$(g-2)_\mu$ at the two-loop level — large contributions from heavy squarks

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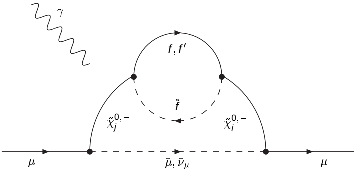
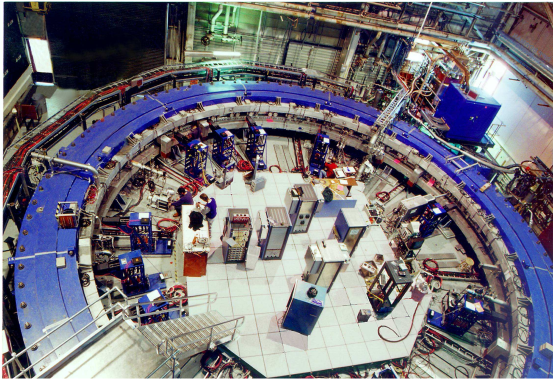
TU Dresden

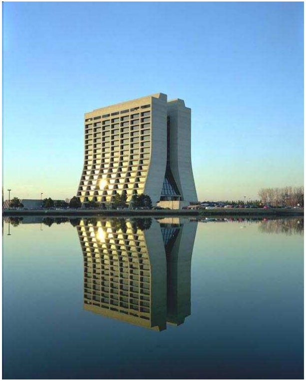


SUSY 2013, August 2013, Trieste

The Opportunity



$\Rightarrow$

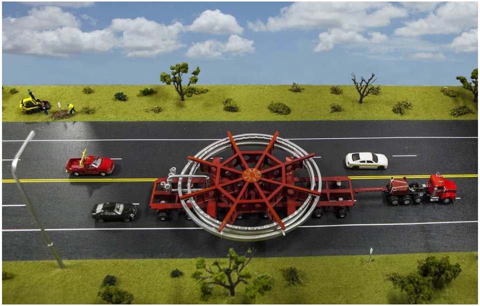


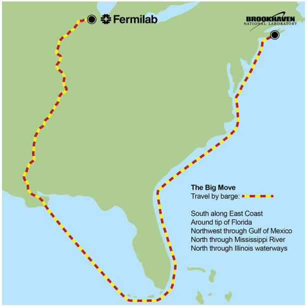
Data in 2016:

$$a_\mu^{\mathrm{Exp-SM}} = 28(8) \times 10^{-10}$$

$$\longrightarrow a_\mu^{\mathrm{Exp-SM}} = ???(1.6)_{\mathrm{Exp}}(3)_{\mathrm{SM}} \times 10^{-10}$$

becomes reality





29/09/12 Official CD-0 approval

24/06/13 Get started!

19/07/13 Past St. Louis

21/07/13 Arrived!

Outline

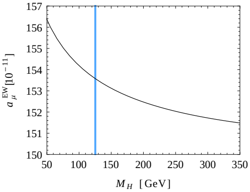
1. New Fermilab experiment
2. $g - 2$ is still important for low-energy SUSY
3. New $f\tilde{f}$-loop contributions
4. Large numerical effects

$a_\mu = (g-2)_\mu/2$ motivation

Also: recent SM theory progress:

- convergence of hadronic contributions [Davier et al; Hagiwara et al; Benayoun et al]
- QED 5-loop [Aoyama, Hayakawa, Kinoshita, Nio '12],
- weak (full 2-loop) with $M_H = 126$ GeV

  [Gnendiger, DS, Stöckinger-Kim '13]

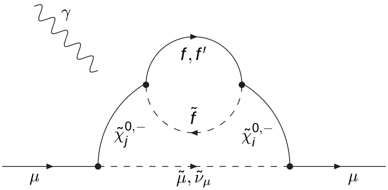


a_μ remains important constraint on SUSY…even after LHC results

- e.g. Constrained MSSM cannot explain a_μ any more
- tension motivates non-traditional models
  - e.g. sleptons$\ll$squarks $\Rightarrow$ split/hierarchical spectra

    [Endo, Hamaguchi, Iwamoto, Yanagida, D.P. Roy, et al]

The new contributions with $f\tilde{f}$ loops



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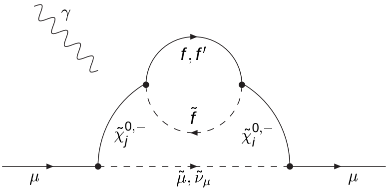

Motivation:

- Split spectra / Big step towards full 2-loop calculation
- remaining class with dependence on squarks
- maximum complexity: 5 heavy + 2 light scales
- computed exactly, including renormalization

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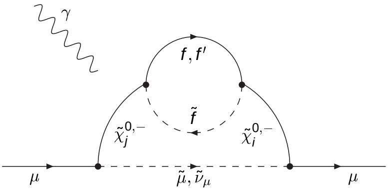

Motivation:

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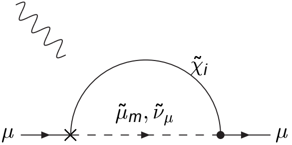
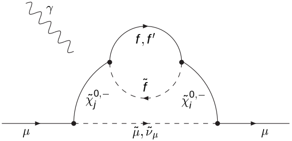
- known before:
  - SUSY corrections to SM 1L diagrams [Heinemeyer, DS, Weiglein '03,'04]
  - $\tan^2\beta$-corrections to SUSY 1L diagrams [Marchetti, Mertens, Nierste, DS '08]
  - photonic corrections to SUSY 1L diagrams [v. Weitershausen, Schäfer, Stöckinger-Kim, DS '10]
  - resulting theory error $\approx 3 \times 10^{-10}$ [DS '06]

Result contains large logs, $\Delta\rho$

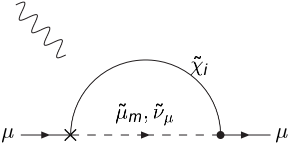
1. 

$\rightarrow a_\mu^{1L} \times \Delta\rho$

2. 

$\rightarrow a_\mu^{1L} \times \log(m_{\tilde{f}})$

Result contains large logs, $\Delta\rho$

1 

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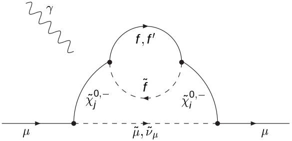
2 

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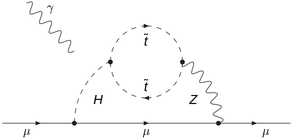
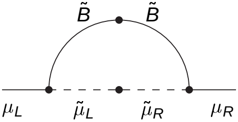
Old

3 

$\to a_\mu^{1L} \times \frac{1}{m_{\tilde{f}}^2}$

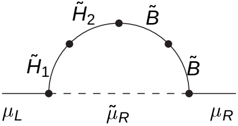
Results — first some one-loop results

1-loop bino



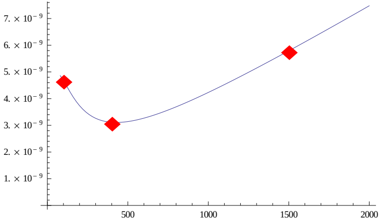
$\propto \mu$ for $\mu \to \infty$

1-loop $\tilde{\mu}_R$

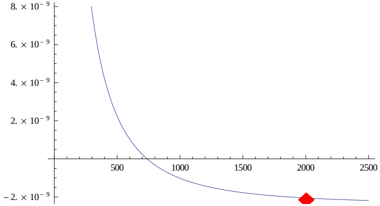


$\propto$ other sign!

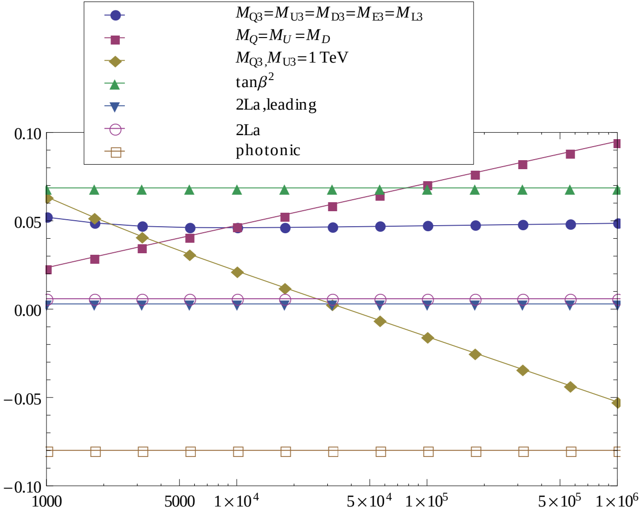
small/large μ



small/large $M_{\tilde{\mu}_L}$

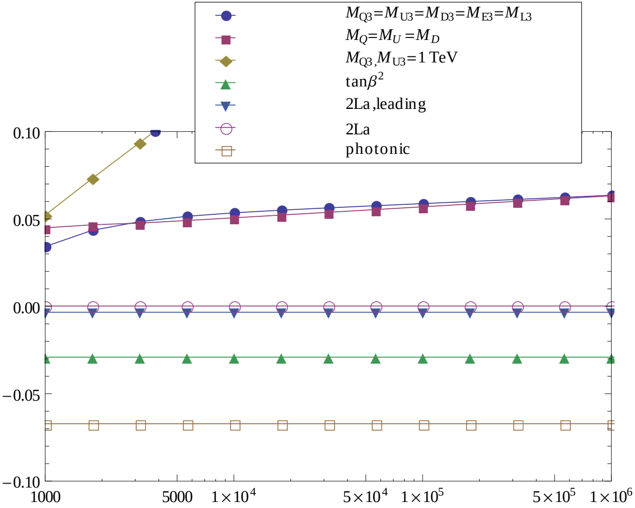


Results for $f\tilde{f}$-loops: Large contributions from heavy squarks



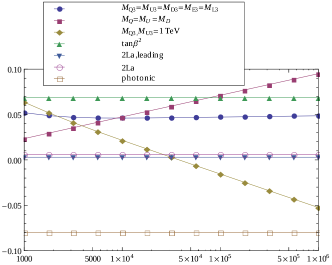
$$\mu = M_2 = 2M_1 = 300 \text{ GeV}, m_{\tilde{\mu}_{L,R}} = 400 \text{ GeV}, \tan\beta = 40$$

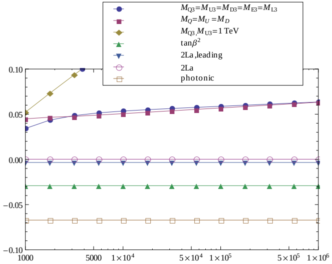
Results for $f\tilde{f}$-loops: Large contributions from heavy squarks



$$\mu = -M_1 = -150,\ m_{\tilde{\mu}_R} = 200,\ M_2 = m_{\tilde{\mu}_L} = 2000 \text{ GeV},\ \tan\beta = 50$$

Results for $f\tilde{f}$-loops: Large contributions from heavy squarks

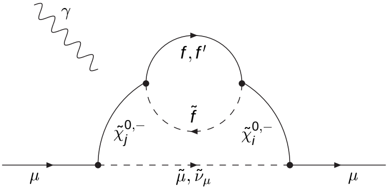


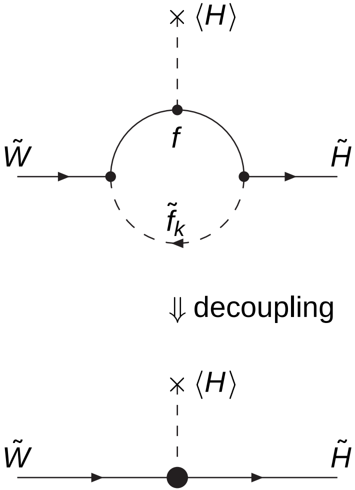


new $f\tilde{f}$-loop contributions

- compete with photonic, $\tan^2\beta$-corrections,
- can be largest 2L contribution $\mathcal{O}(10\%)$
  (for very heavy squarks)

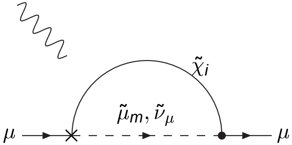
Where do these logs come from?





renormalizable but non-SUSY term in EFT

Contributions involving $\Delta\rho$

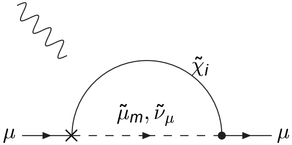


$$= a_\mu^{1\mathrm{L}} \times \left(\ldots + \frac{\delta(e^2/s_W^2)}{e^2/s_W^2} \right)$$
$$= a_\mu^{1\mathrm{L}} \times \left(\Delta\alpha - \frac{c_W^2}{s_W^2} \Delta\rho + \ldots \right)_{f,\tilde{f}\text{-loops}}$$

One-loop ambiguity

Fixed by full $2Lf\tilde{f}$ calculation

Contributions involving $\Delta\rho$



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One-loop ambiguity

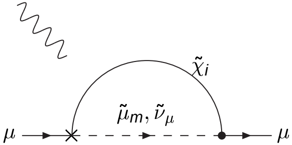
Fixed by full $2Lf\tilde{f}$ calculation

$$\left.\begin{array}{lll} a_\mu^{\mathrm{1L}} & = \alpha(0)\ldots & = 29.4 \\ a_\mu^{\mathrm{1L}} & = \alpha(M_Z)\ldots & = 31.6 \\ a_\mu^{\mathrm{1L}} & = \alpha(G_F)\ldots & = 30.5 \end{array}\right\}$$

differ by $\Delta\alpha$, $\Delta\rho$: 2L$f\tilde{f}$-terms

(for SPS1a, unit: 10^{-10})

Contributions involving $\Delta\rho$



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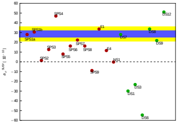
Fixed by full $2Lf\tilde{f}$ calculation

$$a_\mu^{{\rm 1L+2L}f\tilde{f}} = 32.2$$

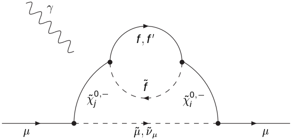
differ by $\Delta\alpha$, $\Delta\rho$: $2\mathrm{L}f\tilde{f}$-terms

(for SPS1a, unit: 10^{-10})

Summary

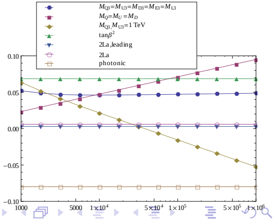


- a_μ still viable, complementary constraint on SUSY
  - motivates split scenarios



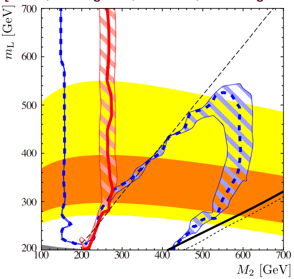
- $a_\mu^{2Lf\tilde{f}}$ computed
  - first full calculation of a_μ^{SUSY} 2L 5-scale diagrams
  - elegant results

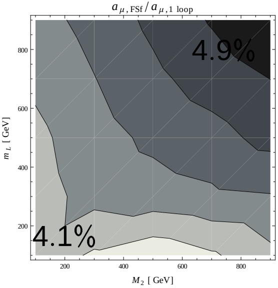
- New contributions are relevant particularly for heavy squarks
  - fix 1L ambiguity $\alpha(0) \leftrightarrow \alpha(M_Z) \leftrightarrow \alpha(G_F)$
  - $\log(m_{\tilde{f}})$-enhanced
  - up to $\mathcal{O}(10\%)$



Further numerical examples

Point 4 from [Endo,Hamaguchi,Iwamoto,Yoshinaga '13]





- 2L$f\tilde{f}$ contributions under control, two very different calculations
- decreases theory uncertainty
- numerically significant particularly for split spectra

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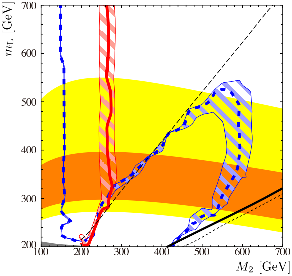

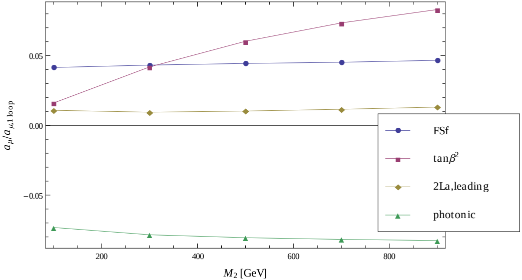

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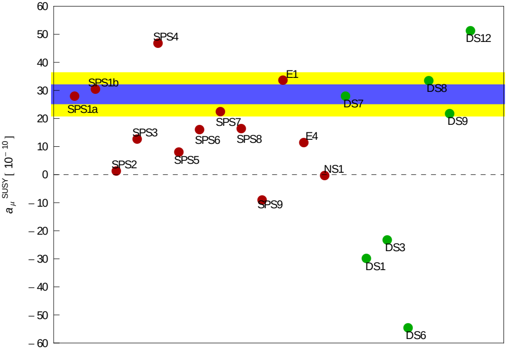
a_μ central complement for SUSY parameter analyses

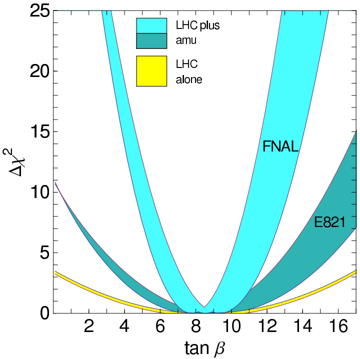


SPS benchmark points

LHC Inverse Problem (300fb^{-1}) can't be distinguished at LHC [Sfitter: Adam, Kneur, Lafaye, Plehn, Rauch, Zerwas '10]

- a_μ sharply distinguishes SUSY models
- breaks LHC degeneracies (before Linear Collider!)

a_μ central complement for SUSY parameter analyses



[Hertzog, Miller, de Rafael, Roberts, DS '07]

$\tan\beta = \frac{v_2}{v_1}$
central for understanding EWSB

LHC: $(\tan\beta)^{\text{LHC,masses}} = 10 \pm 4.5$ bad
[Sfitter: Lafaye, Plehn, Rauch, Zerwas '08, assume SPS1a]

a_μ improves $\tan\beta$ considerably
Also complementary to LC!

vision: test universality of $\tan\beta$, like for $\cos\theta_W = \frac{M_W}{M_Z}$ in the SM:

$$(t_\beta)^{a_\mu} = (t_\beta)^{\text{masses}} = (t_\beta)^H = (t_\beta)^b?$$