First Row CKM Unitarity Tests and the MSSM

Sky Bauman
University of Wisconsin-Madison

Work in Collaboration with Michael Ramsey-Musolf

Motivation

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

We are computing MSSM corrections to the CKM matrix element V_{ud}, as measured from beta decay. This determines the benchmark of precision for CKM unitarity tests to constrain the MSSM.

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}

The matrix element 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}.

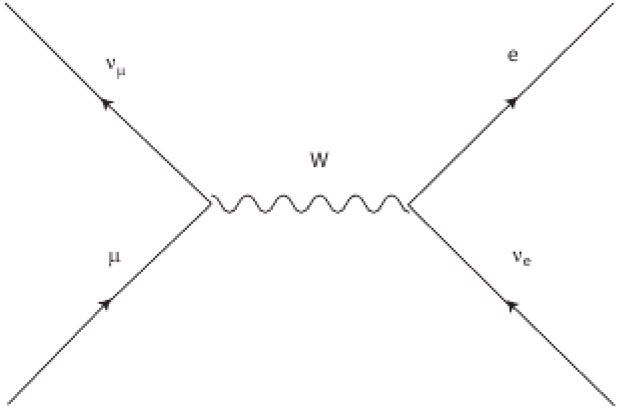
Hence, the measured value of V_{ud} may not be the actual value. Apparent violations of CKM unitarity can occur.

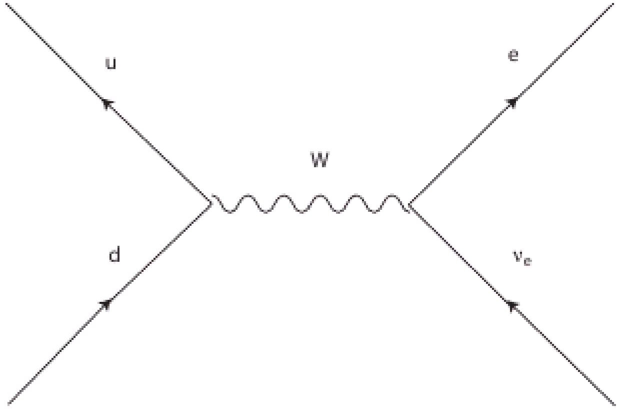
MSSM Corrections to the Fermi Constant

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 the hope of constraining the parameter space of the model.

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

Muon and Beta Decay

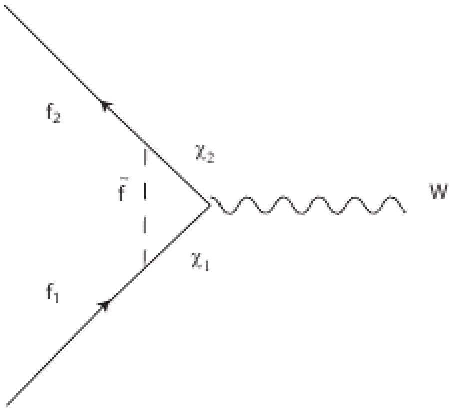


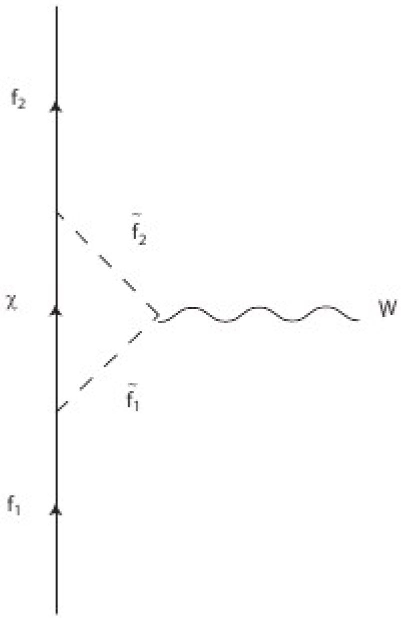


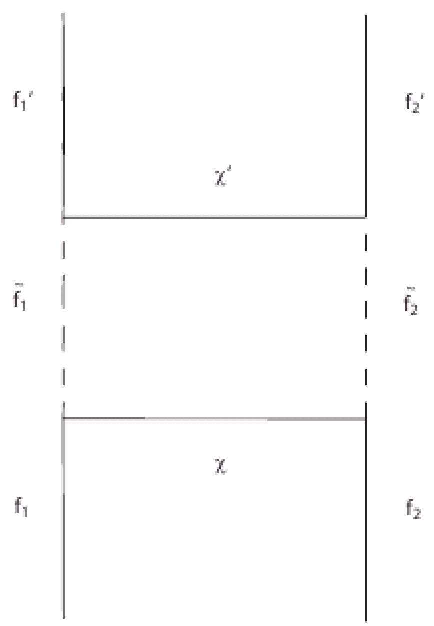
Superpartner loops enter external leg, vertex and box graphs.

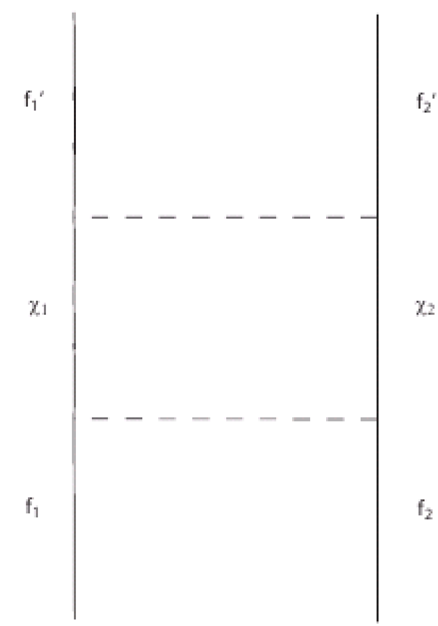
Vacuum polarization diagrams cancel in $\Delta r_\beta^{(V)} - \Delta r_\mu$. Regulator dependence cancels as well.

Example Graphs






f1′
f2′
χ′
f̃1
f̃2
χ
f1
f2

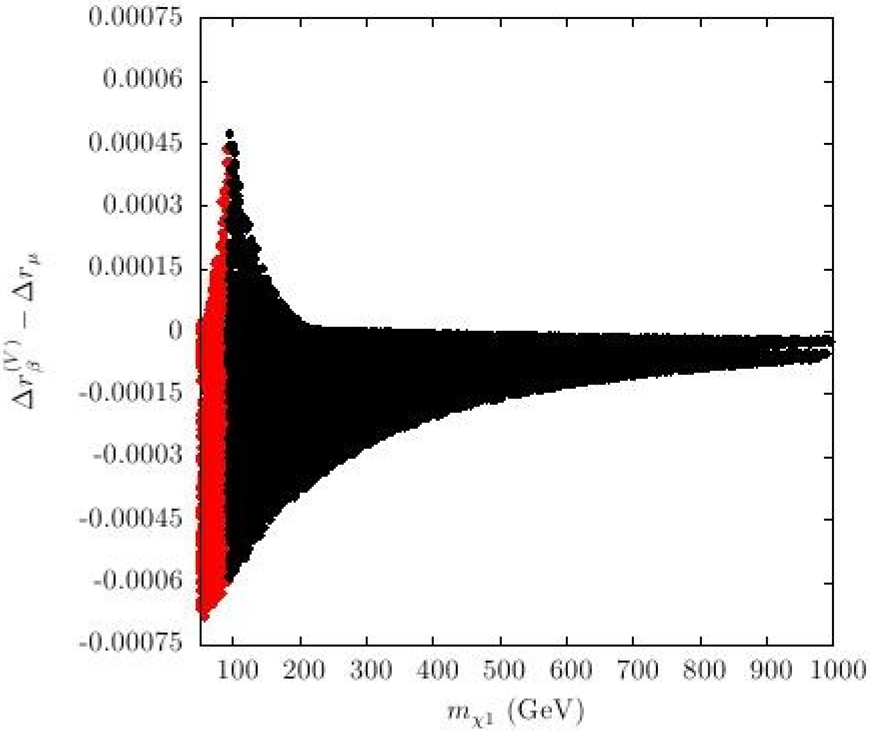

f1′
f2′
χ1
χ2
f1
f2

Our Setup

- We wrote a code to scan over parameters of the MSSM.
- For every point of parameter space in the scan, our code diagonalizes gauginos and Higgsinos into charginos and neutralinos, and diagonalizes slepton and squark masses.
- Our code computes MSSM corrections to $\Delta r_\beta^{(V)}$ and Δr_μ from all one-loop diagrams, in the chargino-neutralino basis.
- Our code outputs 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.

Results

- The correction $\Delta r^{(V)}_{\beta} - \Delta r_{\mu}$ is on the order of 10^{-4}. This is of a similar size as the current uncertainty in V_{ud} measurements.
- Corrections are maximized when there is a large difference between first generation squark and second generation slepton masses. (Either $\Delta r^{(V)}_{\beta}$ or Δr_{μ} is suppressed in the difference, $\Delta r^{(V)}_{\beta} - \Delta r_{\mu}$.)
- We analyzed correlations between MSSM corrections to beta decay and leptonic pion decay. These correlations can be non-trivial.



50 GeV < M_1, $|M_2|$, $|\mu|$ < 1000 GeV, M_3 = 10 TeV, tan β = 1.
Slepton masses = 110 GeV, squark masses = 10 TeV, left-right sfermion mass mixings vanish.

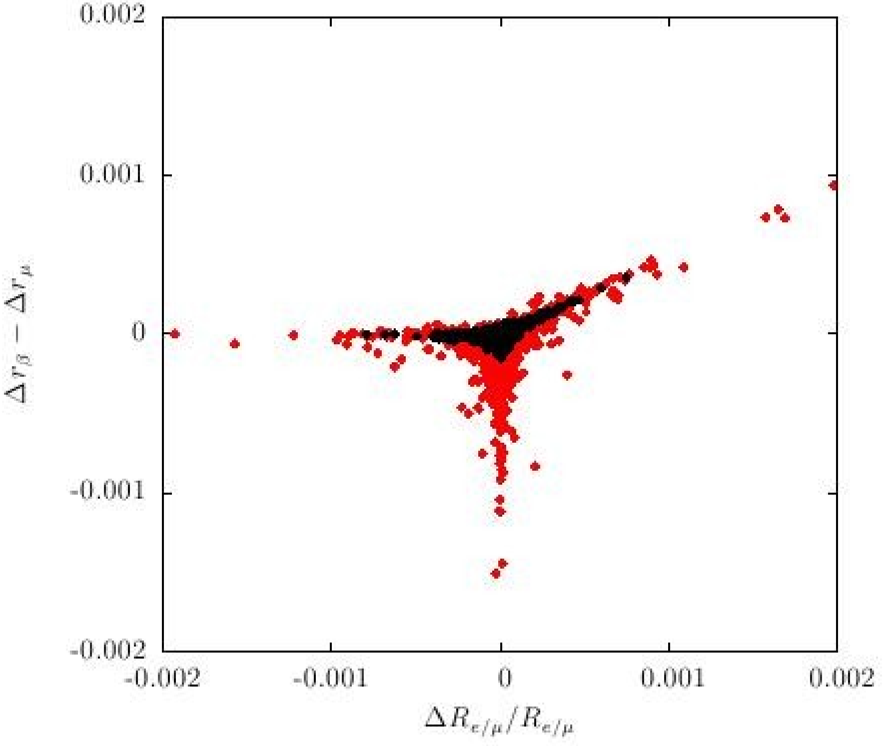
Points inside current bounds on superparticle masses and oblique parameters are black. Points outside current bounds are red.

A previous analysis by Ramsey-Musolf, Su and Tulin computed MSSM corrections to $R_{e/\mu} = \Gamma(\pi^+ \to e^+\nu_e)/\Gamma(\pi^+ \to \mu^+\nu_\mu)$ as a function of MSSM parameters [Phys. Rev. D **76**, 095017 (2007); arXiv:0705.0028].

Results are parametrized as $\Delta R_{e/\mu}/R_{e/\mu}$. ($\Delta R_{e/\mu}$ is the MSSM correction to $R_{e/\mu}$.)

We reproduced these results.

We computed correlations between $\Delta r_\beta^{(V)} - \Delta r_\mu$ and $\Delta R_{e/\mu}/R_{e/\mu}$. These correlations can constrain MSSM parameters, and help distinguish the MSSM from other models.

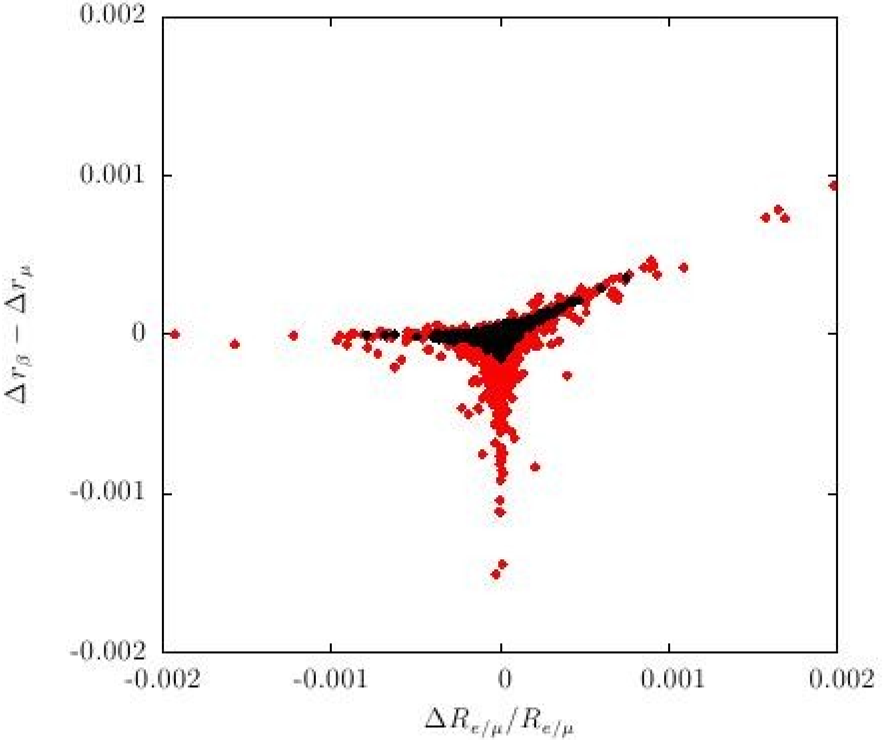


Correlations between β-decay and leptonic pion decay can be non-trivial.

45 GeV < M_1, $|M_2|$, $|\mu|$, m_{uL} < 1000 GeV.

45 GeV < $m_{\nu e}$, $m_{\nu\mu}$ < 5000 GeV.

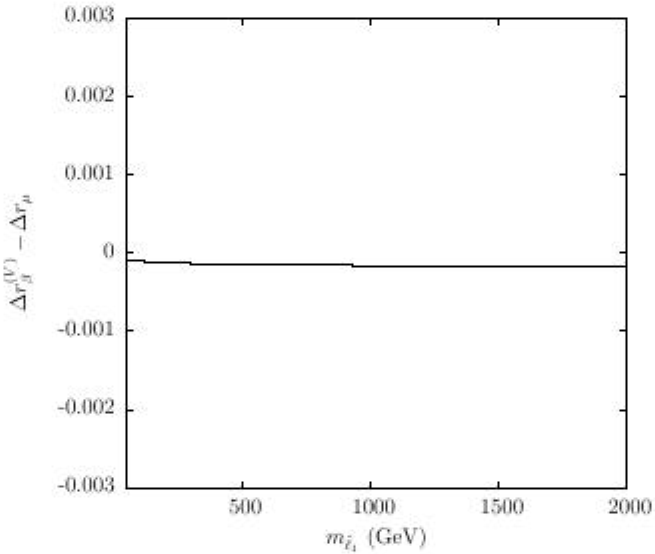
1 < tan β < 50.



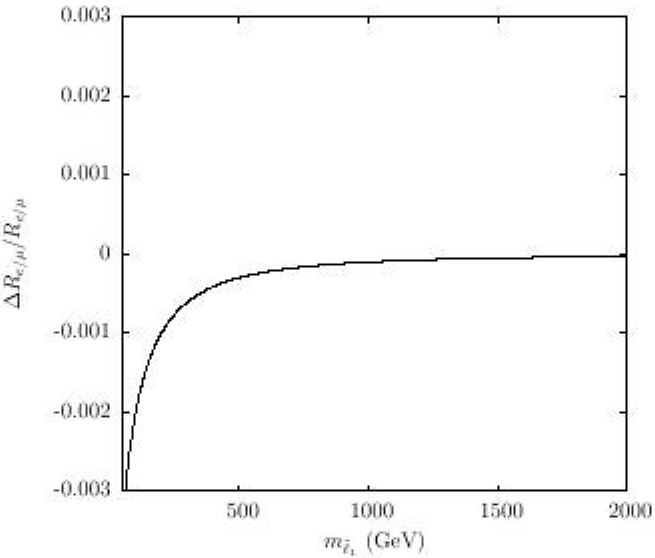
Both $\Delta r_\beta - \Delta r_\mu$ and $\Delta R_{e/\mu}/R_{e/\mu}$ are positively enhanced in the limit of small second generation slepton mass.

The quantity $\Delta R_{e/\mu}/R_{e/\mu}$ is negatively enhanced in the limit of a small first generation slepton mass, but $\Delta r_\beta - \Delta r_\mu$ receives no enhancement.

The quantity $\Delta r_\beta - \Delta r_\mu$ is negatively enhanced in the limit of a small first generation squark mass, but $\Delta R_{e/\mu}/R_{e/\mu}$ receives no enhancement.

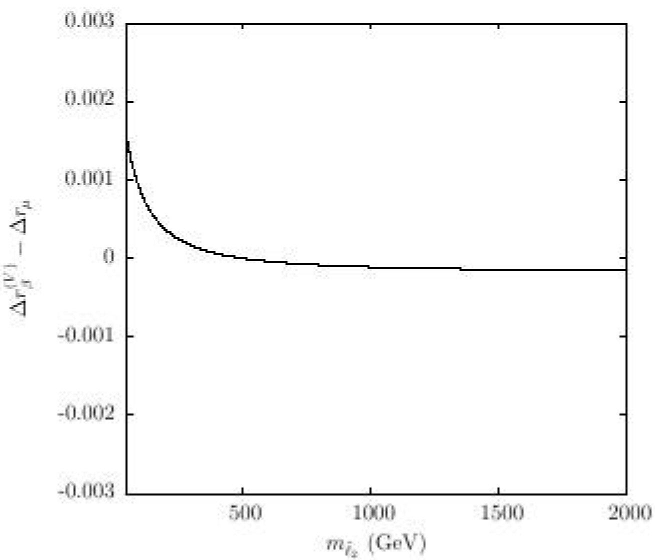


(a) $\Delta r_\beta^{(V)} - \Delta r_\mu$ vs. $m_{\tilde{\ell}_1}$.

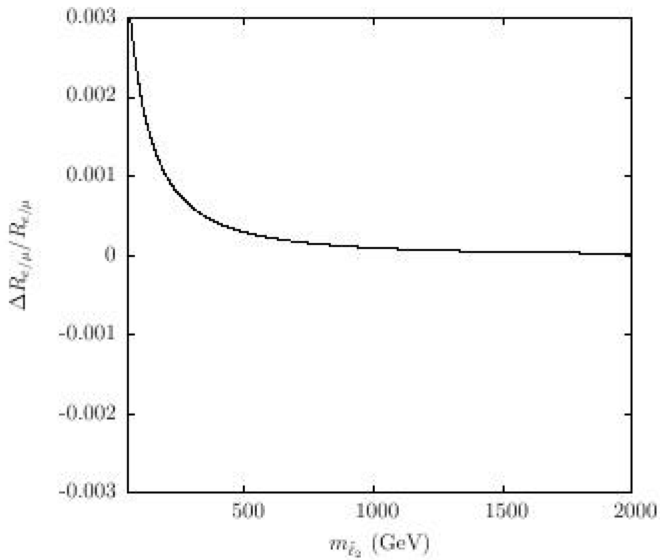


(b) $\Delta R_{e/\mu}^{(SUSY)}/R_{e/\mu}$ vs. $m_{\tilde{\ell}_1}$.

$M_1 = M_2 = \mu = 45$ GeV, $M_3 = 10$ TeV, $\tan\beta = 1$, $m_{L3} = m_{Q2} = m_{Q3} = 10$ TeV. $m_{L2} = 5$ TeV, $m_{Q1} = 500$ GeV.

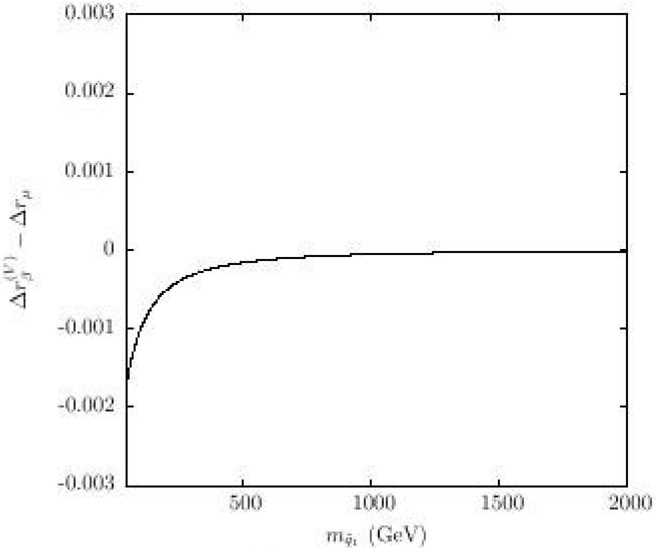


(c) $\Delta r_\beta^{(V)} - \Delta r_\mu$ vs. $m_{\tilde{\ell}_2}$.

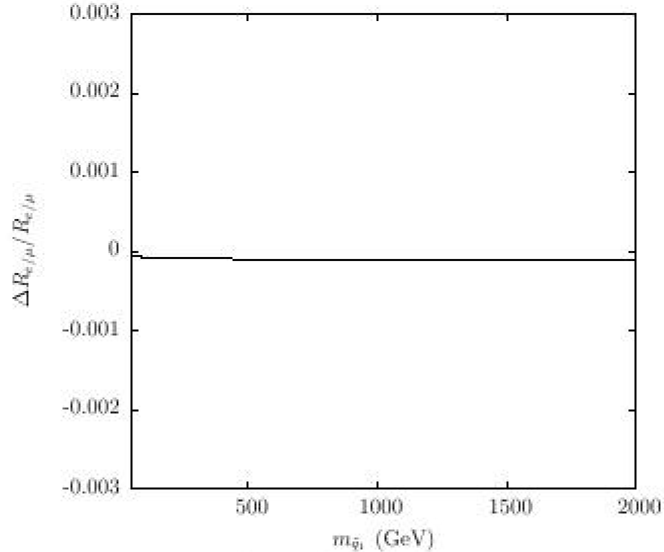


(d) $\Delta R_{e/\mu}^{(SUSY)}/R_{e/\mu}$ vs. $m_{\tilde{\ell}_2}$.

$M_1 = M_2 = \mu = 45$ GeV, $M_3 = 10$ TeV, $\tan\beta = 1$, $m_{L3} = m_{Q2} = m_{Q3} = 10$ TeV. $m_{L1} = 5$ TeV, $m_{Q1} = 500$ GeV.



(e) $\Delta r_\beta^{(V)} - \Delta r_\mu$ vs. $m_{\tilde{q}_1}$.



(f) $\Delta R_{e/\mu}^{(SUSY)}/R_{e/\mu}$ vs. $m_{\tilde{q}_1}$.

$M_1 = M_2 = \mu = 45$ GeV, $M_3 = 10$ TeV, $\tan\beta = 1$, $m_{L3} = m_{Q2} = m_{Q3} = 10$ TeV.
$m_{L1} = 1$ TeV, $m_{L2} = 5$ TeV.

Hadronic Uncertainties

$\Delta r_\beta^{(SM)} - \Delta r_\mu^{(SM)} = (2.361 \pm 0.038)\mathrm{x}10^{-2}$ [Phys. Rev. C **79**, 05550 (2009); arXiv:0812.1202].

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. Lett. **96**, 032002 (2006); arXiv:hep-ph/0510099]

Further reductions in hadronic uncertainties might allow beta decay 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.

- As mentioned previously, Ramsey-Musolf, Su and Tulin performed a scan over the parameter space of the MSSM, to compute SUSY corrections to $\Gamma(\pi^+ \to e^+\nu_e)/\Gamma(\pi^+ \to \mu^+\nu_\mu)$. 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 electroweak 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.

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

We computed correlations between MSSM corrections to beta decay and pion decay, and found that these can be non-trivial. These correlations can help pin down the parameters of the MSSM or distinguish the scenario from other models.

The current uncertainty in $\Delta r_\beta^{(SM)} - \Delta r_\mu^{(SM)}$ is 3.8×10^{-4}, and is dominated by hadronic effects. Remarkable calculational progress is being made, with the hadronic uncertainty recently being reduced by a factor of 2.

Loop corrections to beta decay are at the 10^{-4} level: the threshold for constraining the MSSM.