$g-2$ and New Physics

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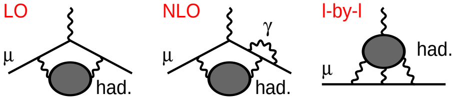
Based on **arXiv:1104.1769** by **G.-C. Cho**, **K. Hagiwara**, **DN** and **Yu Matsumoto**

Introduction: Standard Model prediction for muon $g-2$

QED contribution	11 658 471.808 (0.015) $\times 10^{-10}$	Kinoshita & Nio, Aoyama et al
EW contribution	15.4 (0.2) $\times 10^{-10}$	Czarnecki et al
Hadronic contribution		
LO hadronic	**694.9 (4.3)** $\times 10^{-10}$	HLMNT11
NLO hadronic	-9.8 (0.1) $\times 10^{-10}$	HLMNT11
light-by-light	10.5 (2.6) $\times 10^{-10}$	Prades, de Rafael & Vainshtein
Theory TOTAL	**11 659 182.8 (4.9)** $\times 10^{-10}$	
Experiment	**11 659 208.9 (6.3)** $\times 10^{-10}$	world avg
Exp − Theory	**26.1 (8.0)** $\times 10^{-10}$	**3.3 σ discrepancy**

(Numbers taken from HLMNT11, arXiv:1105.3149)

n.b.: hadronic contributions:



Muon $g-2$:

✓ Powerful probe for New Physics at TeV scale

✓ $\sim \boldsymbol{3\sigma}$ deviation between exp and theory (SM)

$\Longrightarrow$ Signal of new physics?

✓ Possible signal from EW sector of New Physics

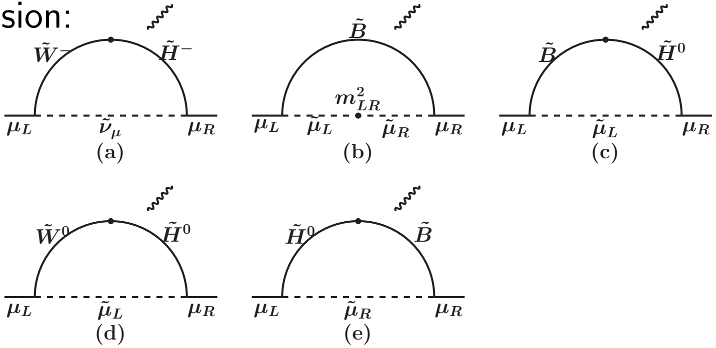
$\Longrightarrow$ What about other EW precision tests?

Now, the question is:
Suppose that a New Physics is responsible for the muon $g-2$ anomaly. **Is it possible for the New Physics to be compatible with the final LEP EW data?**
— **Important question to study BEFORE the LHC**
In this talk I take the MSSM as an example of new physics, since it is one of the most attractive models.

SUSY Contributions to Muon $g-2$

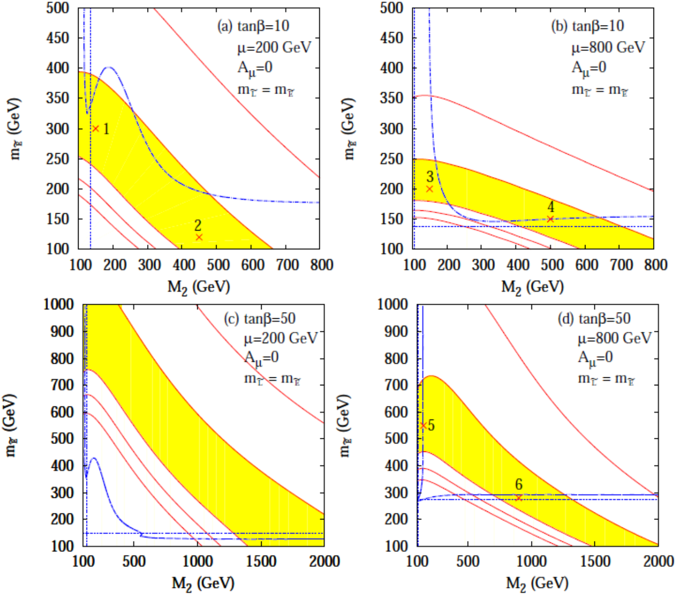
Suppose that the $\sim 3\sigma$ deviation is due to SUSY...

Leading **SUSY contributions** in the $m_Z/m_{\rm SUSY}$ expansion:



In most cases, the $\tilde{\chi}^{\pm}$-$\tilde{\nu}$ diagram (a) and/or the $\widetilde{B}$-$\widetilde{\mu}_{L/R}$ diagram (b) dominate. (Lopez-Nanopoulos-Wang, Chattopadhyay-Nath, Moroi, $\cdots$)

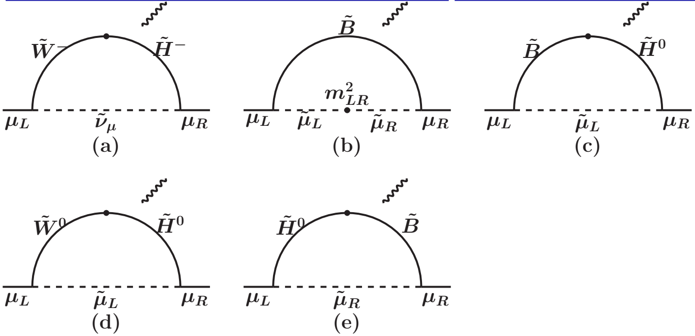
MSSM Contributions to Muon $g-2$



x-axis: M_2
(gaugino mass)

y-axis: $m_{\tilde{l}}$
(slepton mass)

Muon $g-2$ at MSSM sample points



No.	$\tan\beta$	μ	M_2	$m_{\tilde{E}}$	(a)	(b)	(c)	(d)	(e)	(a)-(e)	total
1	10	200	150	300	29.6	1.1	0.7	−2.9	−1.3	27.2	25.0
2	10	200	450	120	27.5	8.8	3.3	−7.1	−6.7	25.9	25.9
3	10	800	150	200	14.3	16.2	0.6	−2.7	−1.3	27.1	27.1
4	10	800	500	150	6.9	21.3	1.0	−2.5	−2.1	24.7	24.3
5	50	800	150	550	26.9	2.4	0.5	−2.6	−1.0	26.3	26.0
6	50	800	900	280	18.0	18.0	2.5	−5.9	−5.1	27.7	27.6

The chargino diagram (a) and/or the Bino-smuon$_{L,R}$ diagram (b) dominate in all the sample points.

Selected SUSY models and muon $g-2$

Selected SUSY Models

	$\tan\beta$	μ	$m_{\tilde{\mu}_L}$	$m_{\tilde{\mu}_R}$	A_μ	M_1	M_2
S G 1 (mSUGRA, $\tan\beta = 10$)	10	396	181	116	-445	103	193
S G 2 (mSUGRA, high $\tan\beta$)	50	762	585	465	-145	277	510
GM 1 (Gauge Med., high $\tan\beta$)	42	504	441	214	25	181	339
GM 2 (Gauge Med., $\tan\beta \sim 10$)	15	300	257	120	-39	169	327
MM1 (Mirage Med., $\alpha > 0$)	10	430	188	255	-465	170	258
MM2 (Mirage Med., $\alpha < 0$)	10	-572	253	108	245	-99	-248
MM3 (Mirage Med., $M_2 < M_1$)	10	534	200	237	509	224	173

Muon $g-2$ in the Selected SUSY Models

	(a)	(b)	(c)	(d)	(e)	(a)-(e)	total	pull
S G 1	25.7	21.5	1.5	-5.2	-5.4	38.1	37.6	1.2
S G 2	20.0	4.8	1.0	-3.4	-2.8	19.5	19.4	-1.0
GM 1	34.6	11.7	1.4	-5.3	-9.2	33.2	33.0	0.7
GM 2	27.1	10.6	1.6	-5.0	-9.0	25.3	24.8	-0.3
MM1	19.4	7.2	1.4	-4.5	-1.9	21.7	21.7	-0.7
MM2	13.2	18.8	0.7	-2.7	-4.2	25.8	24.7	-0.4
MM3	19.6	7.9	1.1	-3.8	-1.8	23.0	23.1	-0.5

Introduction to EW Precision Study

- **LEP-I** ('89 - '95): The Z-boson properties studied in great detail using 17 millions of Z boson decays. (Final report appeared in 2005: `hep-ex/0509008`)
- To confront the EW precision data with theory, the S, T, U **parameters** are useful (Peskin+Takeuchi).

$$\gamma \sim\bullet\sim \gamma = i\, e^2\, \Pi_{QQ}\, g^{\mu\nu} + \cdots$$

$$Z \sim\bullet\sim \gamma = i\, \frac{e^2}{cs} (\Pi_{3Q} - s^2 \Pi_{QQ})\, g^{\mu\nu} + \cdots$$

$$Z \sim\bullet\sim Z = i\, \frac{e^2}{c^2 s^2} (\Pi_{33} - 2s^2 \Pi_{3Q} + s^4 \Pi_{QQ})\, g^{\mu\nu} + \cdots$$

$$W \sim\bullet\sim W = i\, \frac{e^2}{s^2}\, \Pi_{11}\, g^{\mu\nu} + \cdots$$

$$\alpha S \equiv 4e^2 \left[\Pi'_{33}(0) - \Pi'_{3Q}(0)\right],$$

$$\alpha T \equiv \frac{e^2}{s^2 c^2 m_Z^2} \left[\Pi_{11}(0) - \Pi_{33}(0)\right],$$

$$\alpha U \equiv 4e^2 \left[\Pi'_{11}(0) - \Pi'_{33}(0)\right].$$

In this talk, we use an improved version, S_Z, T_Z **and** M_W (Hagiwara, Haidt, Kim & Matsumoto).

S_Z and T_Z (1)

We define the 'bar charges' as

$$\bar{e}^2(q^2) \equiv \hat{e}^2(\mu)\left[1 - \overline{\Pi}^{\gamma\gamma}_{T,\gamma}(q^2)\right], \quad \bar{s}^2(q^2) \equiv \hat{s}^2(\mu)\left[1 + \frac{\hat{c}(\mu)}{\hat{s}(\mu)}\overline{\Pi}^{\gamma Z}_{T,\gamma}(q^2)\right],$$

$$\bar{g}^2_Z(q^2) \equiv \hat{g}^2_Z(\mu)\left[1 - \overline{\Pi}^{ZZ}_{T,Z}(q^2)\right], \quad \bar{g}^2_W(q^2) \equiv \hat{g}^2_W(\mu)\left[1 - \overline{\Pi}^{WW}_{T,W}(q^2)\right],$$

where $\overline{\Pi}^{AB}_{T,V}(q^2) \equiv [\overline{\Pi}^{AB}_T(q^2) - \overline{\Pi}^{AB}_T(m_V^2)]/[q^2 - m_V^2]$ and the hat means the $\overline{\text{MS}}$ coupling. In terms of the bar charges, the S, T and U parameters can be written as

$$\frac{\bar{s}^2(m_Z^2)\bar{c}^2(m_Z^2)}{\bar{\alpha}(m_Z^2)} - \frac{4\pi}{\bar{g}^2_Z(0)} = \frac{S}{4},$$

$$\frac{\bar{s}^2(m_Z^2)}{\bar{\alpha}(m_Z^2)} - \frac{4\pi}{\bar{g}^2_W(0)} = \frac{S+U}{4},$$

$$1 - \frac{\bar{g}^2_W(0)}{m_W^2}\frac{m_Z^2}{\bar{g}^2_Z(0)} = \alpha T.$$

S_Z and T_Z (2)

The S, T and U parameters:

$$
\begin{aligned}
\frac{\bar{s}^2(m_Z^2)\bar{c}^2(m_Z^2)}{\bar{\alpha}(m_Z^2)} - \frac{4\pi}{\bar{g}_Z^2(0)} &= \frac{S}{4}, \\
\frac{\bar{s}^2(m_Z^2)}{\bar{\alpha}(m_Z^2)} - \frac{4\pi}{\bar{g}_W^2(0)} &= \frac{S+U}{4}, \\
1 - \frac{\bar{g}_W^2(0)}{m_W^2}\frac{m_Z^2}{\bar{g}_Z^2(0)} &= \alpha T.
\end{aligned}
$$

The last eq. can be written as

$$\frac{1}{\bar{g}_Z^2(0)} = \frac{1 - \alpha T + \bar{\delta}_G}{4\sqrt{2}G_F m_Z^2},$$

We are more interested in physics at the Z pole $\Longrightarrow$ Replace $\bar{g}_Z(0)$ with $\bar{g}_Z(m_Z^2)$: (S_Z and T_Z parameters)

S_Z-T_Z Plane Analysis

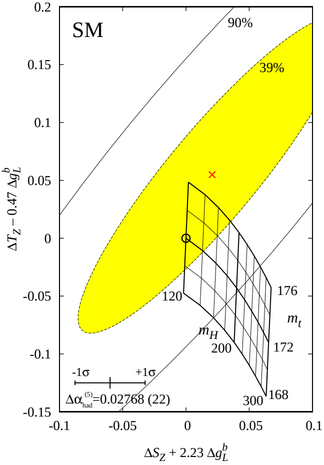
1. Calculate $\mathcal{O}_i^{\rm th}(\Delta S_Z, \Delta T_Z, \ldots)$, where $\mathcal{O}_i$ are EW precision observables $(\Gamma_Z, \sigma_h^0, A_f, \ldots)$.

2. Construct the χ^2 function as

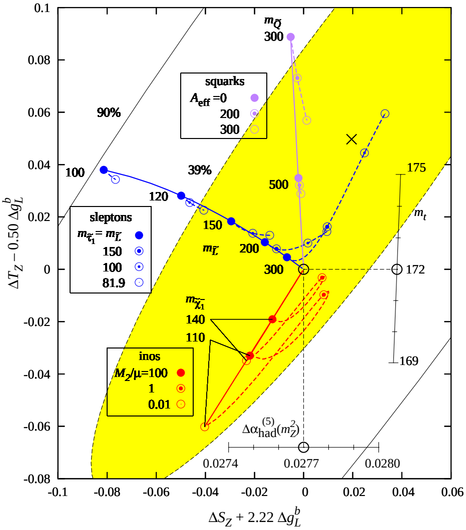
$$\chi^2 = \sum_{i,j} \left(\mathcal{O}_i^{\rm th}(\Delta S_Z, \Delta T_Z, \ldots) - \mathcal{O}_i^{\rm exp}\right) \times \left(V^{-1}\right)_{ij} \left(\mathcal{O}_j^{\rm th}(\Delta S_Z, \Delta T_Z, \ldots) - \mathcal{O}_j^{\rm exp}\right),$$

where V is the covariance matrix,
$V_{ij} = (\delta\mathcal{O}_i^{\rm exp})(\delta\mathcal{O}_j^{\rm exp})\rho_{ij}$.

3. Find the minimum of χ^2 with respect to ΔS_Z, ΔT_Z etc. Draw the contours $\chi^2 - \chi^2_{\rm min} = {\rm const}$ if necessary.



EW Precision Data vs MSSM, (I) S_Z-T_Z plane analysis



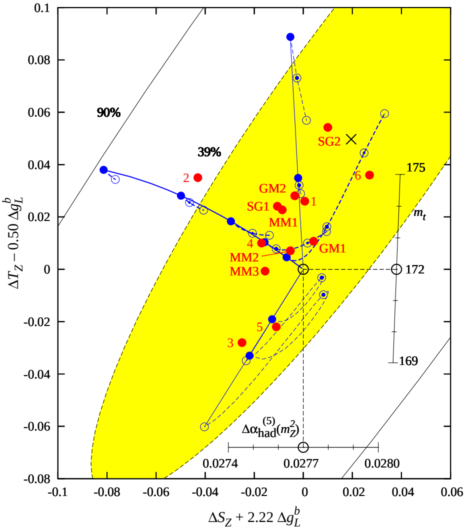
Using the final LEP EW precision data, we can give a constraint on MSSM contributions to S_Z and T_Z.

Our Results:

✓ The SM with $m_H \sim 100$ GeV gives a good description.

✓ In the MSSM, light sfermions tend to be disfavored.

EW Precision Data vs MSSM, (II) S_Z-T_Z plane analysis

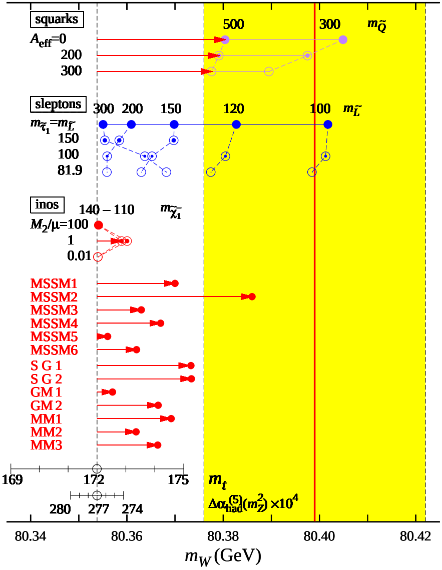


Using the final LEP EW precision data, we can give a constraint on MSSM contributions to $\boldsymbol{S_Z}$ and $\boldsymbol{T_Z}$.

Our Results:

✓ All the sample points are within or close to the 1-$\boldsymbol{\sigma}$ favored region.

EW Precision Data vs MSSM (III), M_W



In our framework, M_W is a calculable quantity, which can be compared to the data.

Our Results:

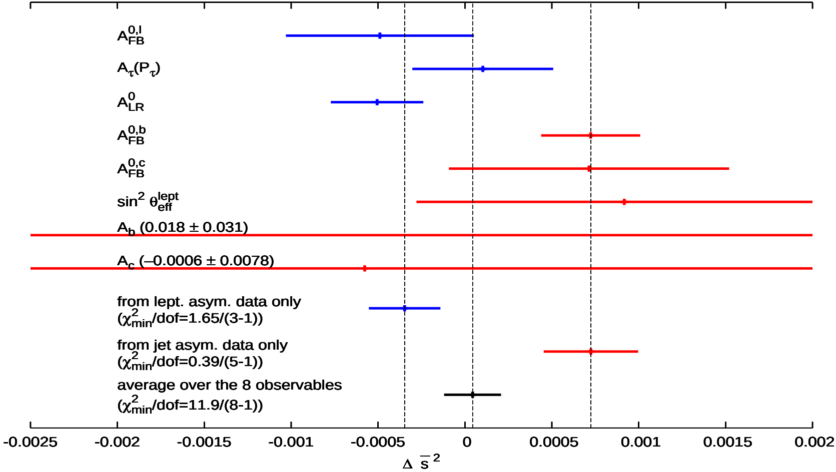
✓ Light squarks and sleptons tend to make the fit better.

✓ Inos do not give contributions to Δm_W very much.

✓ The MSSM with $\mathcal{O}(100)$ GeV SUSY masses gives a good description.

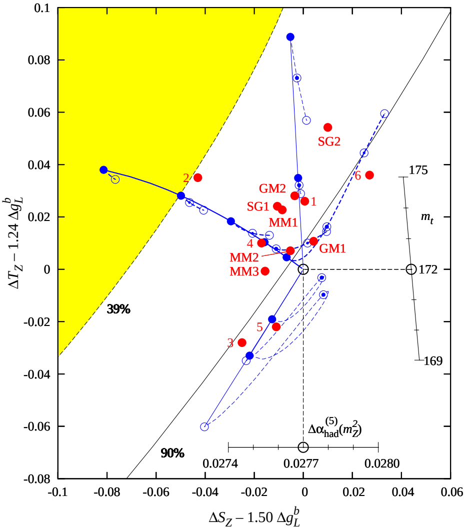
But this is not the full story...

Problem in Jet Asymmetry Data?



The value of the effective mixing angle $\bar{s}^2$ determined from leptonic asymmetry data and that from jet asym. data do not agree very well

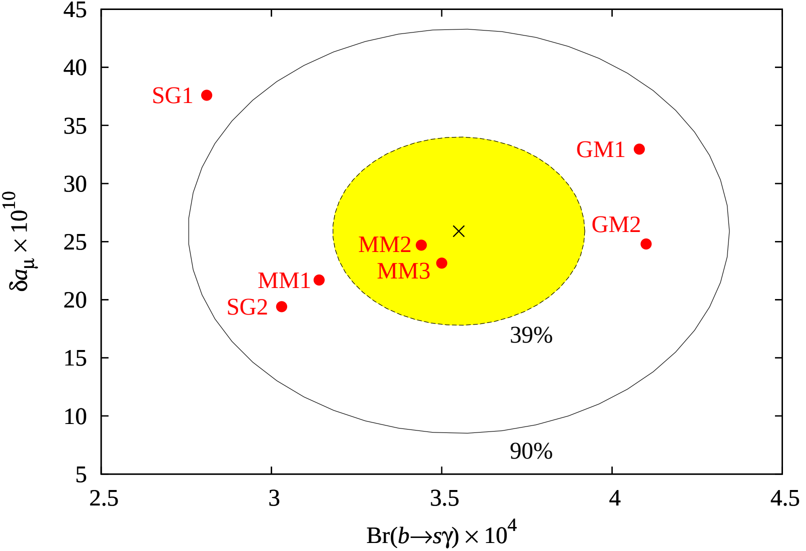
$\Longrightarrow$ **problem in jet asym. data (or in the analysis)?**



If we do not use the jet asymmetry data, the favored rigion shifts to the left. (Negative $\boldsymbol{\Delta S_Z}$ is favored.)

✓ Light sleptons are favored.

Constraints from muon $g-2$ and $b \to s\gamma$



Summary

- We have studied the favored parameter region of MSSM using the results of the muon $g-2$ and the EW precision data.
- From muon $g-2$: when $\tan\beta = 10$, the slepton mass of a few hundred GeV is favored. When $\tan\beta = 50$, the sleptons as heavy as 1 TeV are allowed within 1-σ.
- From EW precision data: SUSY particles of a few hundred GeV are OK.
- In well-studied models like mSUGRA, Gauge Med. and Mirage Med. there still is some parameter region favored from muon $g-2$ and EW precision data.
- If we leave out the jet asymmetry data, light sleptons become more favored, which is favored from muon $g-2$ as well.