Radiative Corrections to Neutrino Nucleon Deep Inelastic Scattering in the MSSM

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outline :

- Introduction
  - deep inelastic νN scattering @ NuTeV
  - possible explanations

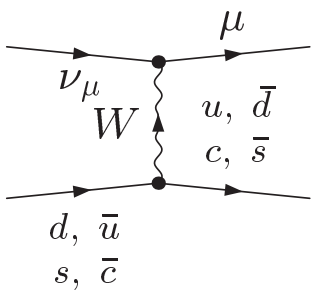
- MSSM radiative corrections to $\nu_\mu N$ DIS
  - Definition of $\Delta R^{\nu,\bar{\nu}} = R^{\nu,\bar{\nu}}_{\mathrm{MSSM}} - R^{\nu,\bar{\nu}}_{\mathrm{SM}}$
  - superpartner loop corrections

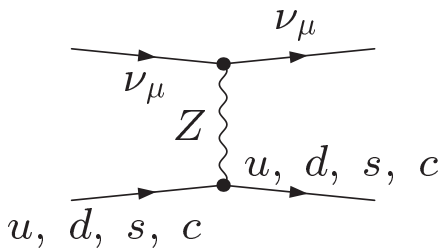
- Results for ΔR^{ν}
  - MSSM parameter scan

• Introduction

– deep inelastic νN scattering @ NuTeV

In the SM neutral (NC) and charged current (CC) neutrino nucleon scattering are described in LO by t-channel W and Z exchange.





At NuTeV ν_μ and $\bar{\nu}_\mu$ beams of a mean energy of 125 GeV were scattered off a target detector and the ratios

$$R^\nu = \frac{\sigma^\nu_{\mathrm{NC}}}{\sigma^\nu_{\mathrm{CC}}}\,, \qquad\qquad R^{\bar{\nu}} = \frac{\sigma^{\bar{\nu}}_{\mathrm{NC}}}{\sigma^{\bar{\nu}}_{\mathrm{CC}}}$$

were measured.

NuTeV measured also the weak mixing angle [NuTeV '02].

$$\sin^2\theta_w^{\text{on-shell}} = 0.2277 \pm 0.0013 \pm 0.0009$$

$\rightarrow$ This is about 3σ below the SM prediction !

But the measurement is indirect, using the measurements of $R^\nu, R^{\bar\nu}$ and making use of the Paschos-Wolfenstein relation

$$R^- = \frac{R^\nu - r R^{\bar\nu}}{1-r} = \frac{1}{2} - \sin^2\theta_w + \cdots\,, \qquad r = \frac{\sigma^{\bar\nu}_{\text{CC}}}{\sigma^{\nu}_{\text{CC}}} \approx \frac{1}{2}\,.$$

More precisely, ratios of counting rates $R^{\nu}_{\text{exp}} \approx R^{\nu}, R^{\bar{\nu}}_{\text{exp}} \approx R^{\bar{\nu}}$ are measured which are related to $R^{\nu}, R^{\bar{\nu}}$ by a detailed MC physics simulation.

The deviation from the SM in terms of $R^{\nu}_{\text{exp}}, R^{\bar{\nu}}_{\text{exp}}$ are [NuTeV '02]:

$$\Delta R^{\nu} = R^{\nu}_{\text{exp}} - R^{\nu}_{\text{exp}}(SM) = -0.0032 \pm 0.0013 \,,$$
$$\Delta R^{\bar{\nu}} = R^{\bar{\nu}}_{\text{exp}} - R^{\bar{\nu}}_{\text{exp}}(SM) = -0.0016 \pm 0.0028 \,.$$

$\rightarrow$ simple starting point for studying MSSM radiative corrections

– possible explanations

- statistical fluctuation, errors underestimated ?
  - → re-analyses of EW rad. corr. [Diener, Dittmaier, Hollik '03, talk of Arbuzov]
- relevant SM effects neglected ?
  - → strange sea asymmetry ($s \neq \bar{s}$)
  - → isospin violation ($u_p \neq d_n$)
  - → nuclear effects
  - → etc. ...
- new physics ?
  - → modified gauge boson interactions (e.g. in extra dimensions)
  - → non-renormalizable operators
  - → leptoquarks (e.g. R parity violating SUSY)
  - → SUSY loop effects (e.g. in MSSM)
  - → etc. ...

Although the NuTeV "anomaly" is far from settled,
it is interesting, if the MSSM *could* account for such an effect.

Earlier Studies:

- Davidson et al. '02 :
  - rough study in terms of oblique corr. (i.e. $q^2 = 0$)
  - no detailed parameter dependence studied
  - no PDFs used
- Kurylov, Ramsey-Musolf, Su '03 :
  - detailed parameter dep. studied
  - $q^2 = 0$ approximation
  - no PDFs used

results so far: MSSM not responsible (size ok, but wrong sign)

- our calculation: try to include kinematic effects
  - full q^2 dependence
  - use PDFs
  - use NuTeV cuts on hadronic Energy in final state
  - use mean neutrino beam energy (125 GeV)

• MSSM radiative corrections to $\nu_\mu N$ DIS

– Definition of $\Delta R^{\nu,\bar{\nu}} = R^{\nu,\bar{\nu}}_{\rm MSSM} - R^{\nu,\bar{\nu}}_{\rm SM}$

The difference between MSSM and SM prediction, $\delta R^n = R^n_{\rm MSSM} - R^n_{\rm SM}$ with $R^n = \sigma^n_{\rm NC}/\sigma^n_{\rm CC} (n = \nu, \bar{\nu})$, using

$$(\sigma^n_{\rm XC})_{\rm NLO} = (\sigma^n_{\rm XC})_{\rm LO} + \delta\sigma^n_{\rm XC} \; ({\rm X} = {\rm N,C}; n = \nu, \bar{\nu})$$

can be expanded

$$\delta R^n = \left(\frac{\sigma^n_{\rm NC}}{\sigma^n_{\rm CC}}\right)_{\rm LO} \left(\frac{(\delta\sigma^n_{\rm NC})_{\rm MSSM} - (\delta\sigma^n_{\rm NC})_{\rm SM}}{(\sigma^n_{\rm NC})_{\rm LO}} - \frac{(\delta\sigma^n_{\rm CC})_{\rm MSSM} - (\delta\sigma^n_{\rm CC})_{\rm SM}}{(\sigma^n_{\rm CC})_{\rm LO}} \right).$$

$\rightarrow$ Only differences between MSSM and SM rad. corr. and LO cross section expressions appear.

Because of R parity conservation in the MSSM:

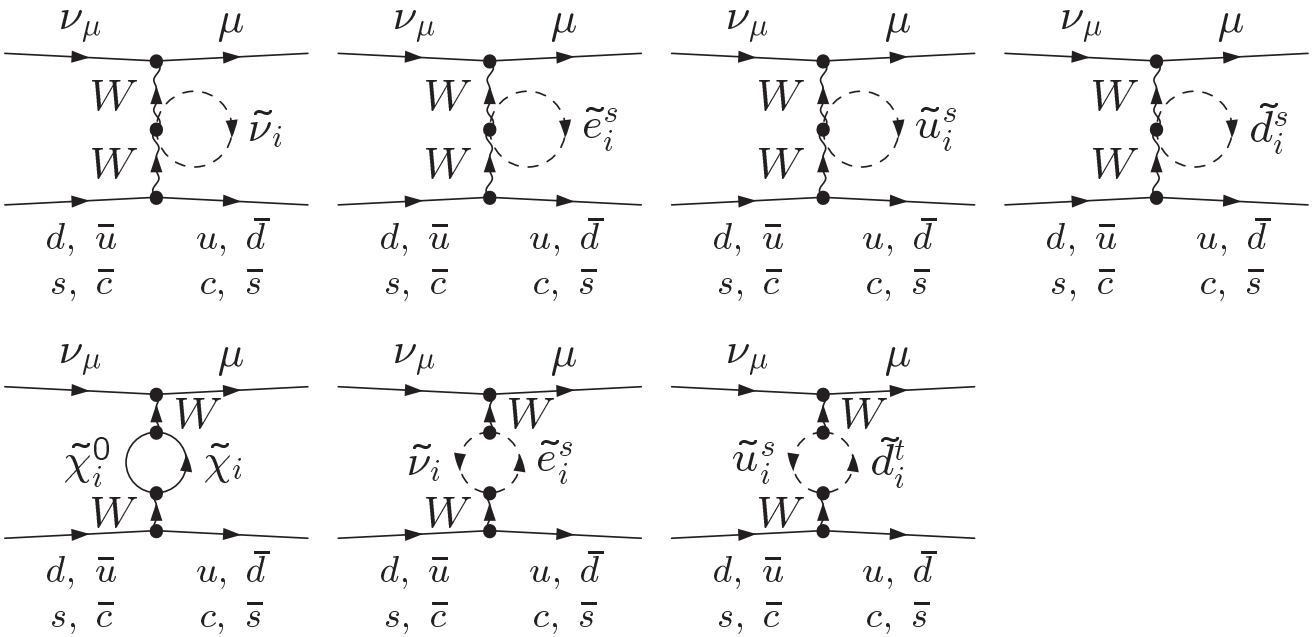
- Born : SM = MSSM (very good approx.)
- real photon emission : SM = MSSM (very good approx.)
- SM = MSSM for SM-like 1-loop graphs without virtual Higgs

Thus:

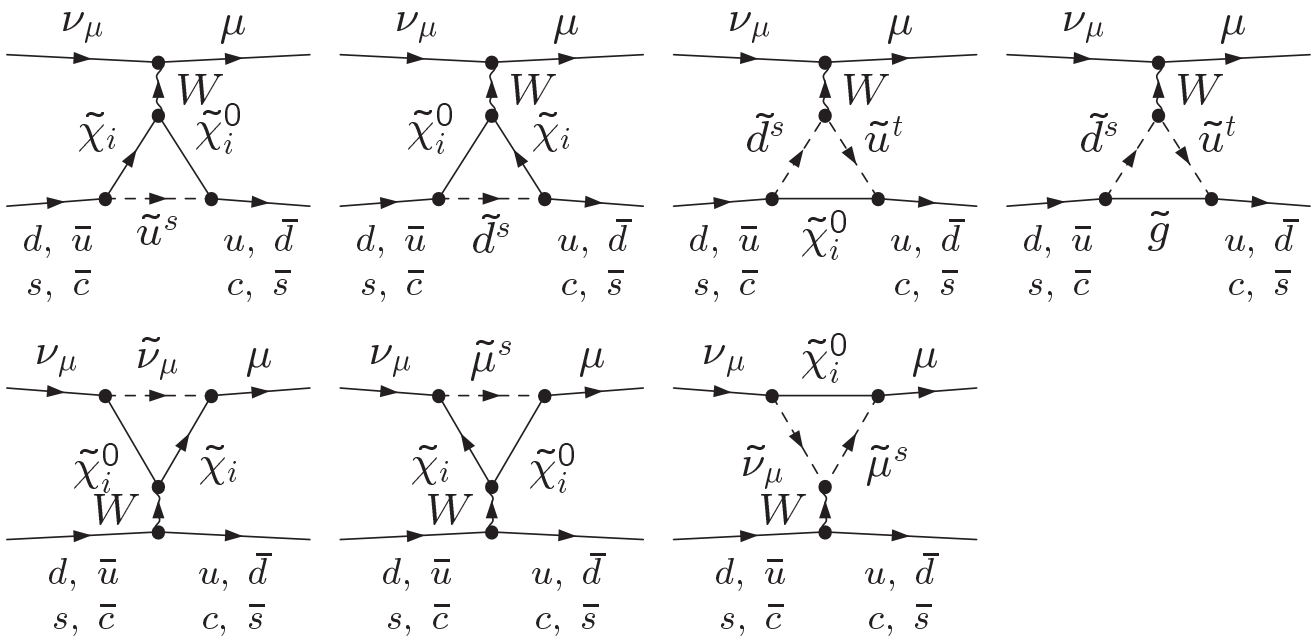
$$\delta R^n = \text{const.} \times \Big([\text{superpartner loops}] + [\text{Higgs graphs MSSM} - \text{Higgs graphs SM}] \Big) .$$

– superpartner loop corrections

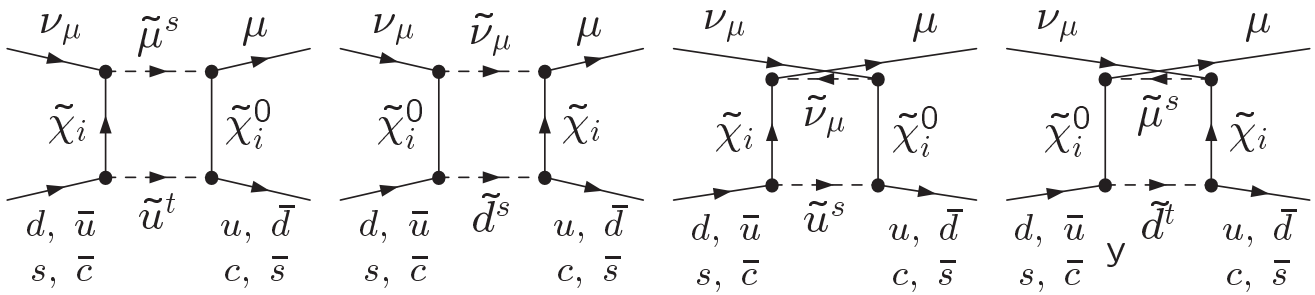
CC self energy insertions



CC vertex corrections

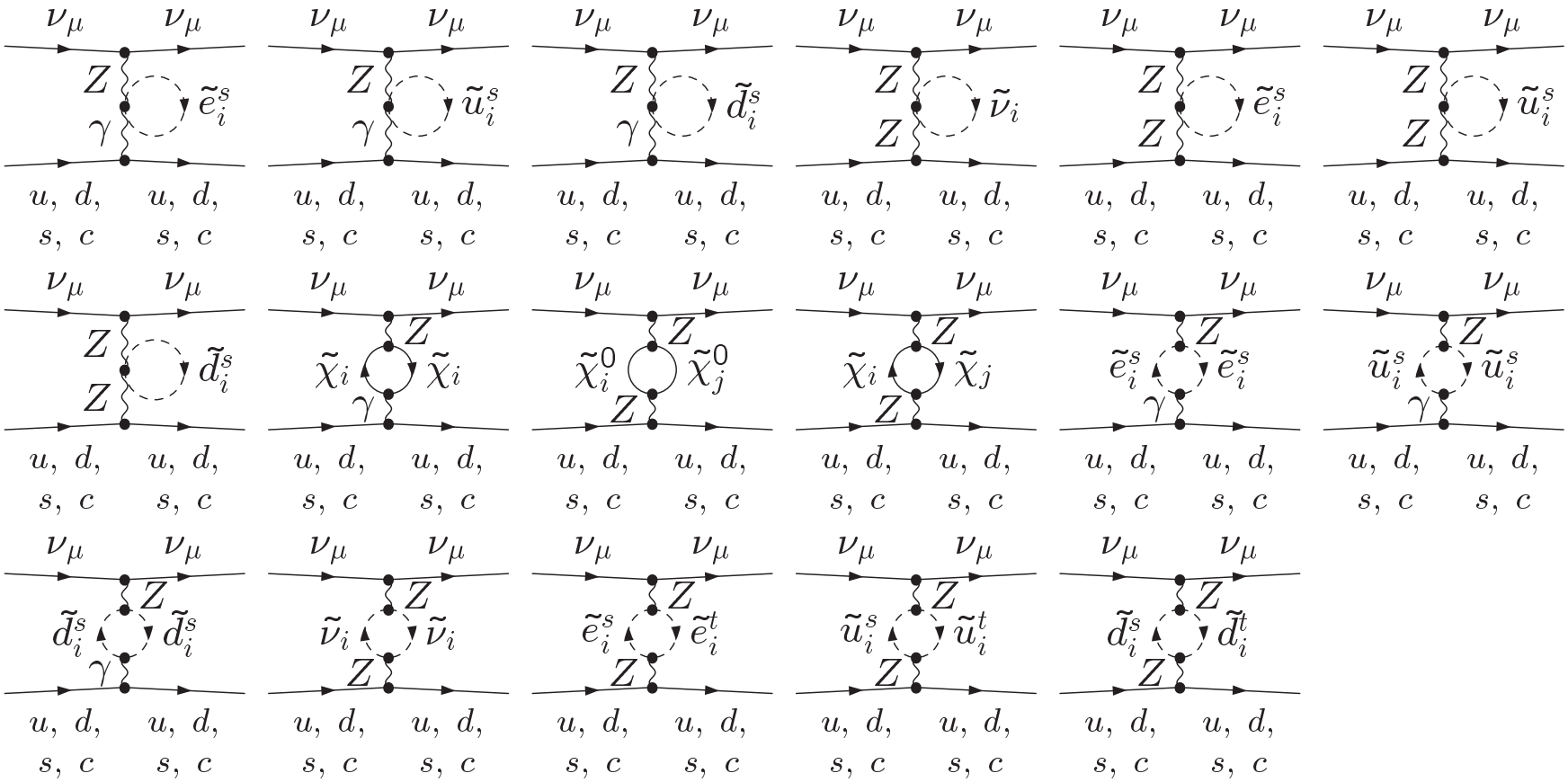


CC box corrections

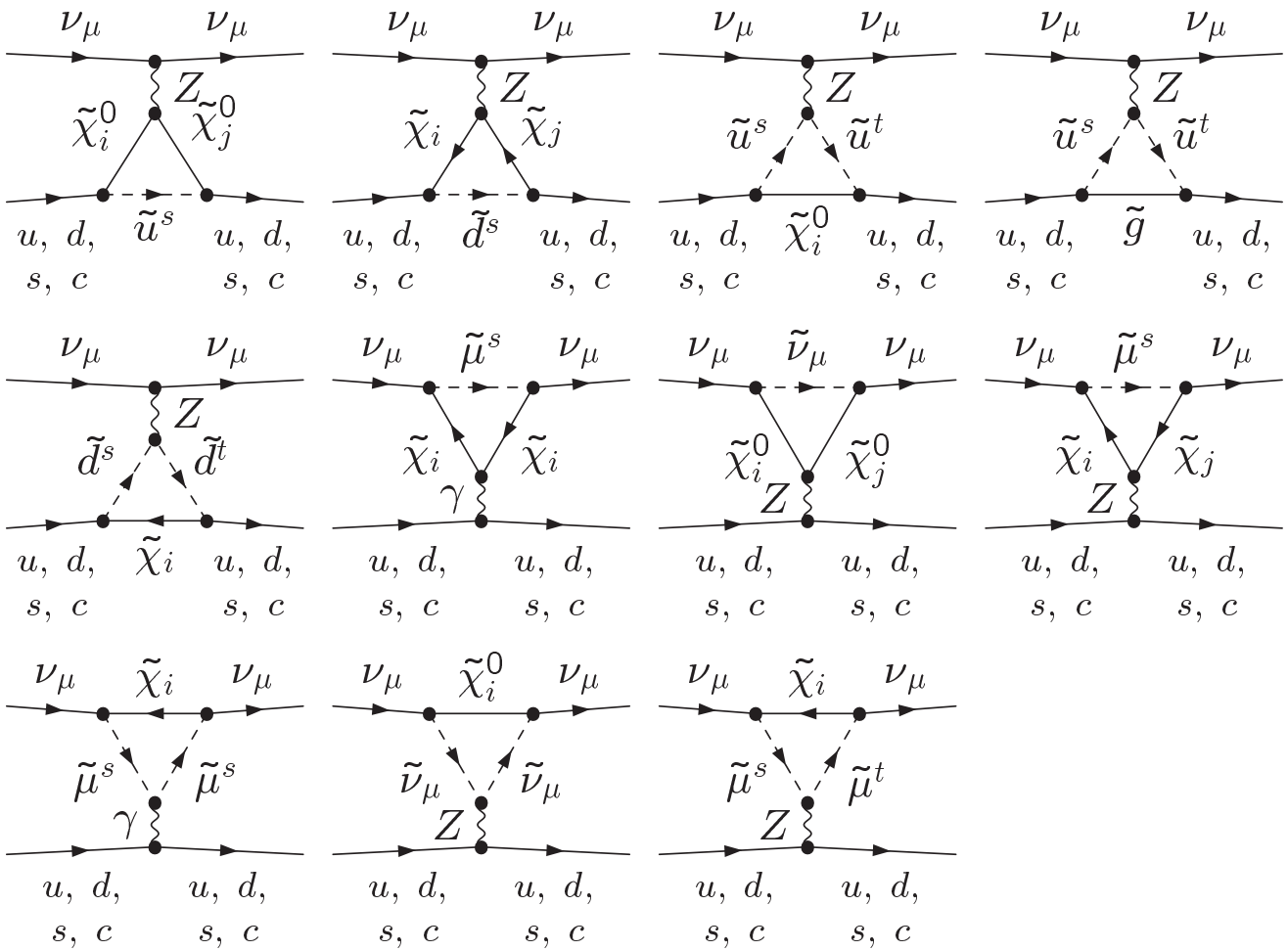


– superpartner loop corrections

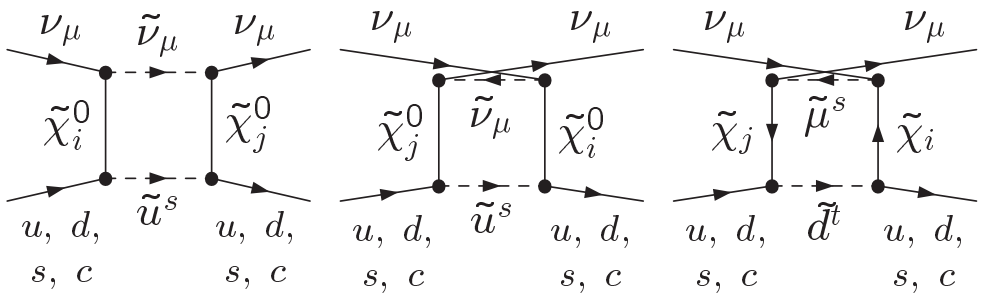
NC self energy insertions



NC vertex corrections



NC box corrections



The partonic processes were calculated using FeynArts/FormCalc.
[Küblbeck, Böhm, Denner'90],
[Eck '95], [Hahn, Perez-Victoria '99], [Hahn '01],
[Hahn, Schappacher '02], [Fritzsche '02], [...]

see : www.feynarts.de

• Results for ΔR^{ν}

– MSSM parameter scan

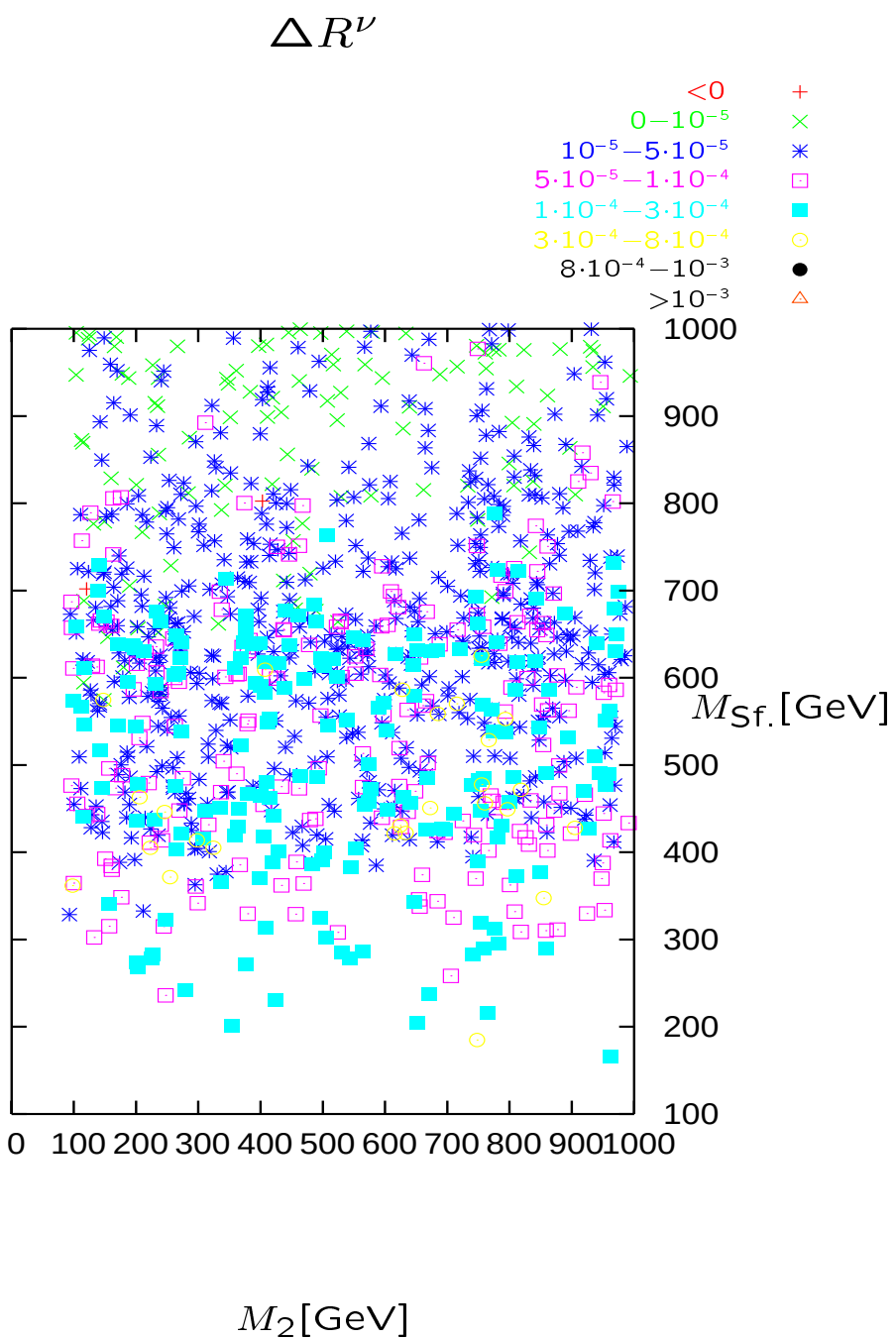
choice: $m_A = 500\,\text{GeV}$
$\rightarrow$ SM-like Higgs sector
$\rightarrow$ superpartner loops determine δR^n

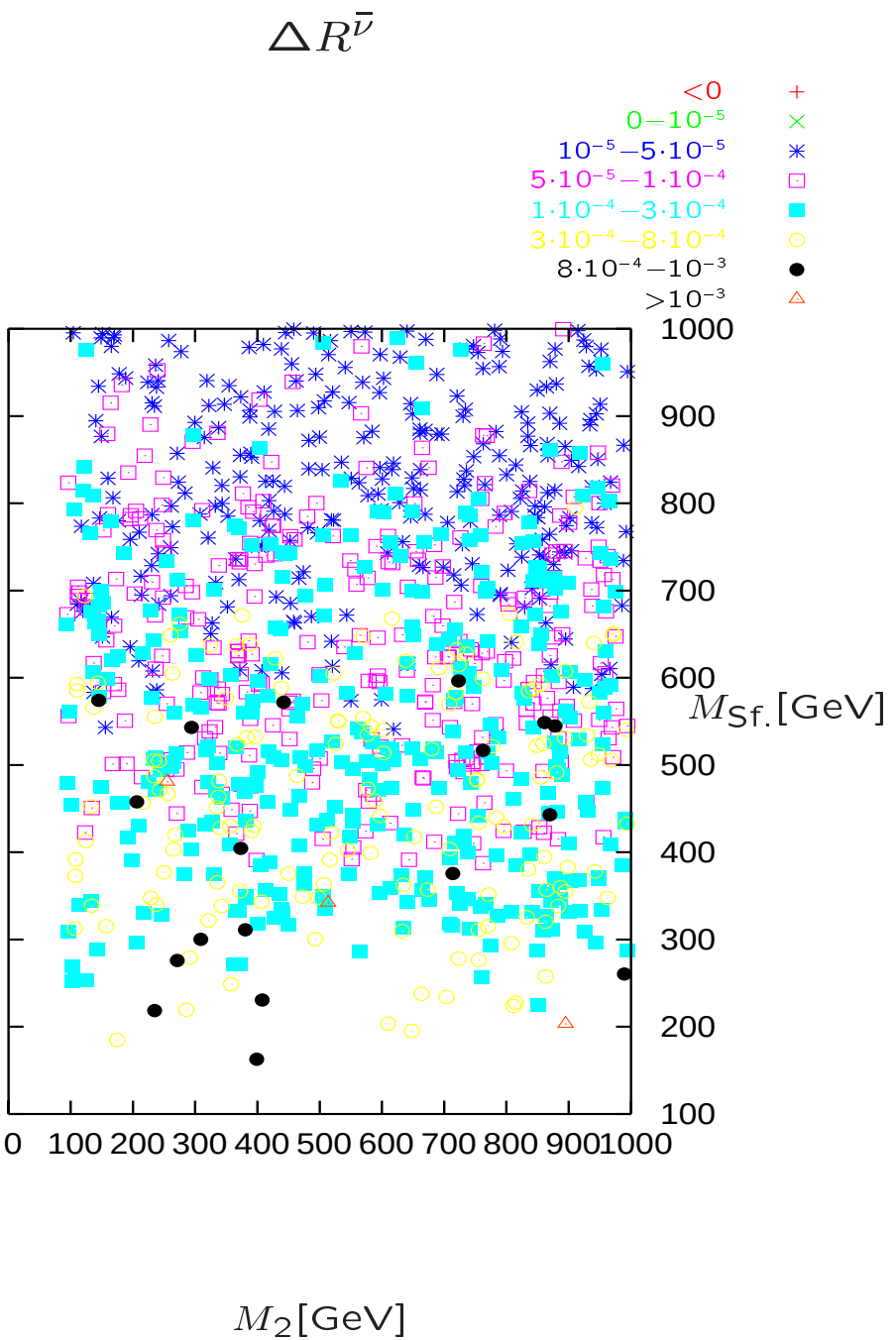
restrictions taken into account:

- mass exclusion limits for Higgs bosons and superpartners
- $\Delta\rho$-constraint on sfermion mixing

quantities varied:

M_1	:	$50 \ldots 1000\,\text{GeV}$	μ	:	$-2000 \ldots 2000\,\text{GeV}$
M_2	:	$50 \ldots 1000\,\text{GeV}$	A_t	:	$-2000 \ldots 2000\,\text{GeV}$
M_{gluino}	:	$50 \ldots 1000\,\text{GeV}$	A_b	:	$-2000 \ldots 2000\,\text{GeV}$
$M_{\text{Sf.}}$	:	$50 \ldots 1000\,\text{GeV}$	$\tan\beta$	:	$1 \ldots 50$


ΔR^{ν}
<0
0−10⁻⁵
10⁻⁵−5·10⁻⁵
5·10⁻⁵−1·10⁻⁴
1·10⁻⁴−3·10⁻⁴
3·10⁻⁴−8·10⁻⁴
8·10⁻⁴−10⁻³
>10⁻³
1000
900
800
700
600
500
400
300
200
100
$M_{Sf.}$[GeV]
0 100 200 300 400 500 600 700 800 900 1000
M_2[GeV]


$\Delta R^{\bar{\nu}}$
<0
0−10⁻⁵
10⁻⁵−5·10⁻⁵
5·10⁻⁵−1·10⁻⁴
1·10⁻⁴−3·10⁻⁴
3·10⁻⁴−8·10⁻⁴
8·10⁻⁴−10⁻³
>10⁻³
1000
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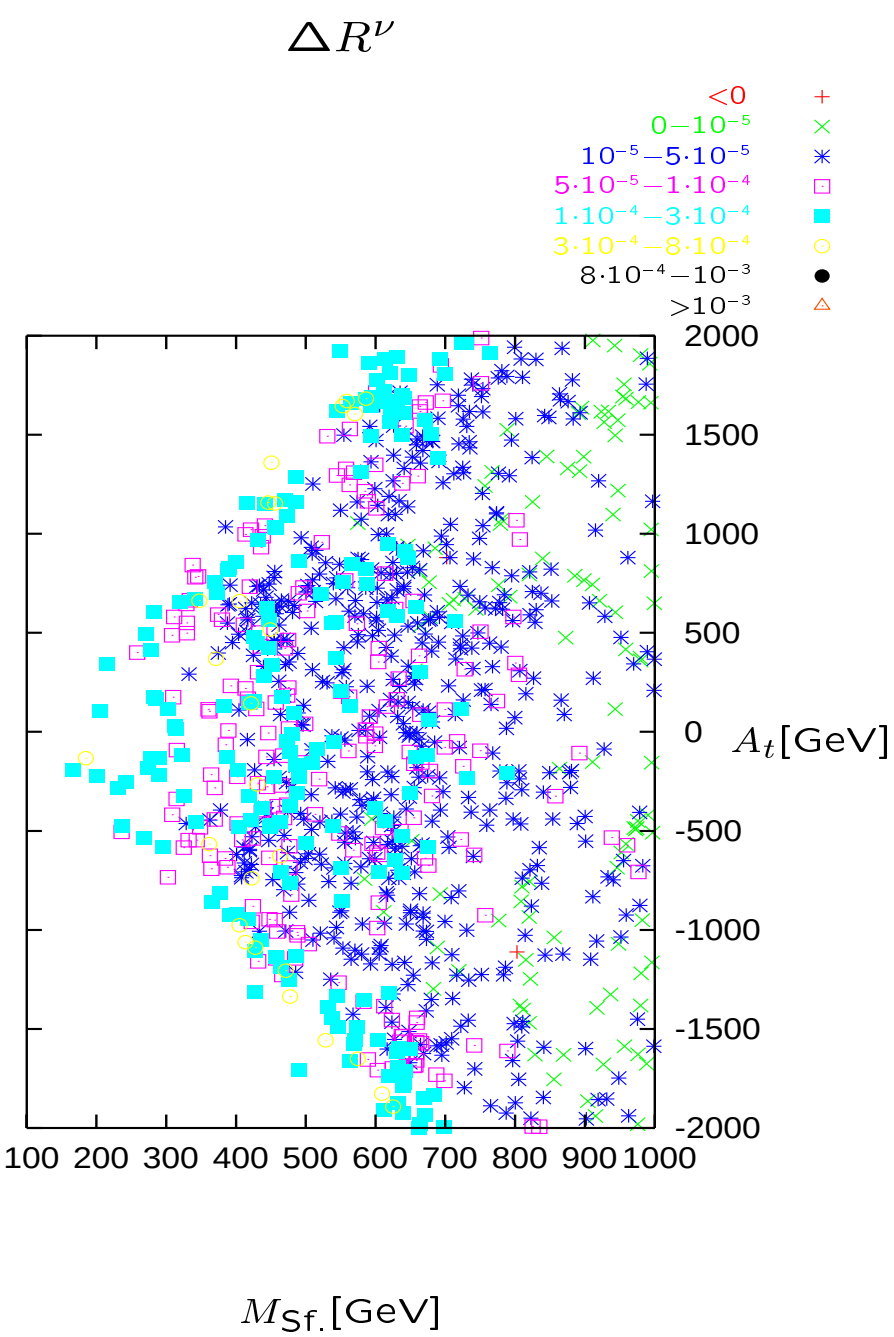
$M_{Sf.}$[GeV]
0 100 200 300 400 500 600 700 800 900 1000
M_2[GeV]


$\triangle R^{\nu}$
<0
0−10⁻⁵
10⁻⁵−5·10⁻⁵
5·10⁻⁵−1·10⁻⁴
1·10⁻⁴−3·10⁻⁴
3·10⁻⁴−8·10⁻⁴
8·10⁻⁴−10⁻³
>10⁻³
2000
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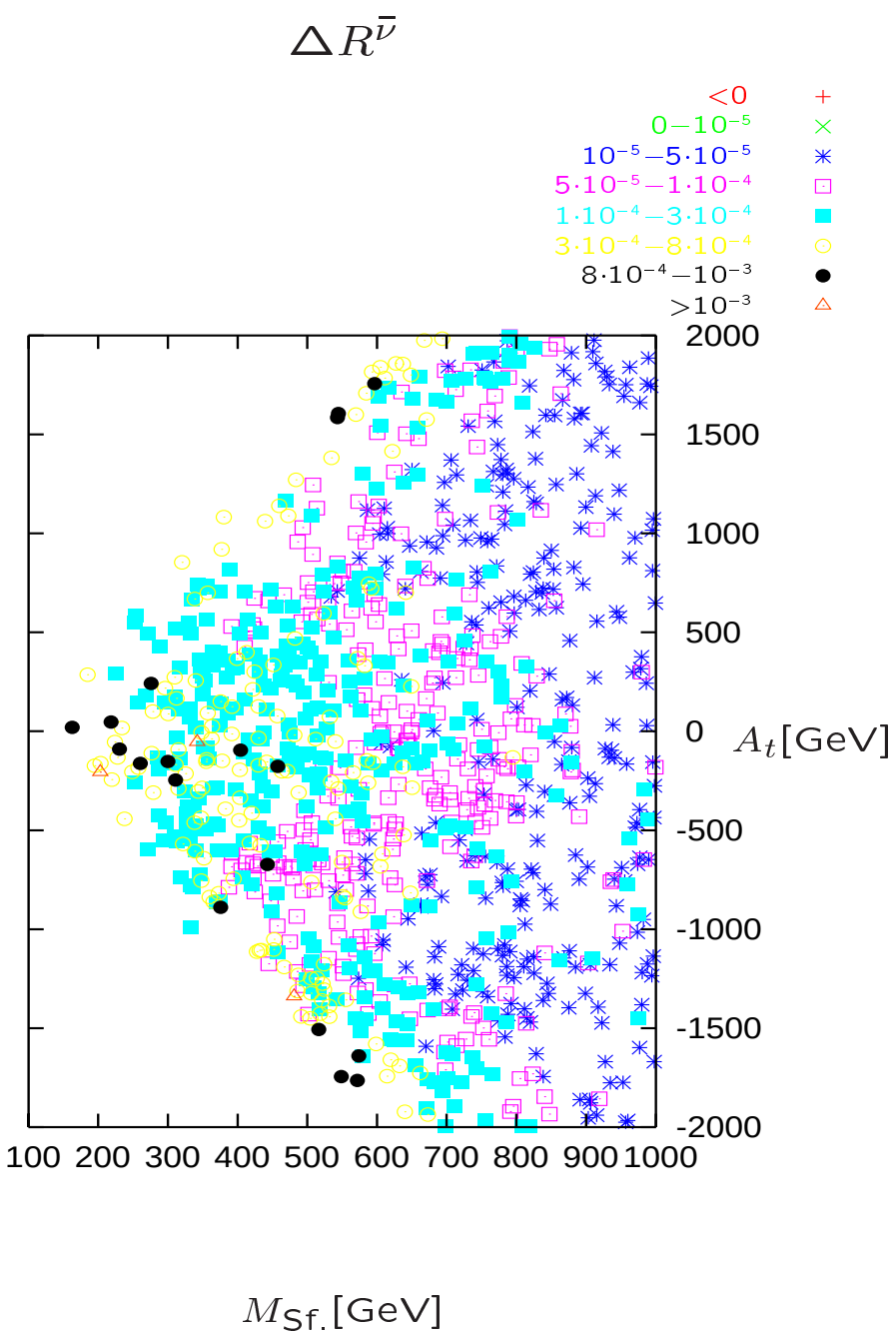
-2000
A_t[GeV]
100 200 300 400 500 600 700 800 900 1000
$M_{\mathrm{Sf.}}$[GeV]


$\triangle R^{\bar{\nu}}$
<0
0−10⁻⁵
10⁻⁵−5·10⁻⁵
5·10⁻⁵−1·10⁻⁴
1·10⁻⁴−3·10⁻⁴
3·10⁻⁴−8·10⁻⁴
8·10⁻⁴−10⁻³
>10⁻³
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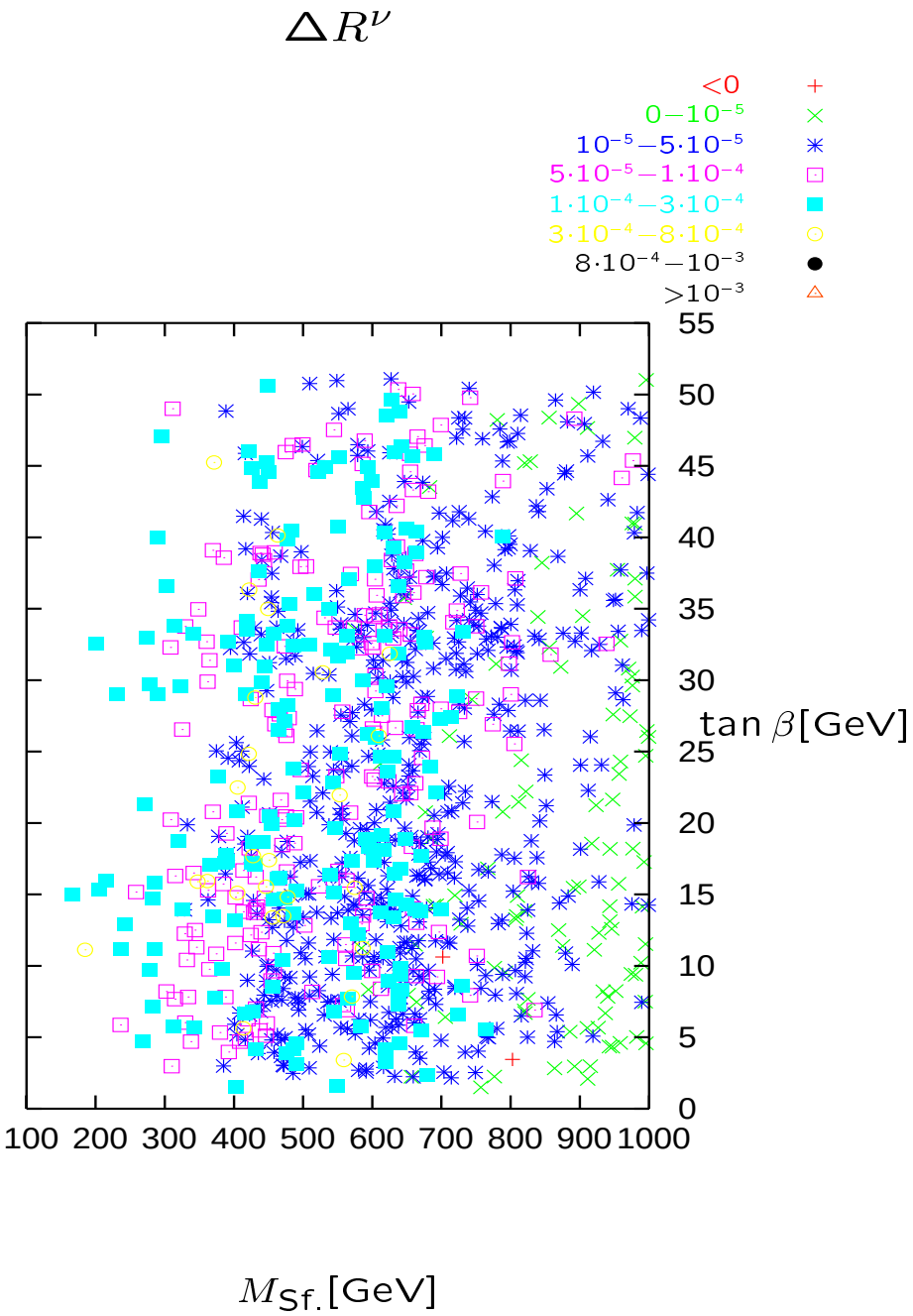
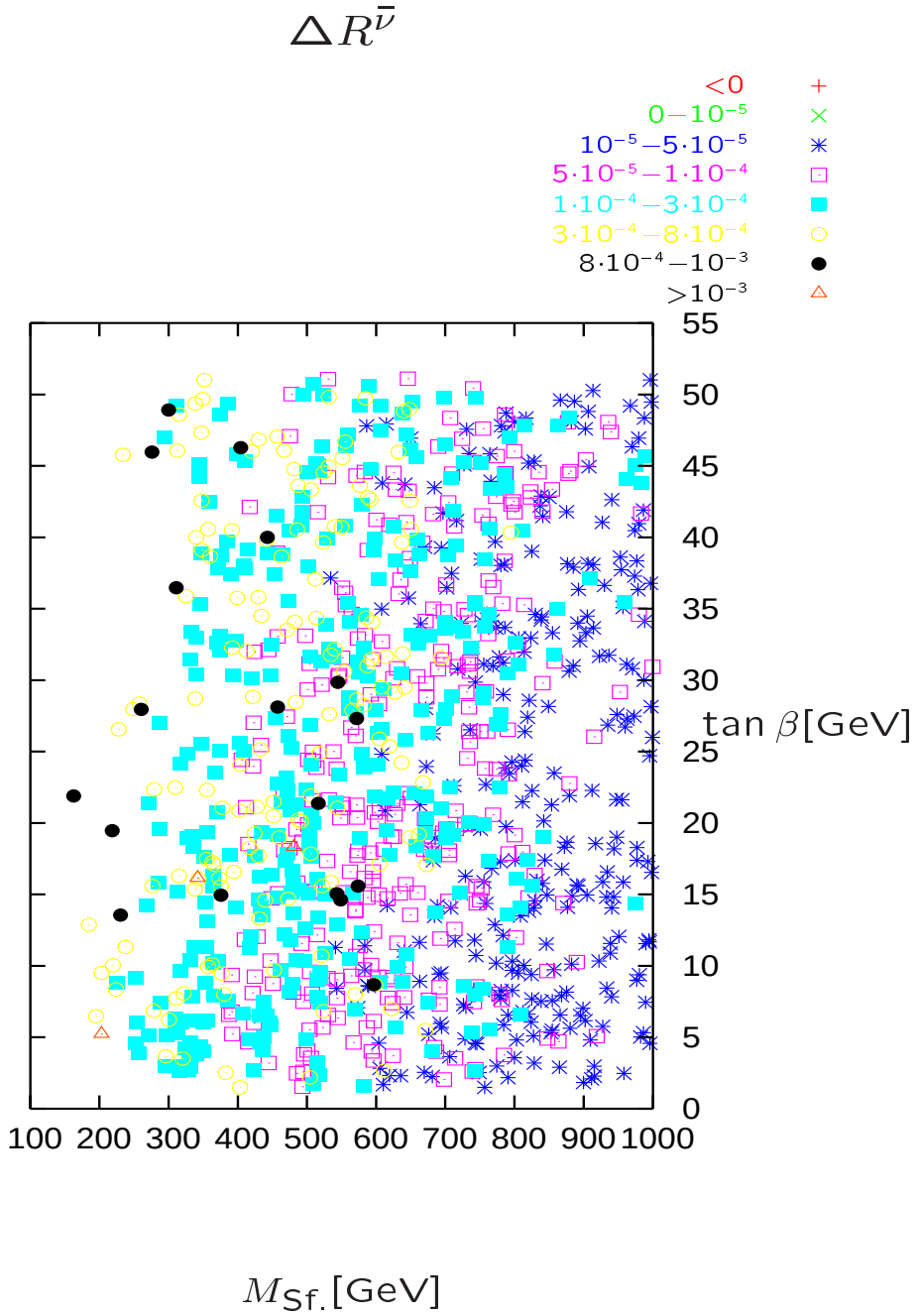
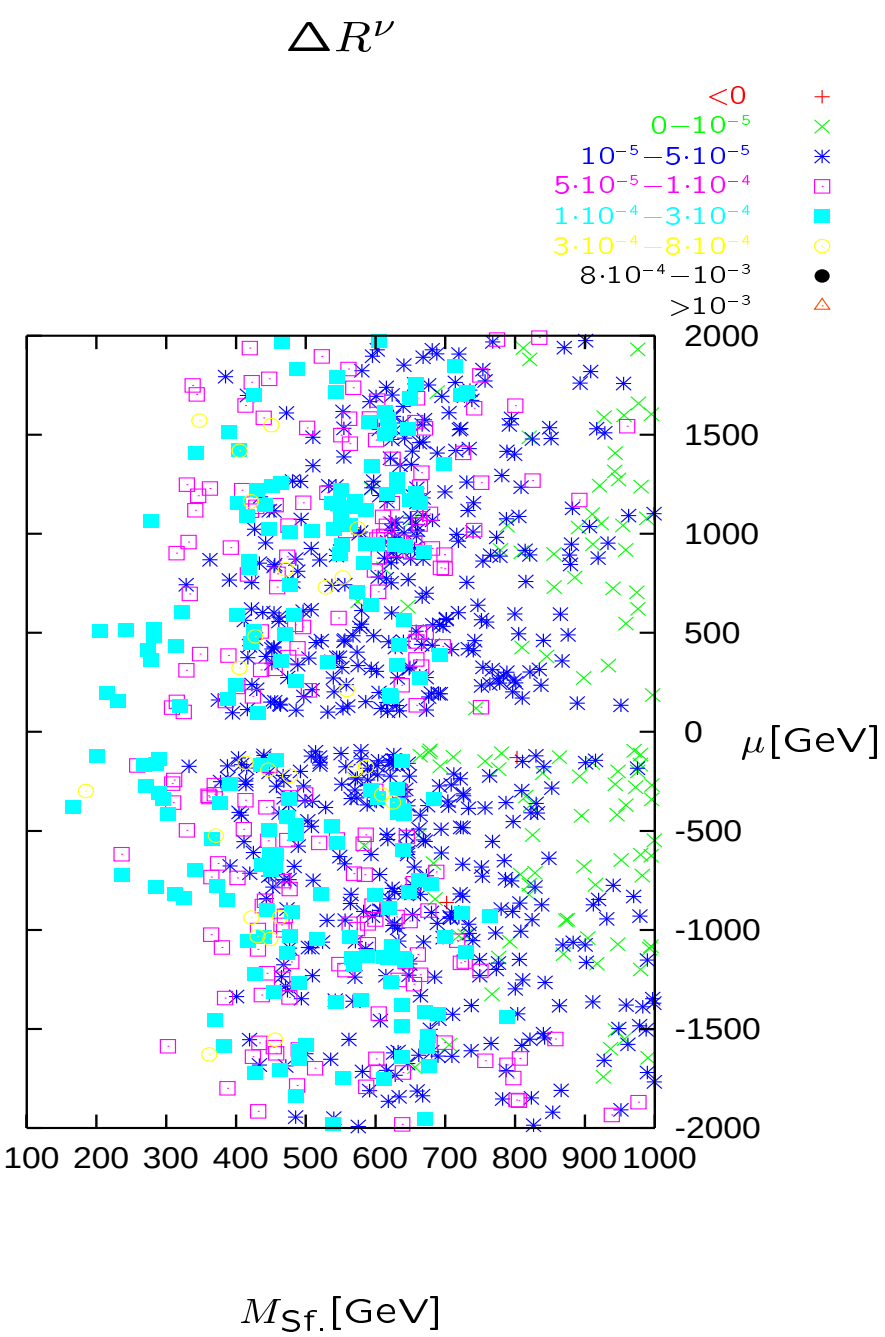
A_t[GeV]
100 200 300 400 500 600 700 800 900 1000
$M_{\mathrm{Sf.}}$[GeV]


ΔR^{ν}
<0
0−10⁻⁵
10⁻⁵−5·10⁻⁵
5·10⁻⁵−1·10⁻⁴
1·10⁻⁴−3·10⁻⁴
3·10⁻⁴−8·10⁻⁴
8·10⁻⁴−10⁻³
>10⁻³
tan β[GeV]
$M_{Sf.}$[GeV]


$\Delta R^{\bar{\nu}}$
<0
0−10⁻⁵
10⁻⁵−5·10⁻⁵
5·10⁻⁵−1·10⁻⁴
1·10⁻⁴−3·10⁻⁴
3·10⁻⁴−8·10⁻⁴
8·10⁻⁴−10⁻³
>10⁻³
tan β[GeV]
$M_{Sf.}$[GeV]


$\triangle R^{\nu}$
<0
0−10⁻⁵
10⁻⁵−5·10⁻⁵
5·10⁻⁵−1·10⁻⁴
1·10⁻⁴−3·10⁻⁴
3·10⁻⁴−8·10⁻⁴
8·10⁻⁴−10⁻³
>10⁻³
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μ[GeV]
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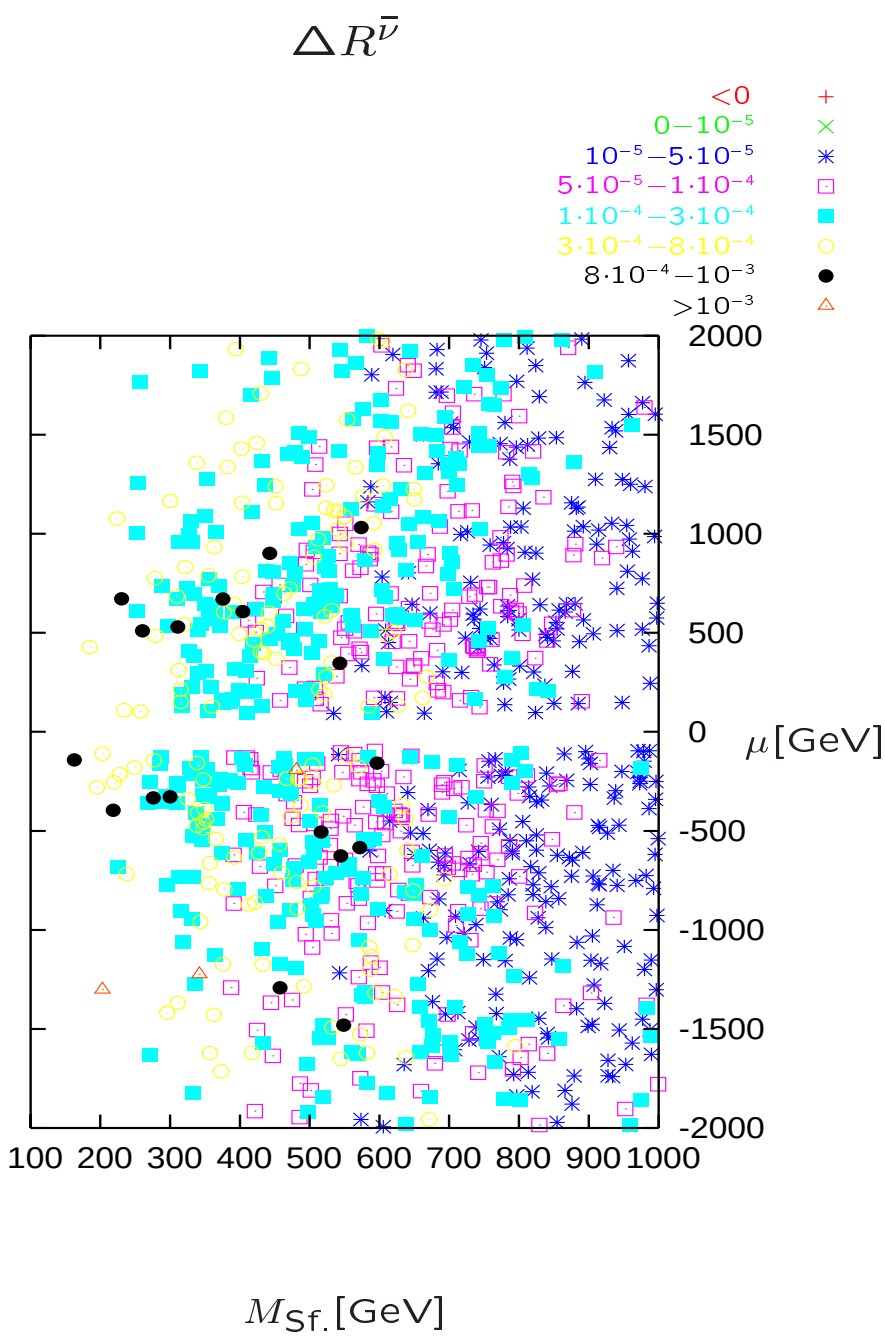
$M_{\mathrm{Sf.}}$[GeV]


$\triangle R^{\bar{\nu}}$
<0
0−10⁻⁵
10⁻⁵−5·10⁻⁵
5·10⁻⁵−1·10⁻⁴
1·10⁻⁴−3·10⁻⁴
3·10⁻⁴−8·10⁻⁴
8·10⁻⁴−10⁻³
>10⁻³
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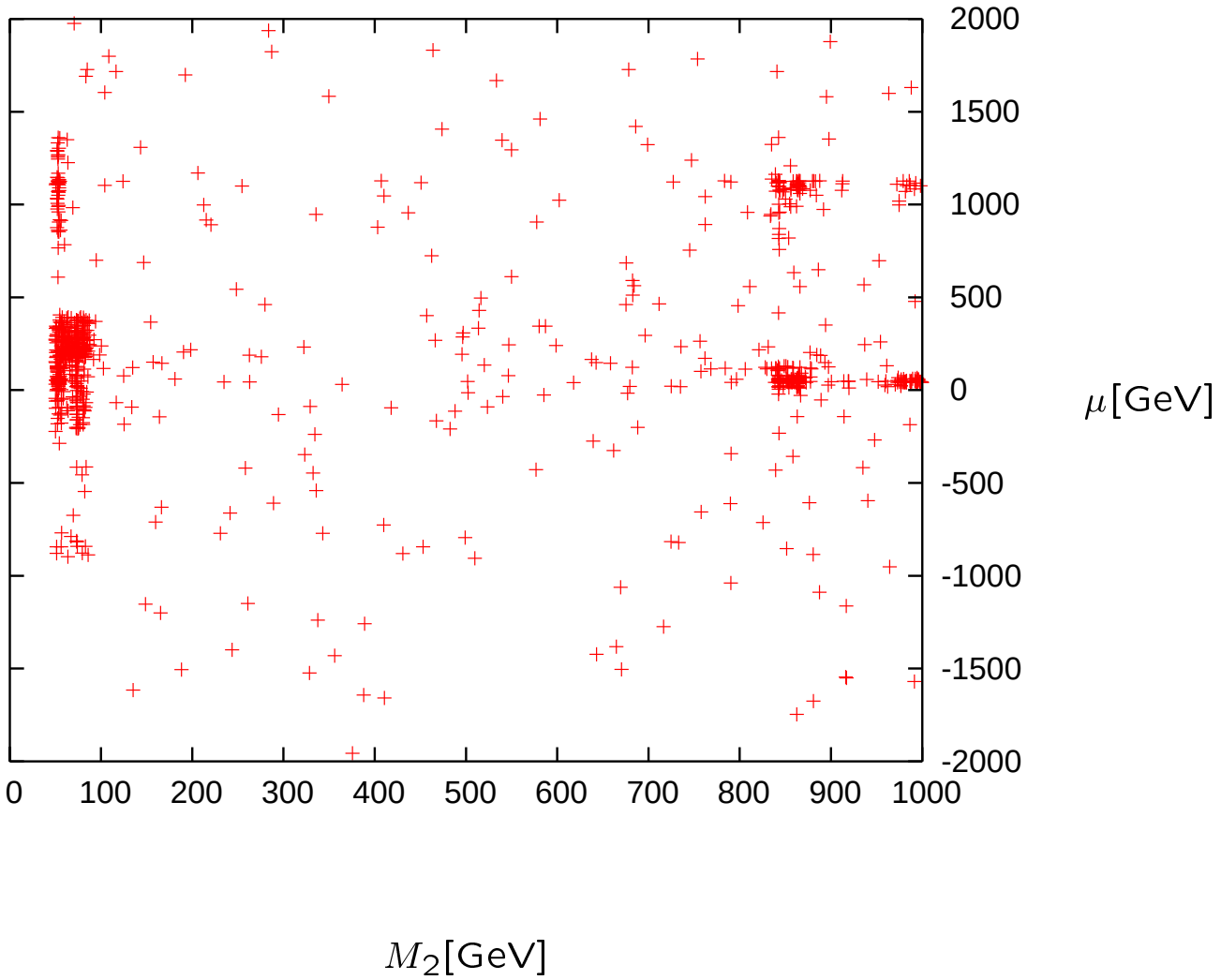
μ[GeV]
100 200 300 400 500 600 700 800 900 1000
$M_{\mathrm{Sf.}}$[GeV]

ΔR^{ν}


all points
2000
1500
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500
0
-500
-1000
-1500
-2000
0
100
200
300
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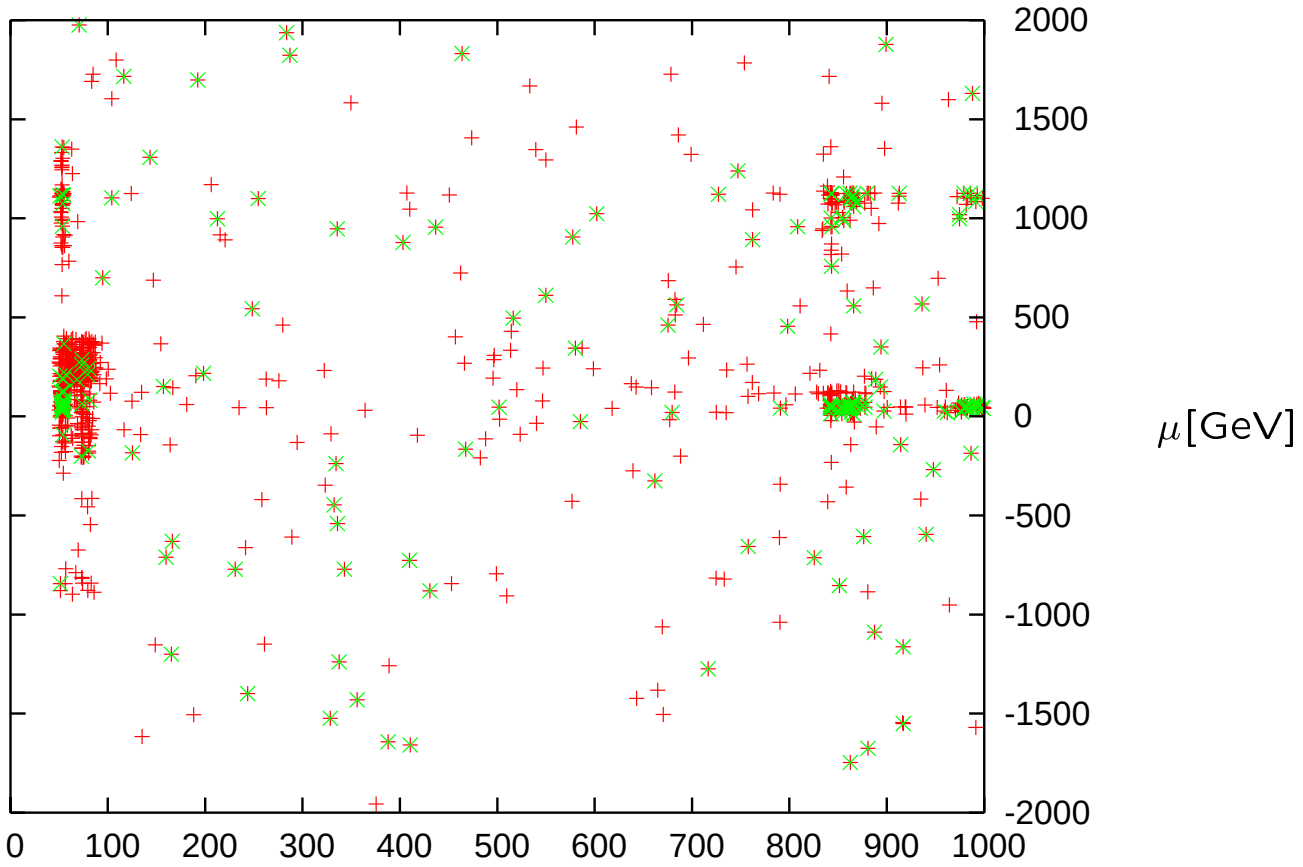
500
600
700
800
900
1000
μ[GeV]
M_2[GeV]

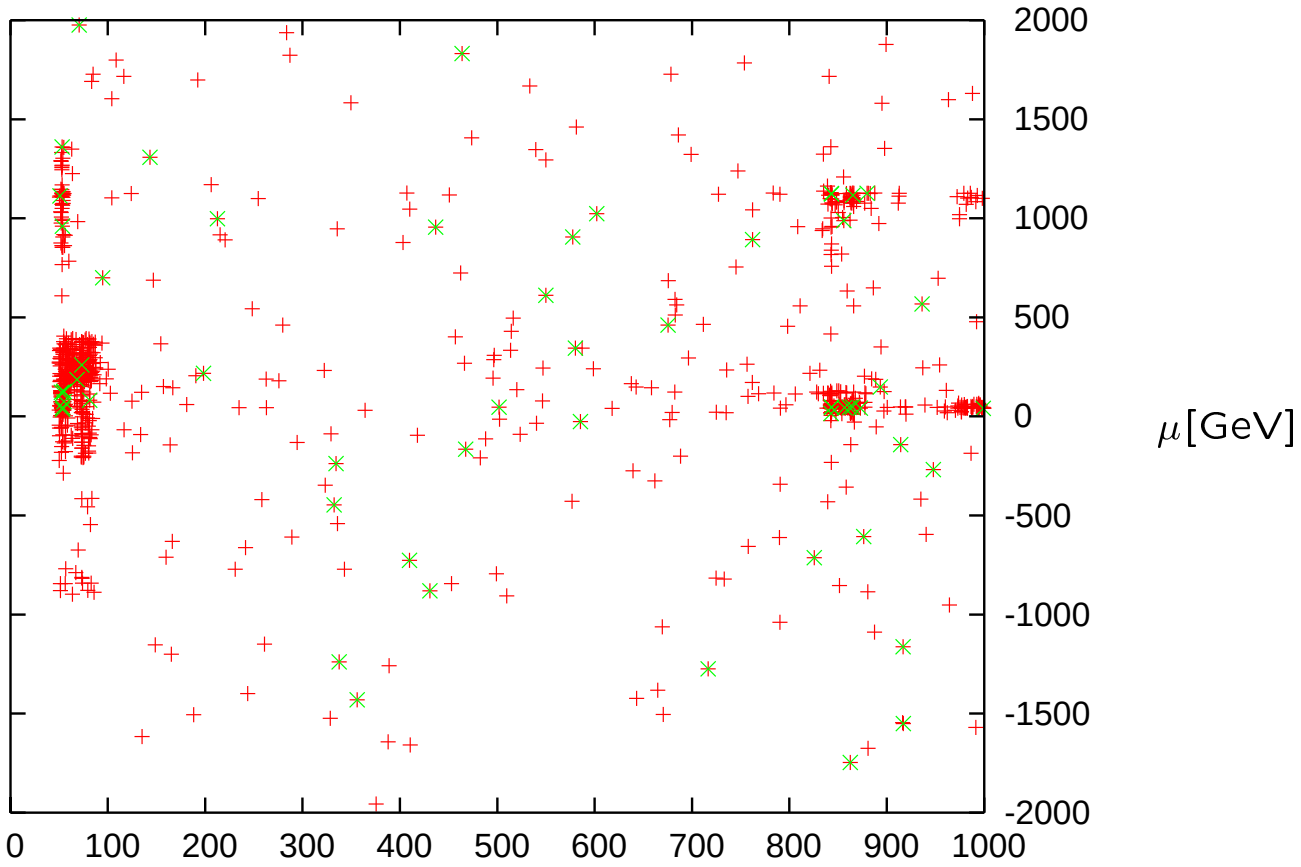
ΔR^{ν}

"Rnu.M1.M2.MGl.MSf.MU.tb.At.Ab.ma500.neg.sc.dat" u 3:6:(abs($1)) +
delta-rho ×



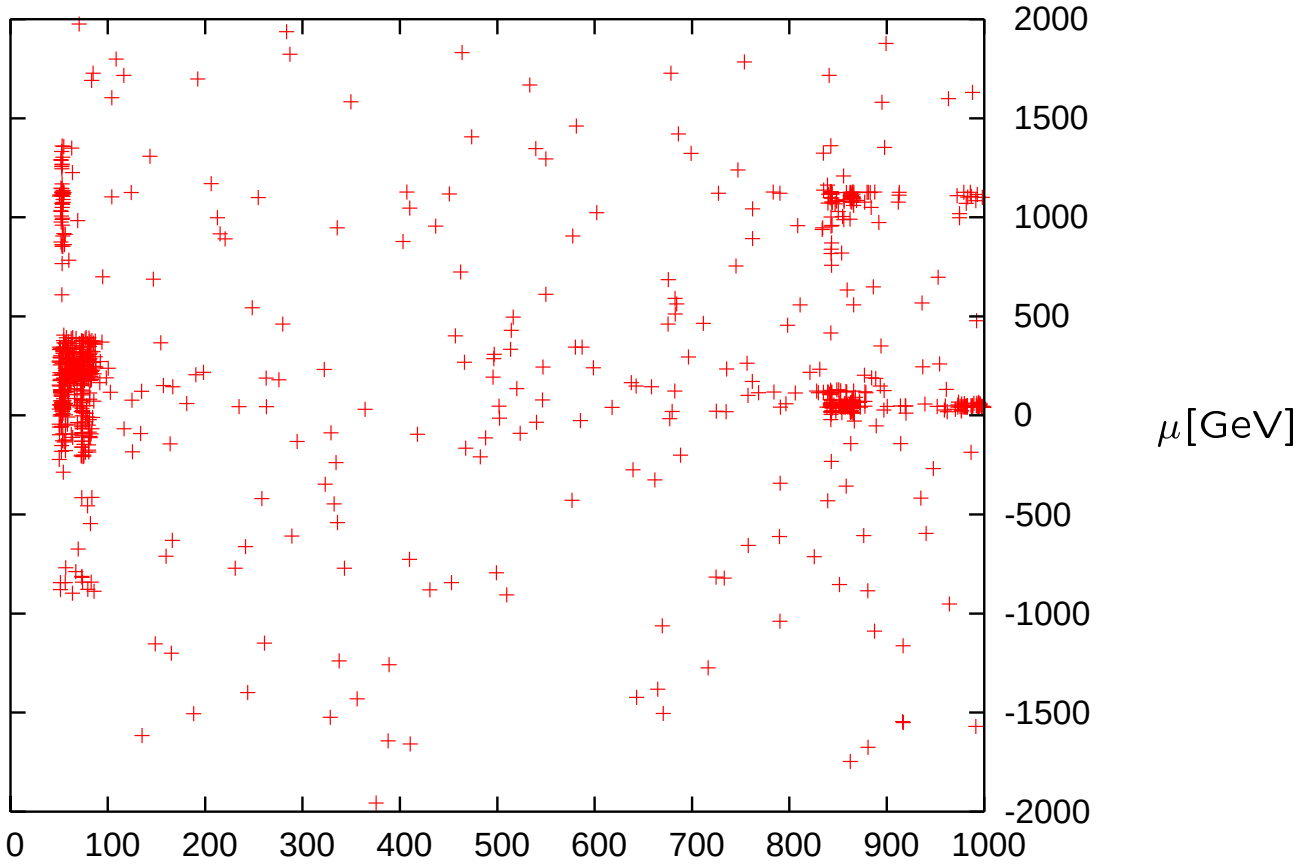
ΔR^{ν}

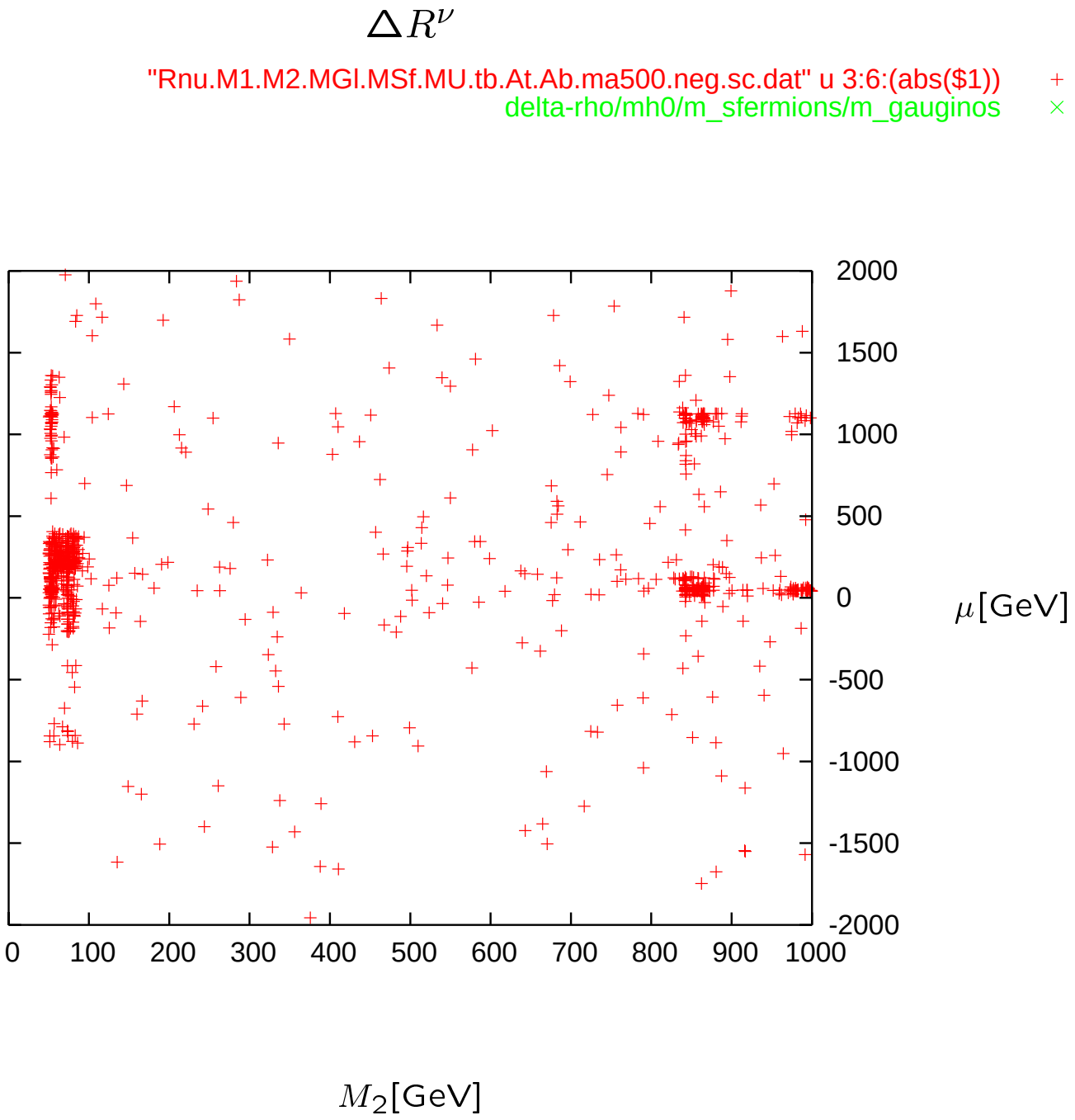
"Rnu.M1.M2.MGl.MSf.MU.tb.At.Ab.ma500.neg.sc.dat" u 3:6:(abs($1)) +
delta-rho/mh0 ×



ΔR^{ν}

"Rnu.M1.M2.MGl.MSf.MU.tb.At.Ab.ma500.neg.sc.dat" u 3:6:(abs($1)) +
delta-rho/mh0/m_sfermion ×




ΔR^{ν}
"Rnu.M1.M2.MGl.MSf.MU.tb.At.Ab.ma500.neg.sc.dat" u 3:6:(abs($1))
delta-rho/mh0/m_sfermions/m_gauginos
2000
1500
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-500
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μ[GeV]
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100
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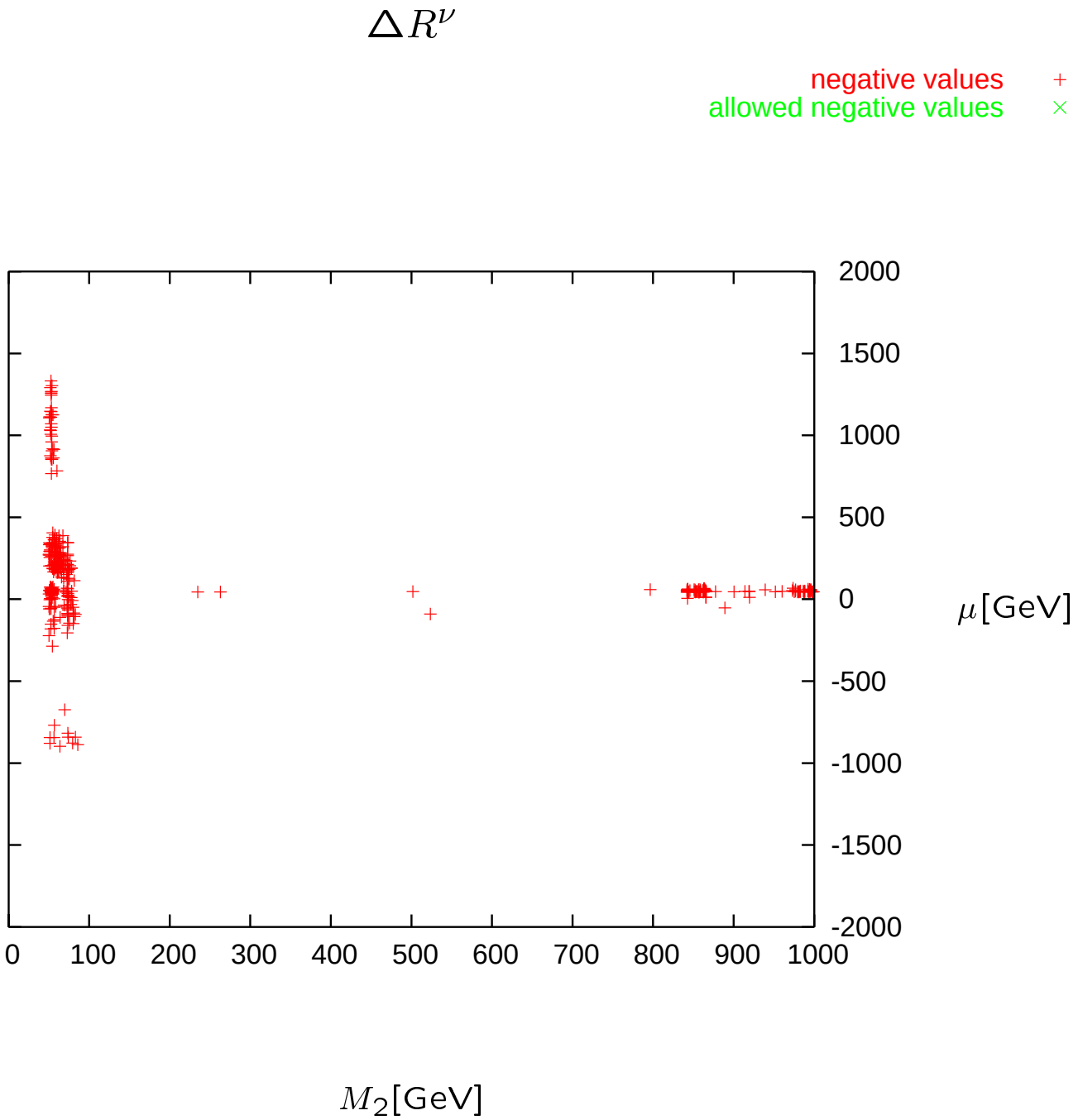
M_2[GeV]


ΔR^{ν}
negative values
allowed negative values
2000
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-2000
μ[GeV]
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800
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1000
M_2[GeV]

summary

- The NuTeV measurement of $\sin^2\theta_w$ is intriguing but has to be further established (especially confirmation by other experiment(s) is desirable).

- Loop effects in the MSSM are most likely not responsible for the NuTeV "anomaly". (size can be right, but sign is wrong).

- To make sure, a full analysis, including the MSSM-SM Higgs sector differences, is needed (and planned).

- If the "anomaly" is established, interesting restrictions on the MSSM parameters arise.