First Row CKM Unitarity Tests and the MSSM

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Motivation

New physics discovered at the LHC may be hard to pin down. High precision tests may be needed. However, the precision of the LHC is limited.

Low energy observables provide a relatively unexplored route for constraining new physics. First row CKM unitarity tests are a possible avenue.

We are constraining the parameters of the MSSM through first row CKM unitarity tests.

First Row CKM Unitarity

CKM unitarity in the Standard Model demands that
$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1.$

Physics beyond the Standard Model can lead to actual or apparent violations of this relation.

An actual violation can occur when there is an extra generation.

An apparent violation occurs when the measured values of CKM matrix elements are not the true values. Standard Model assumptions go into matrix element measurements.

Measuring V_{ud}

V_{ud} is determined from the Fermi constant G_V^β for beta decay. The measured value of V_{ud} is

$$V_{ud}^{(\text{measured})} = \frac{G_V^\beta}{G_\mu(1 + \Delta r_\beta^{(SM)} - \Delta r_\mu^{(SM)})}$$

The weak coupling is measured from G_μ: the Fermi constant for muon decay. The quantities $\Delta r_\beta^{(SM)}$ and $\Delta r_\mu^{(SM)}$ are Standard Model corrections to G_V^β and G_μ. These are not the true values, if new physics contributes to $\Delta r_\beta^{(V)}$ and Δr_μ.

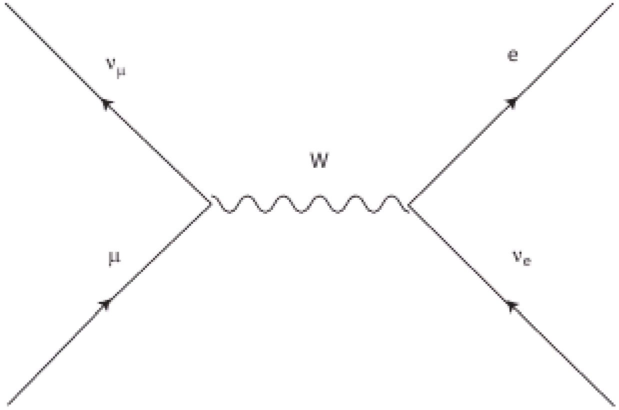
Hence, the measured value of V_{ud} may not be the actual value. Apparent violations of CKM unitarity can occur.

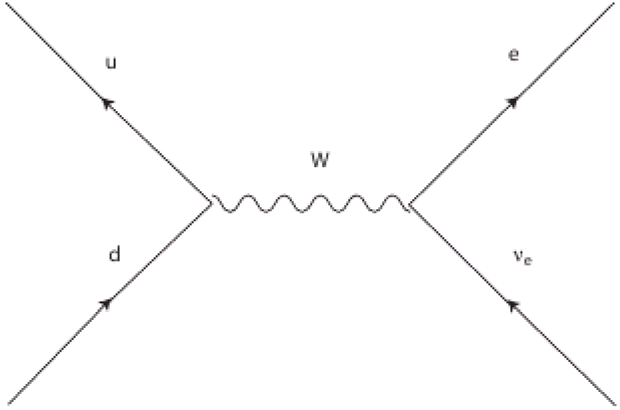
MSSM Corrections to the Fermi Constant

The MSSM might lead to an apparent violation of first-row CKM unitarity. We computed MSSM corrections to $\Delta r_\beta^{(V)} - \Delta r_\mu$, in order to constrain the parameter space of the theory.

We assumed R-parity, and calculated corrections at one-loop order.

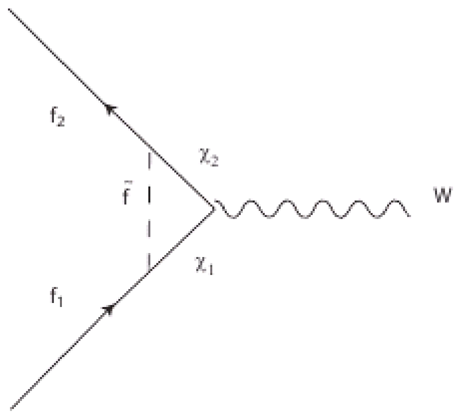
Muon and Beta Decay

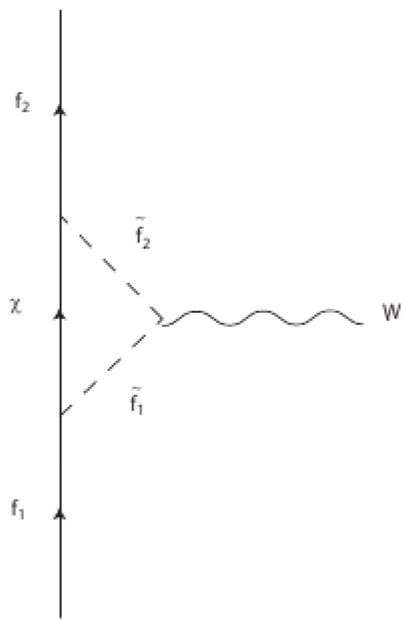


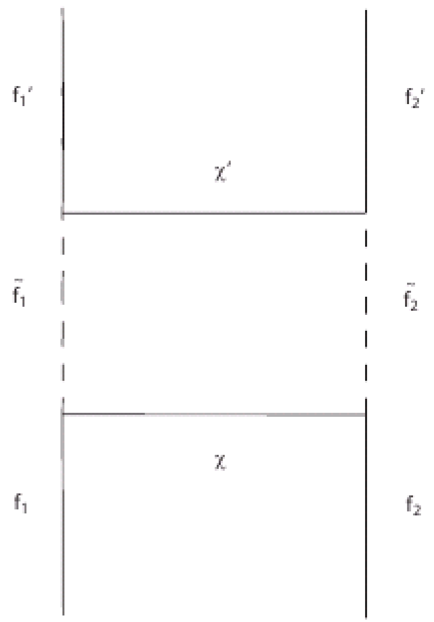


Superpartner loops enter external leg, vertex and box graphs.
Vacuum polarization diagrams cancel in $\Delta r_\beta^{(V)} - \Delta r_\mu$. Regulator dependence cancels as well.

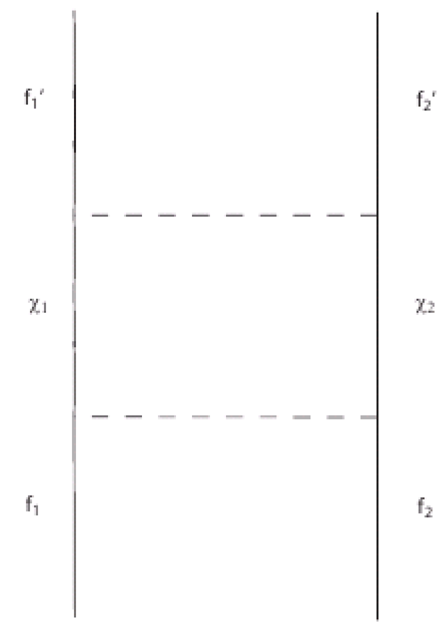
Example Graphs







f1′
f2′
χ′
f̃1
f̃2
χ
f1
f2



f1′
f2′
χ1
χ2
f1
f2

Our Setup

We wrote a code to scan over the parameter space of the MSSM.

For every point of parameter space in the scan, our code diagonalized gauginos and Higgsinos into charginos and neutralinos, and diagonalized slepton and squark masses.

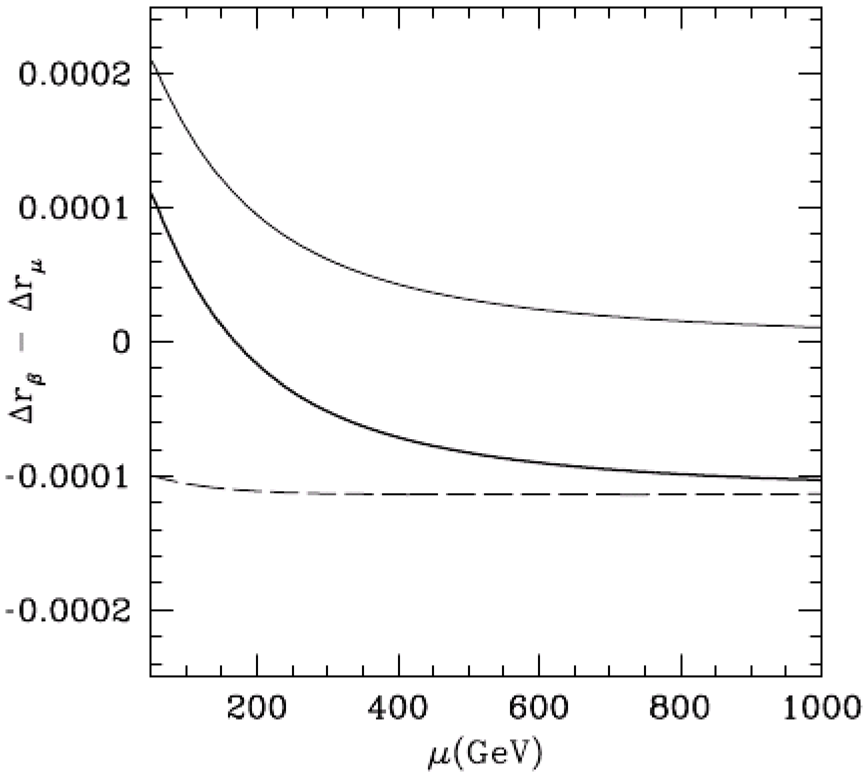
Our code computed MSSM corrections to $\Delta r_\beta^{(V)}$ and Δr_μ from all one-loop diagrams, in the chargino-neutralino basis.

Our code output plots of $\Delta r_\beta^{(V)} - \Delta r_\mu$, as functions of the parameters in the scan. These plots represent MSSM corrections to the Fermi constant, which would show up as apparent violations of first row CKM unitarity.

Dark solid line:
Total correction

Light solid line:
Vertex and external leg contribution

Dashed line: Box graph contribution

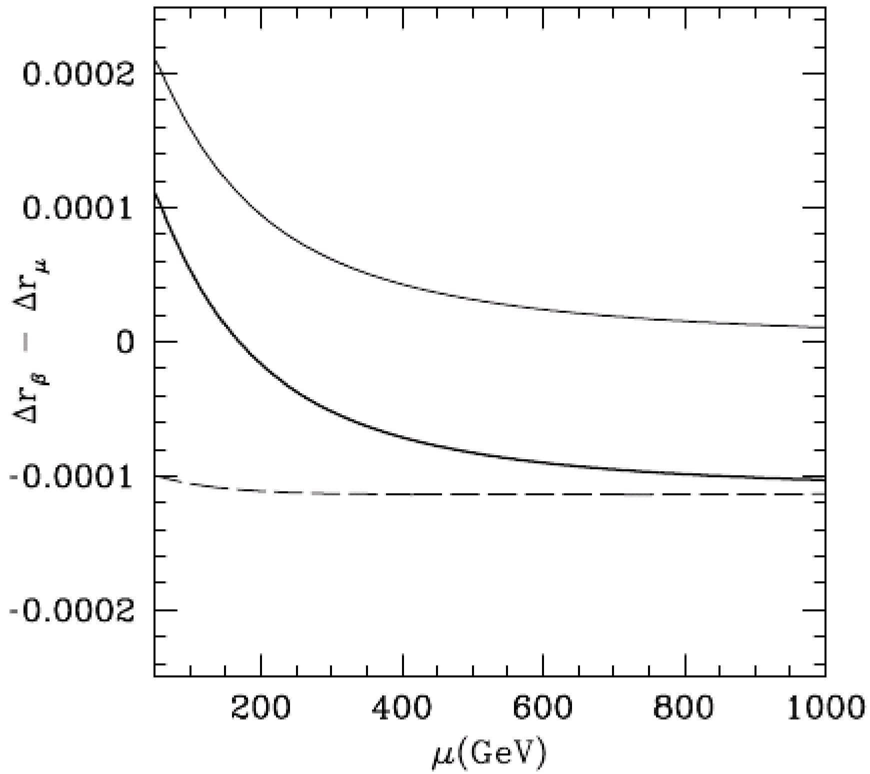


The box graph contribution has the opposite sign as the contribution from the vertex and external leg. Cancellation occurs between them for small values of μ, because they have similar sizes. In the limit of large μ, vertex and external leg contributions cancel, because but the box graph does not. The total correction is maximized in this limit.

Dark solid line:
Total correction

Light solid line:
Vertex and external leg contribution

Dashed line: Box graph contribution



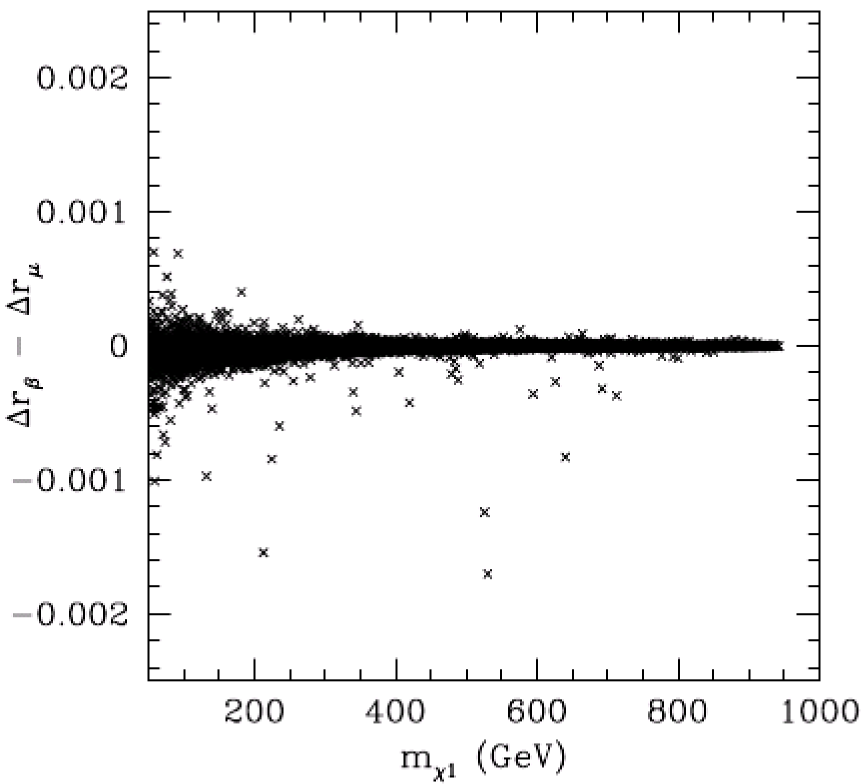
M_1 = 100 GeV, M_2 = 150 GeV, M_3 = 1000 GeV, tan β = 1. The diagonal elements of mL and mR are 200 GeV, and the off-diagonal elements vanish. The diagonal elements of mQ, mU and mD are 500 GeV, and the off-diagonal elements vanish.

$A_l = A_l' = A_u = A_u' = A_d = A_d' = 0$.

The total correction can be on the order of 10^{-4}.

There are some regions of parameter space where the correction appears to be several times larger than what is shown in our plot. We are checking whether these regions are in agreement with known constraints.

Work in progress. . . .


0.002
0.001
0
−0.001
−0.002
$\Delta r_\beta - \Delta r_\mu$
200
400
600
800
1000
$m_{\chi 1}$ (GeV)

Hadronic Uncertainties

$\Delta r_\beta^{(SM)} - \Delta r_\mu^{(SM)} = (2.361 \pm 0.038)\mathrm{x}10^{-2}$.

The uncertainty is dominated by hadronic effects, and is of a similar size as SUSY corrections.

Calculations of the hadronic contributions have undergone remarkable progress in recent years. Marciano and Sirlin recently developed a new technique which reduced hadronic uncertainties by a factor of 2 [Phys. Rev. C **79**, 05550 (2009); arXiv:0812.1202].

Further reductions in hadronic uncertainties might allow SUSY corrections to constrain the MSSM.

Cross Checks

Kurylov and Ramsey-Musolf computed SUSY corrections to the Fermi constant in certain limits [Phys. Rev. Lett. **88**, 071804 (2002); hep-ph/0109222]. Our code reproduces their results in these limits.

Ramsey-Musolf, Su and Tulin performed a scan over the parameter space of the MSSM, to compute SUSY corrections to $\Gamma(\pi^+ \to e^+ \nu_e)/\Gamma(\pi^+ \to \mu^+ \nu_\mu)$ [Phys. Rev. D **76**, 095017 (2007); arXiv:0705.0028]. The computation is similar to that of beta decay. We modified our code, to compute this ratio. Our results are in agreement.

We checked that our code works as expected in the limit of no spontaneous symmetry breaking.

Conclusions

Low-energy precision tests provide new probes to physics beyond the Standard Model. Beta decay is an exciting avenue. New physics corrections to the Fermi constant for beta decay would manifest as apparent violations of CKM unitarity. Nuclear physics effects do not limit the usefulness of beta decay, because current conservation constrains form factors.

We scanned over the parameter space of the MSSM, and computed SUSY corrections to the Fermi constant for beta decay. Effects are on the order of 10^{-4}.

Hadronic uncertainties are of a similar magnitude as SUSY effects. However, remarkable calculational progress is being made, with the hadronic uncertainty recently being reduced by a factor of 2.

Our scans reproduce other results in the literature and agree with expected limiting cases.