Supersymmetry and NuTeV

One loop corrections from the minimal supersymmetric standard model to deep inelastic Neutrino Nucleon scattering at the NuTeV experiment.

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Outline

- Introduction to Supersymmetry and the MSSM
  - Motivation
  - Basic Features of Susy
  - The MSSM
- Neutrino Nucleon Scattering and NuTeV
- Susy loop corrections for NuTeV

Standard model successful but has problems

- fine tuning problem
- hierarchy problem
- too many Parameters to be believed to be fundamental
- gravitation can not be included
- ...

Look for new effective field theory that:

- ➢ reproduces SM for lower energies
- ➢ is renormalizable
- ➢ S-matrix is physical

- yields predictions that are accessible by experiment
- provides possible way towards Gravity
- ...

Try to extend Algebra of SM

$$[P_\mu, P_\nu] = 0$$

$$[P_\mu, M_{\rho\sigma}] = i(g_{\mu\rho}P_\sigma - g_{\mu\sigma}P_\rho)$$

$$[M_{\mu\nu}, M_{\rho\sigma}] = i(g_{\nu\rho}M_{\mu\sigma} - g_{\nu\sigma}M_{\mu\rho} - g_{\mu\rho}M_{\nu\sigma} + g_{\mu\sigma}M_{\nu\rho})$$

} Poincare Algebra

Coleman- Mandula: No Go theorem

Ansatz:

~~$[C_a, C_b] = X^{?}_{ab}$~~

~~$[C_a, P_\mu] = ?_{a\mu} \neq 0$~~

} Symmetry that does not commute with Poincare Algebra

$$[B_a, B_b] = f_{ab}{}^{c} B_c$$

$$[B_a, P_\mu] = 0$$

} Algebra of inner (Gauge) Symmetry

any extension like this leads to
unphysical unphysical S-matrix.
- Infinite Number of particles...

BUT

Other extension of SM Algebra

$$[P_\mu, P_\nu] = 0$$

$$[P_\mu, M_{\rho\sigma}] = i(g_{\mu\rho}P_\sigma - g_{\mu\sigma}P_\rho)$$

$$[M_{\mu\nu}, M_{\rho\sigma}] =$$

$$i(g_{\nu\rho}M_{\mu\sigma} - g_{\nu\sigma}M_{\mu\rho} - g_{\mu\rho}M_{\nu\sigma} + g_{\mu\sigma}M_{\nu\rho})$$

} Poincare Algebra

New Ansatz:

$$\{C_a, C_b\} = X^?_{ab}$$

$$[C_a, P_\mu] = ?_{a\mu} \neq 0$$

} Symmetry that does not commute with Poincare Algebra

$$[B_a, B_b] = f_{ab}{}^{c} B_c$$

$$[B_a, P_\mu] = 0$$

} Algebra of inner (Gauge) Symmetry

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Impose consistency conditions with quantum field theory

- S-matrix based on local relativistic theory of 4-dim.
- Finite number of particles that have the same mass
- There exists an energy gap between the lightest particle and the vacuum

do Algebra, use Jacobi identities ..

Most general graded Lie algebra of symmetries consistent with QFT

$$[P_m, P_n] = 0$$

$$[P_m, Q_\alpha^L] = [P_m, \overline{Q}_{\dot\alpha}^L] = 0$$

$$[P_m, B_l] = 0$$

$$\{Q_\alpha^L, \overline{Q}_{\dot\beta M}\} = 2\sigma_{\alpha\dot\beta}{}^m P_m \delta^L_M$$

$$\{Q_\alpha^L, Q_\beta^M\} = \varepsilon_{\alpha\beta} X^{LM}$$

$$\{\overline{Q}_{\dot\alpha}^L, \overline{Q}_{\dot\beta}^M\} = \varepsilon_{\dot\alpha\dot\beta} X^{+}{}_{LM}$$

$$[X_{LM}, Everything] = 0$$

$$[B_a, B_b] = i f_{ab}{}^c B_c$$

$$[Q_\alpha^L, B_l] = S_l{}^L{}_M Q_\alpha^M$$

$$[\overline{Q}_{\dot\alpha L}, B^l] = -S_L^{*l M} \overline{Q}_{\dot\alpha M}$$

L:1...N

$\alpha, \dot\alpha$:1,2

Simplest version for N=1:

(Haag, Lopuszanski und Sohnius)

N=1 Supersymmetry

$$[P_m, P_n] = 0$$

$$[P_m, Q_\alpha] = [P_m, \bar{Q}_{\dot{\alpha}}] = 0$$

$$[P_m, B_l] = 0$$

$$\{Q^L_\alpha, \bar{Q}_{\dot{\beta} M}\} = 2\sigma_{\alpha\dot{\beta}}{}^m P_m \delta^L_M$$

/ / :1,2

$$\{Q^L_\alpha, Q^M_\beta\} = 0$$

$$\{\bar{Q}^L_{\dot{\alpha}}, \bar{Q}^M_{\dot{\beta}}\} = 0$$

$$[B_a, B_b] = i f_{ab}{}^c B_c$$

$$[Q_\alpha, B_l] = S_l \; Q_\alpha$$

$$[\bar{Q}_{\dot{\alpha}}, B^l] = -S^{*l} \; \bar{Q}_{\dot{\alpha}}$$

Supersymmetric QFT

- find representation of Algebra
- find extended gauge-susy transformations
- construct Lagrangian that is invariant under this transformation
- match new theory that it contains SM (Boson <-> Fermion , New Higgs sector)
- break supersymmetry (Superpartners not observed)
- calculate!
  Feynman rules, renormalise ...

It works!

The MSSM

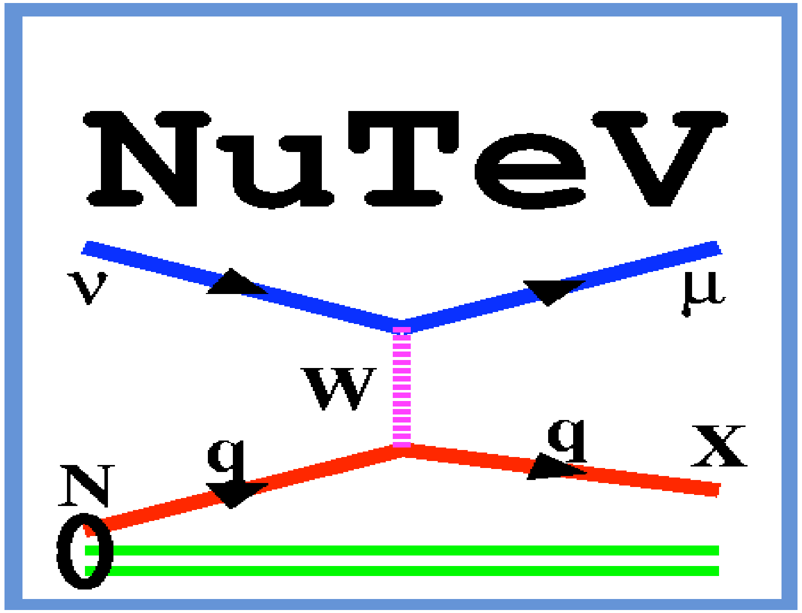
Minimal **S**upersymmetric **S**tandard model

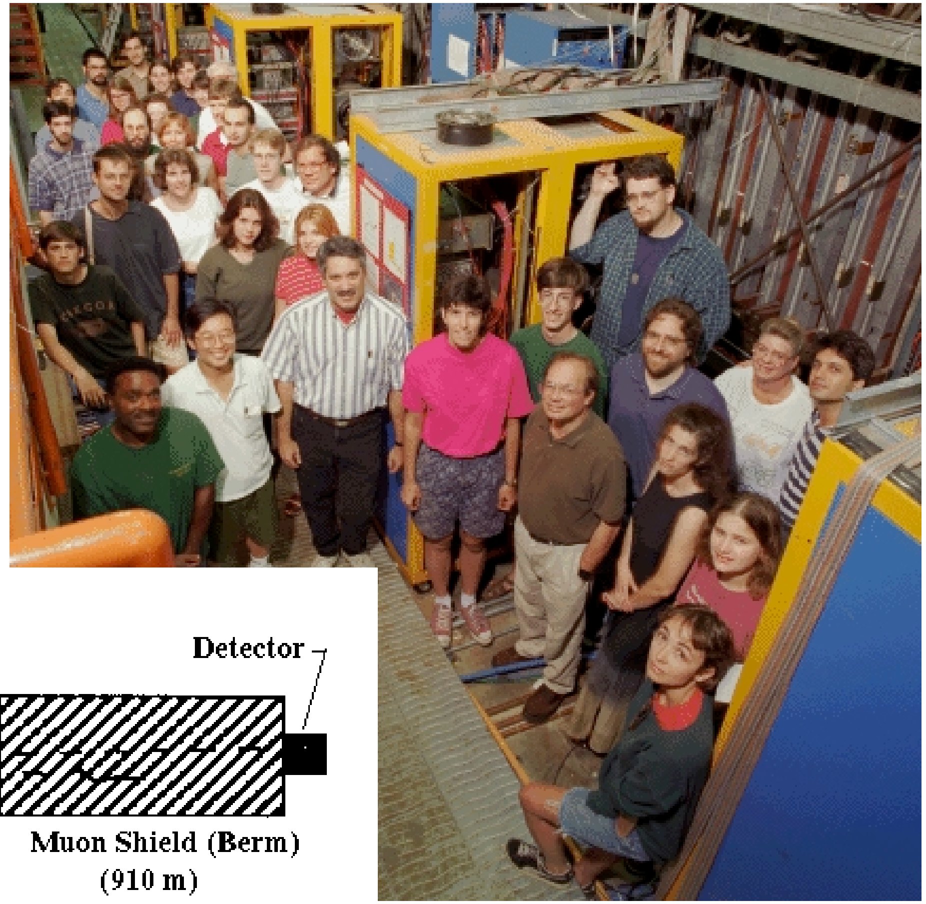
Name	Superfeld	SM-Teilchen	Spin	Superteilchen	Spin
Quarks - Squarks	Q	$q_L = (u_L, d_L)$	$1/2$	$\tilde{q}_L = (\tilde{u}_L, \tilde{d}_L)$	0
	U	u_R	$1/2$	$\tilde{u}_R^+$	0
	D	d_R	$1/2$	$\tilde{d}_R^+$	0
Leptonen - Sleptonen	E	$l_L = (\nu_L, e_L)$	$1/2$	$\tilde{l}_L = (\tilde{\nu}_L, \tilde{e}_L)$	0
	L	l_R	$1/2$	$\tilde{l}_R^+$	0
Higgs - Higgsinos	H_1	H_1^0, H_1^-	0	$\tilde{H}_1^0, \tilde{H}_1^-$	$1/2$
	H_2	H_2^+, H_2^0	0	$\tilde{H}_2^+, \tilde{H}_2^0$	$1/2$
B-Boson - Bino	B	B^0	1	$\tilde{B}^0$	$1/2$
W-Boson - Wino	W_I	$W^0, W^\pm$	1	$\tilde{W}^0, \tilde{W}^\pm$	$1/2$
Gluon - Gluino	G_I	g_I	1	$\tilde{g}_I$	$1/2$

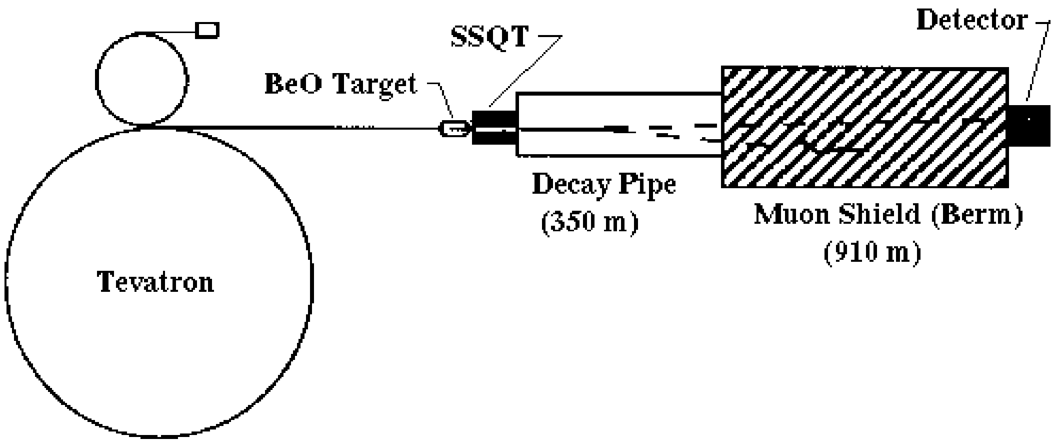
Parameters

The MSSM has a lot of free parameters
(most of them closely connected to the masses
of the new particles) which
have to be fixed by experiment

The NuTeV experiment







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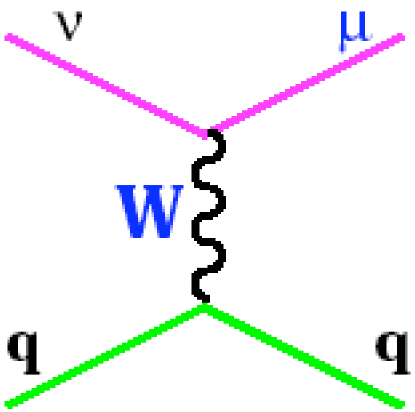
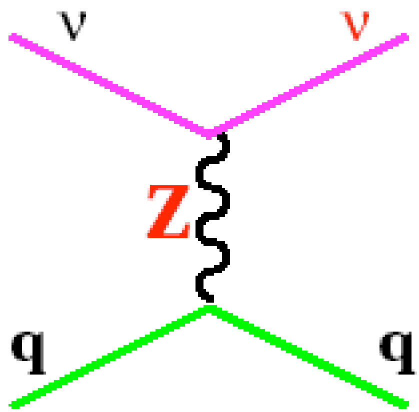
What do they measure



$$\sin\theta_W = 1 - \frac{M_W^2}{M_Z^2}$$



Coupling $\propto\ I^{(3)}_{\mathrm{weak}}$

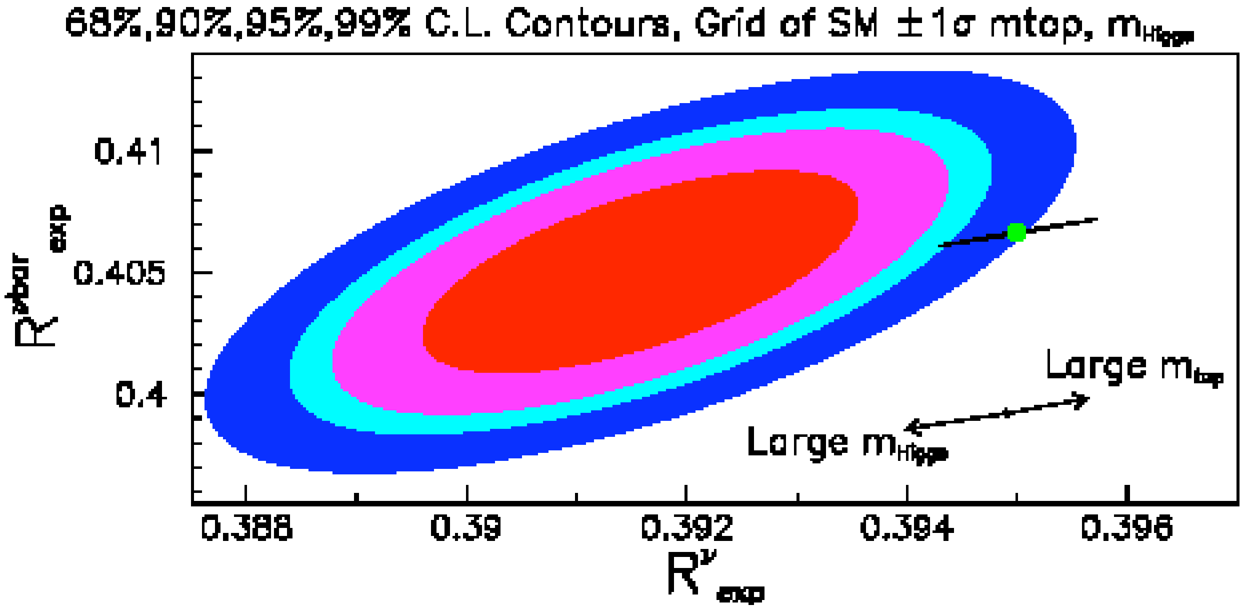
Coupling $\propto \left(I^{(3)}_{\mathrm{weak}} - Q_{\mathrm{em}} \sin^2\theta_W \right)$

$$R^{\nu(\overline{\nu})} = \frac{\sigma^{\nu(\overline{\nu})}_{NC}}{\sigma^{\nu(\overline{\nu})}_{CC}} = \rho^2 \left(\frac{1}{2} - \sin^2\theta_W + \frac{5}{9}\sin^4\theta_W \left(1 + \frac{\sigma^{\overline{\nu}(\nu)}_{CC}}{\sigma^{\nu(\overline{\nu})}_{CC}} \right) \right)$$

(Llewellyn-Smith)

The NuTeV discrepancy

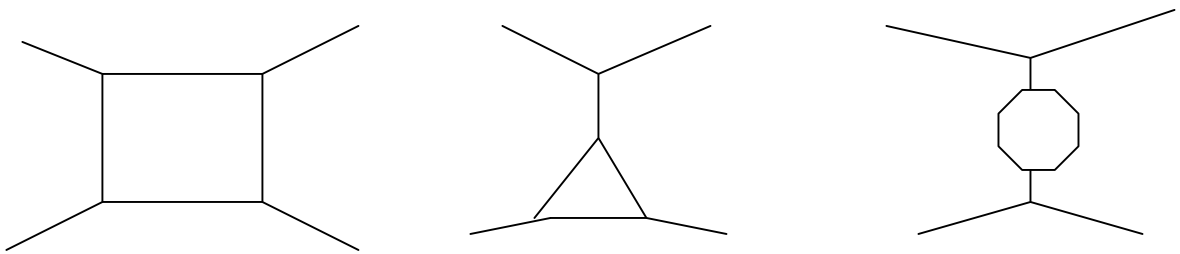
A discrepancy of 3σ…



Can MSSM corrections explain the R_ν discrepancy?

To get $\sigma_{NC(CC)}$ one needs to

- calculate all possible Feynman graphs at 1 loop level

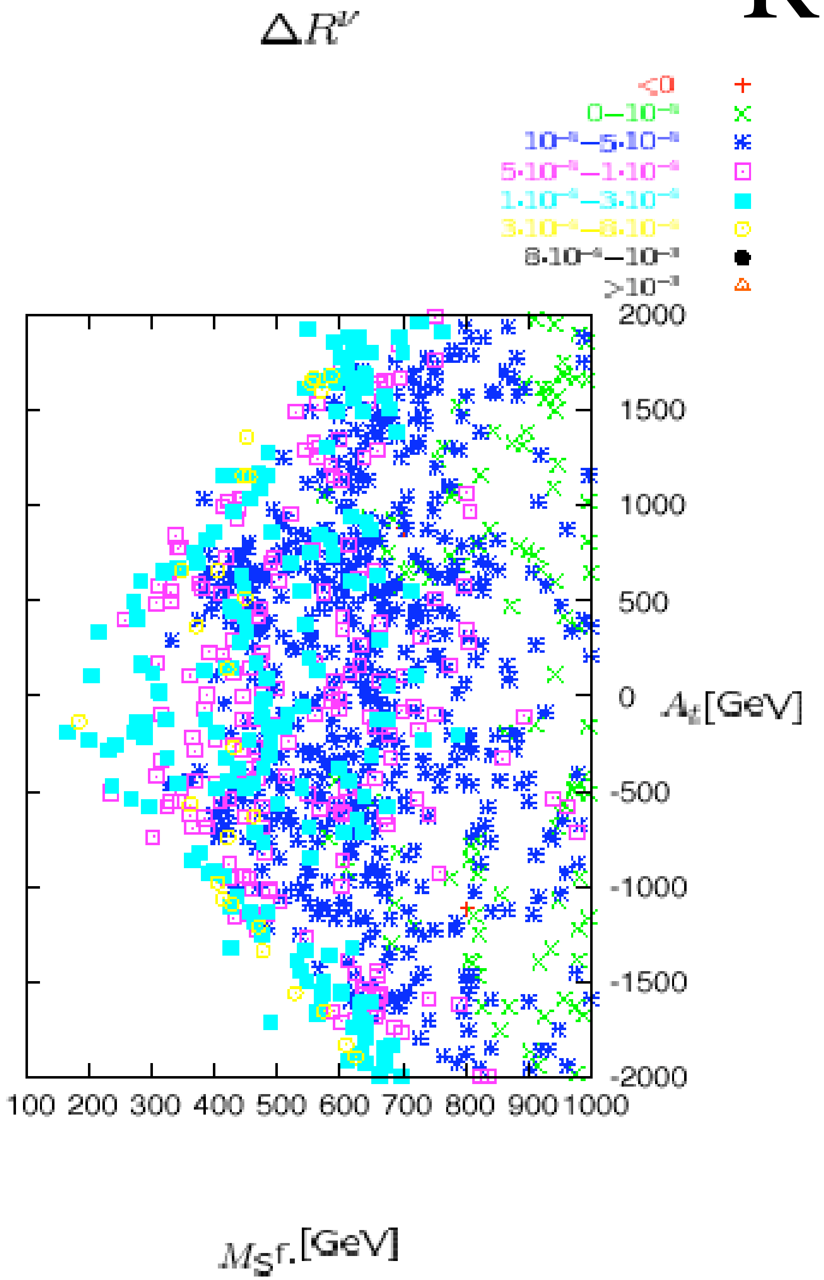


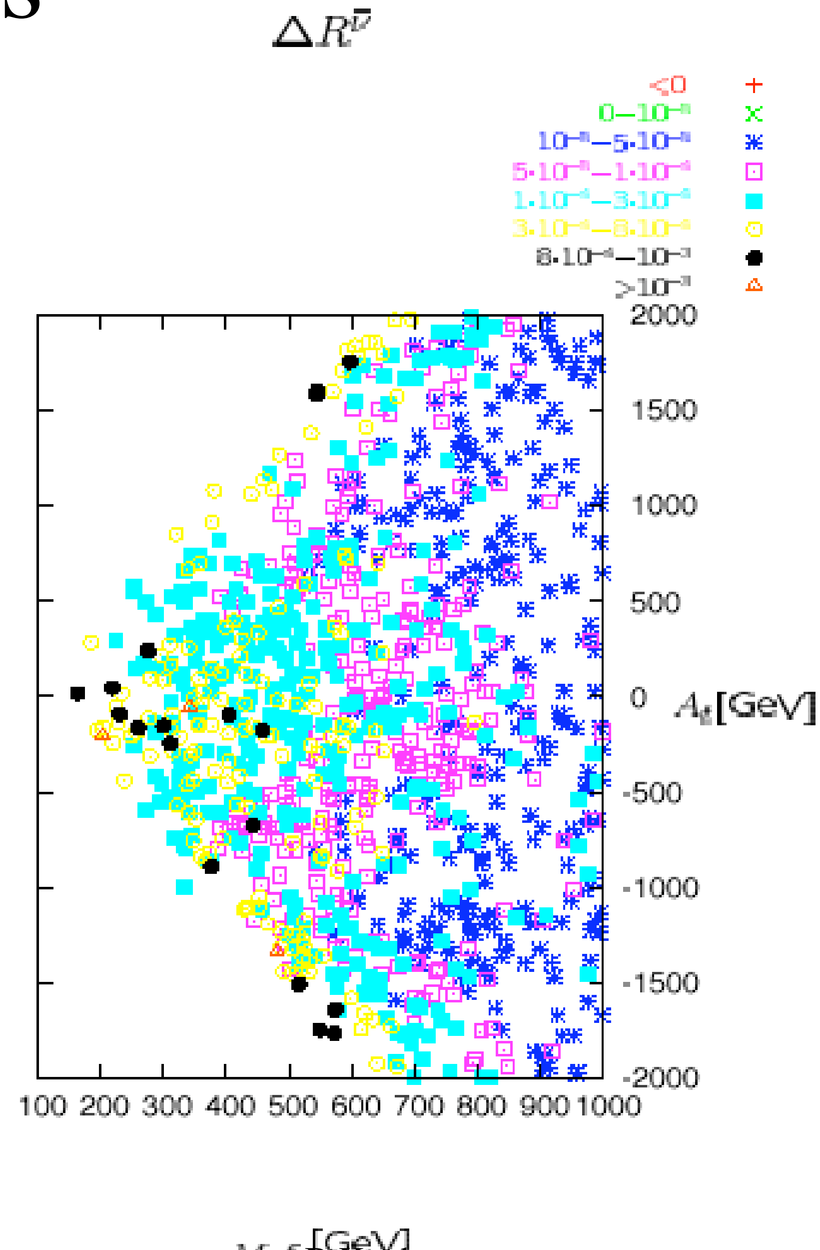
$\approx$100 Diagr.
+Renorm.

(Koch, Brein)

- convolute the differential cross sections with the PDFs for all different Quark-flavours
- see for which choices of the MSSM parameters the MSSM gives the "right" contribution to R_ν. (parameter scan)

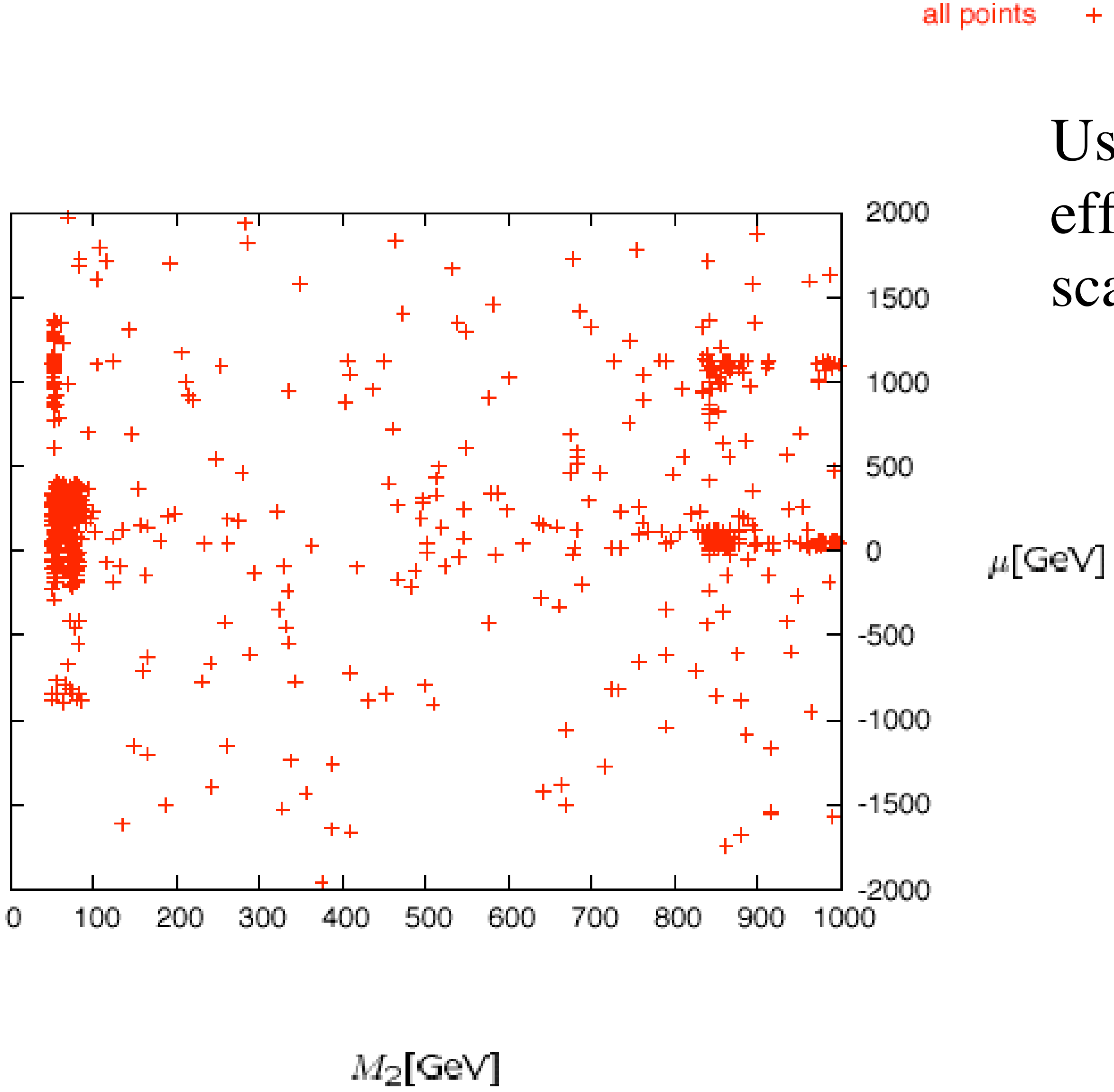
Results (Koch, Brein)





(Koch, Brein)

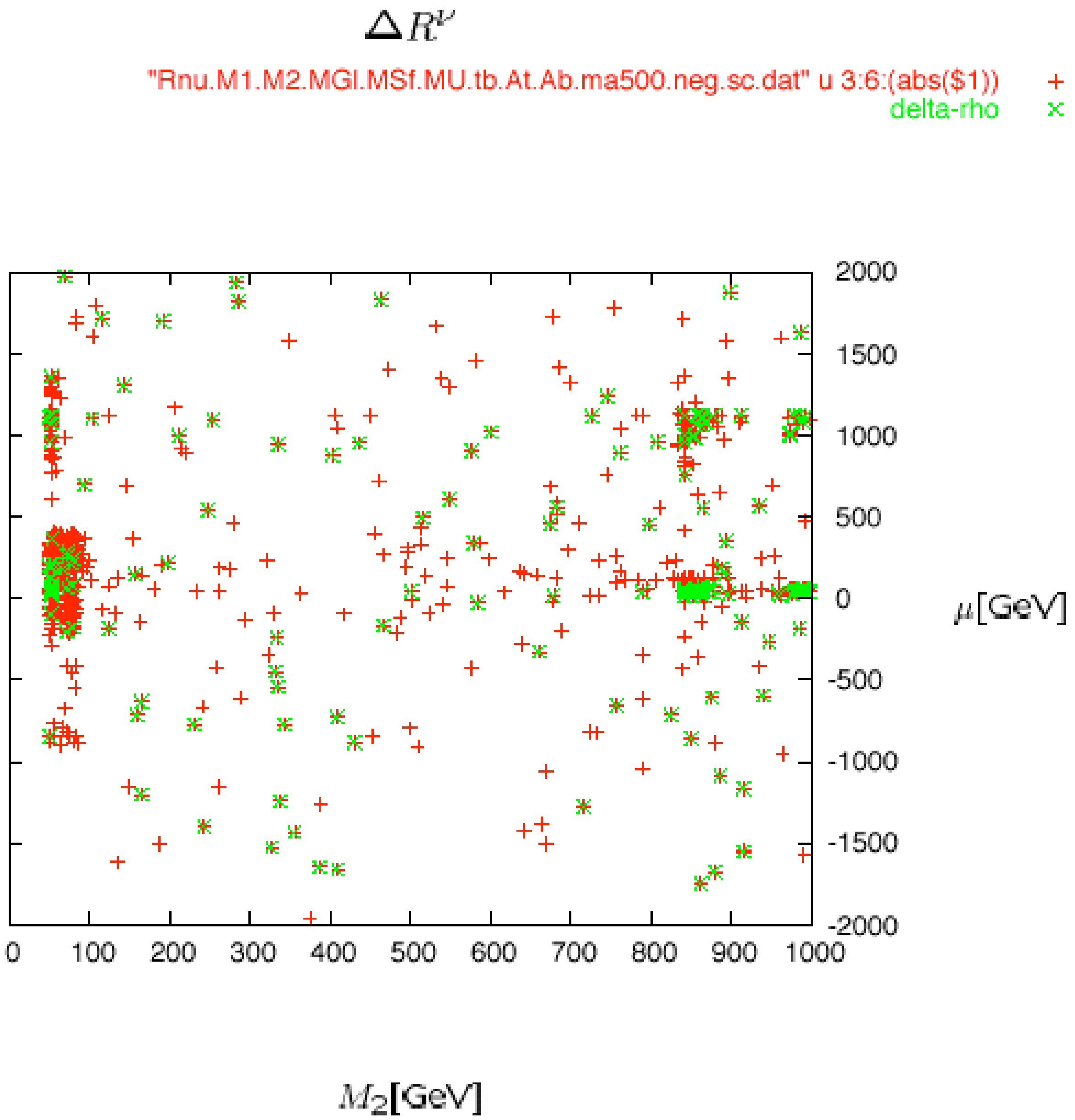
ΔR^{ν} Results



Use Vegas for more effective parameter scan:

Look closer if value of is significant below 0.

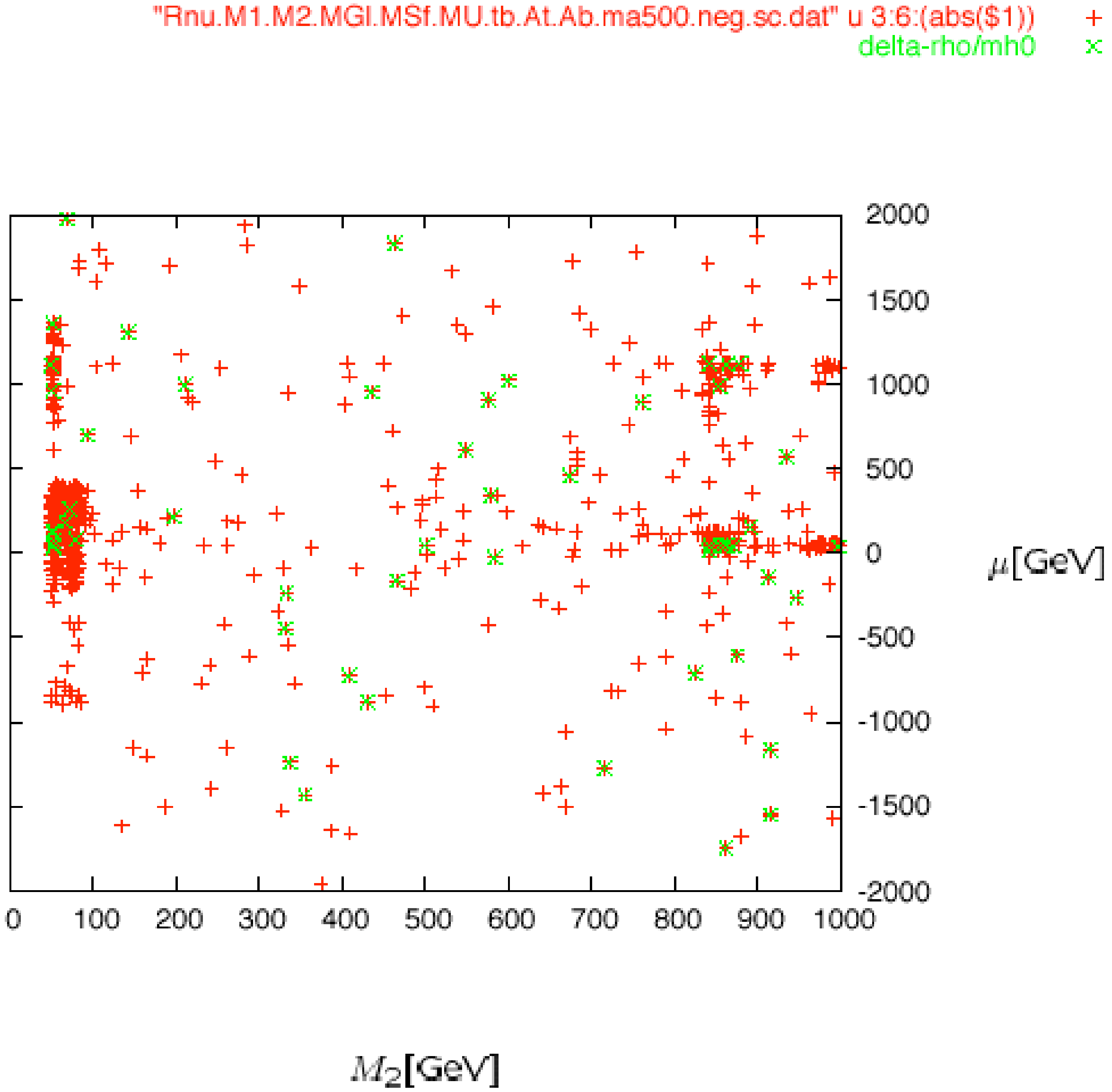
(Koch, Brein)



-Negative values for

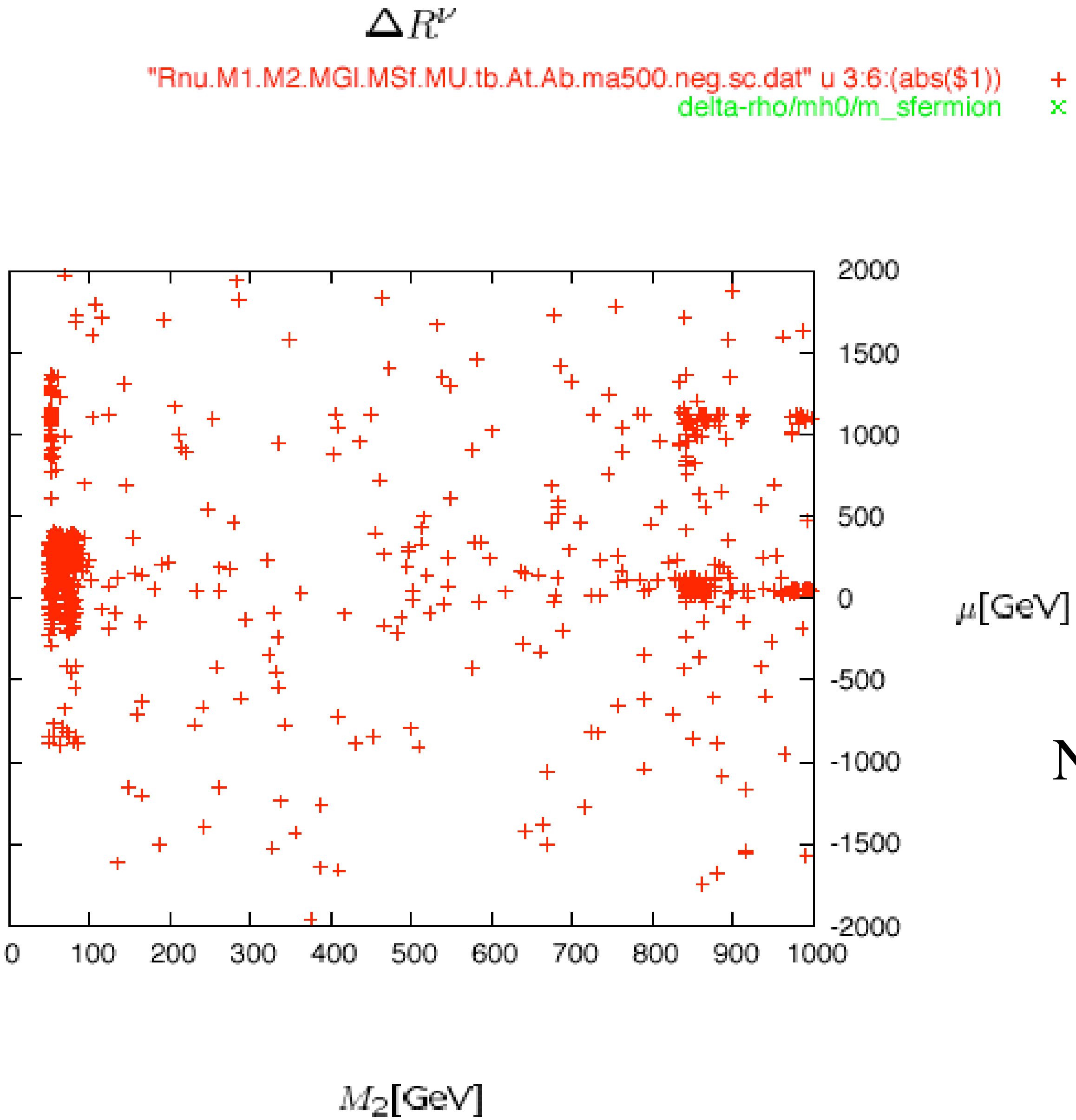
ΔR^{ν}

(Koch, Brein)



with latest constraints for Higgsmass

(Koch, Brein)



with latest constraints for Higgs mass and s-fermion masses

Nothing left

Summary

- Supersymmetry well motivated and bad confirmed theory
- S-Loop effects are most likely not able to explain NuTeV anomaly (too small or wrong sign)
- Full analysis needed to be sure
- If anomaly confirmed with smaller errors than bounds for MSSM parameters could be derived