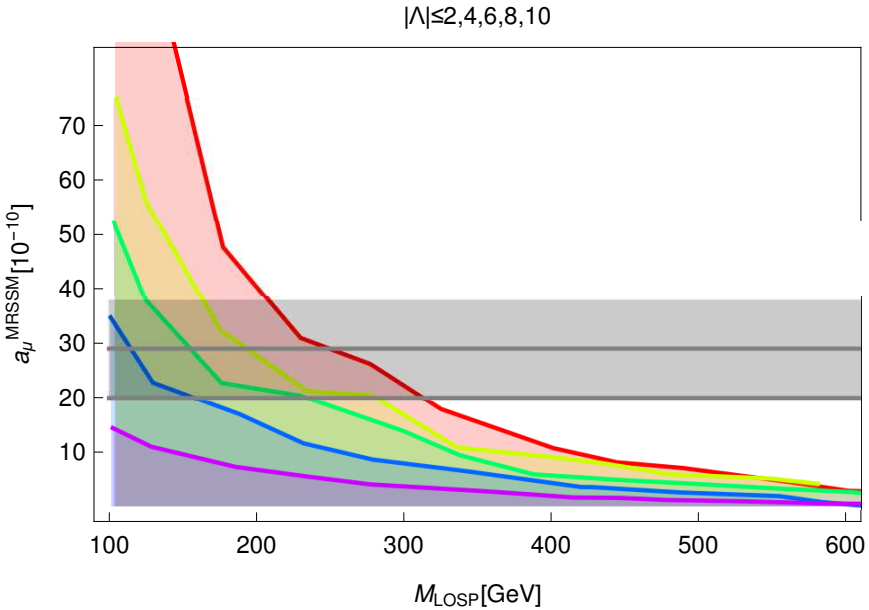


[DS '07]



[Kotlarski,Park,DS,Stöckinger-Kim]

Results and outlook

- Large a_μ in MRSSM for $m_{\mathrm{SUSY}} \sim 100 \ldots 300$ GeV and $\Lambda \gg 1$
- Otherwise, prediction: a_μ very small

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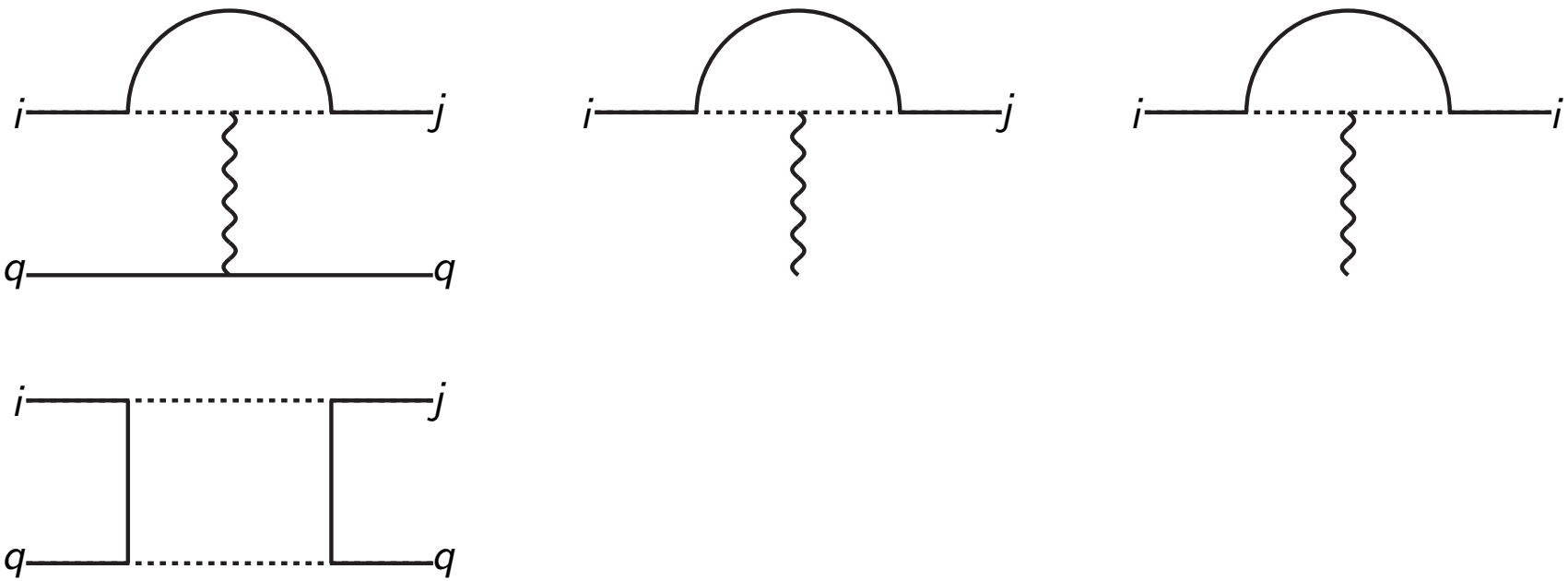
- Otherwise, prediction: a_μ very small
- Outlook: correlation with lepton flavour violation:

$\mu \to e$ $\quad$ $\mu \to e\gamma$ $\quad$ $(g-2)_\mu$



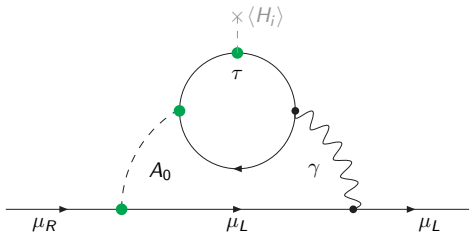
- For given $(g-2)$: $\mu \to e$ could be larger than in MSSM
- COMET bounds promising to restrict SUSY parameter space!

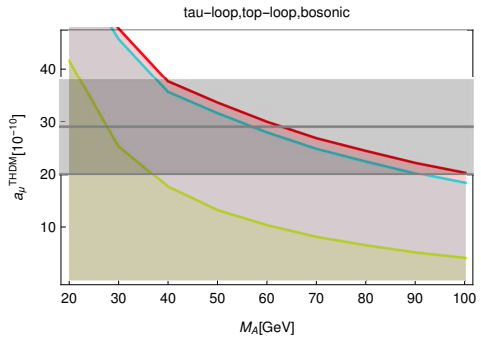
Outline

Conclusions

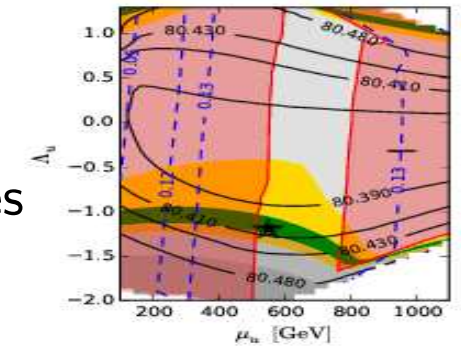
- Currently $a_\mu^{\rm Exp} - a_\mu^{\rm SM} \approx (28.1 \pm 6.3 \pm 3.6) \times 10^{-10}$
  - Experimental progress in sight: $6.3 \to 1.6$

- Two-Higgs doublet model
  - $g-2 \rightsquigarrow$ light A_0
  - non-Type X
  - large couplings to τ, t

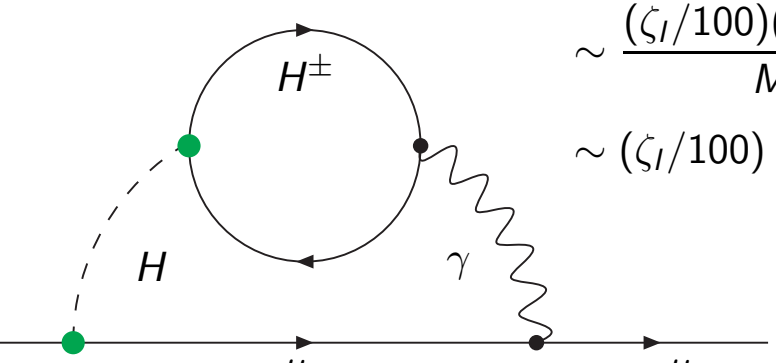




- R-symmetric SUSY
  - motivated by fundamental symmetry
  - explore phenomenology $\rightsquigarrow$ many pleasant surprises
  - very interesting interplay $g-2/\mu \to e\gamma/\mu \to e$



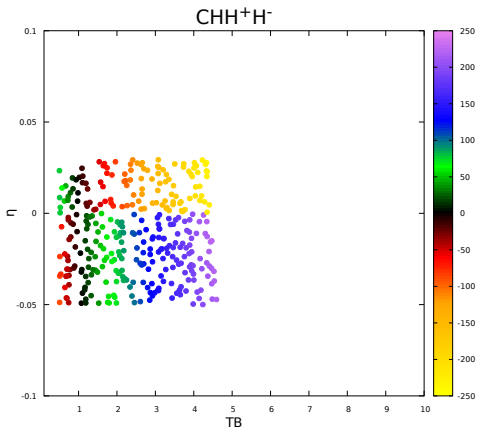
Backup: Two-Higgs Doublet Model: $H^{\pm}$-loop



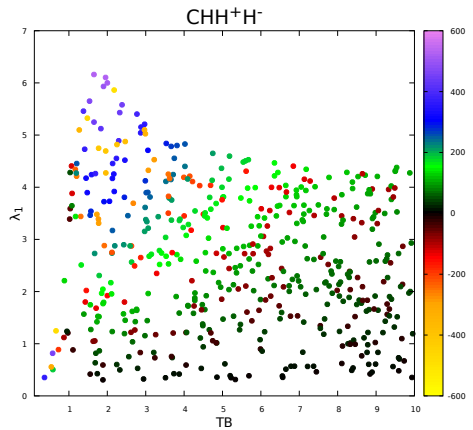
$$\sim \frac{(\zeta_l/100)(C^{HH^+H^-}/v)}{M^2_{H,H^{\pm}}}$$

$$\sim (\zeta_l/100) \times (-4 \ldots 4) \cdot 10^{-10}$$

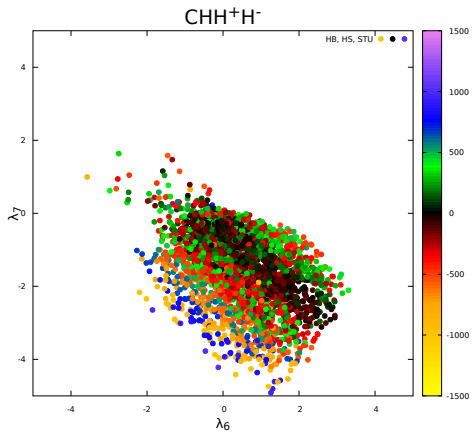
But: constraints on $M_{H,H^{\pm}}$, $C^{HH^+H^-}$ from $\Delta\rho$, direct searches, pert.-unitarity! And depends on generality of Higgs potential



$M_A = 40$, $M_{H,H^{\pm}} = 150$, λ_1 =fixed



$M_A = 80$, $M_{H,H^{\pm}} = 150$



$M_A = 80$, $\lambda_{6,7} \neq 0$

Promising: $gg \rightarrow$top-loop$\rightarrow H$, $H \rightarrow \tau\tau$ decay!

[Cherchiglia, DS, Stöckinger-Kim]

Large Higgs self couplings, $H \rightarrow A_0 A_0$ or $h \rightarrow A_0 A_0$ possible