MUON ANOMALOUS MAGNETIC MOMENT CONSTRAINTS ON SUPERSYMMETRIC U(1)' MODELS

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What is muon anamalous magnetic moment?

MUON ANOMALOUS MAGNETIC MOMENT

CONSTRAINTS ON

SUPERSYMMETRIC U(1)' MODELS

What are the U(1)' models?
and
Why do we need this model?

OUTLINE

- **Introduction**
  - Goal of the Study
- **U(1)' Models**
  - Comparison of the Models
  - Motivations for U(1)' Models
- **Analysis**
  - Parameters
  - Results
- **Conclusion**

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INTRODUCTION

- What is the muon anomalous magnetic moment ?

$$a_\mu = \frac{g-2}{2}$$

The value of the gyromagnetic ratio @ tree level, $g = 2$

Discrepancy from $g_{tree} = 2$

- Experimental result @ Brookhaven National Laboratory E821 experiment

$$a_\mu^{Exp} = (116592089 \pm 63) \times 10^{-11}$$

- Theoretical prediction: $a_\mu^{SM} = (116591773 \pm 48) \times 10^{-11}$

Smaller than a_μ^{Exp}

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- $\delta a_\mu = a_\mu^{Exp} - a_\mu^{SM} = (316 \pm 79) \times 10^{-11}$ corresponds to $3-4\sigma$ difference.

Deviation of the muon magnetic moment

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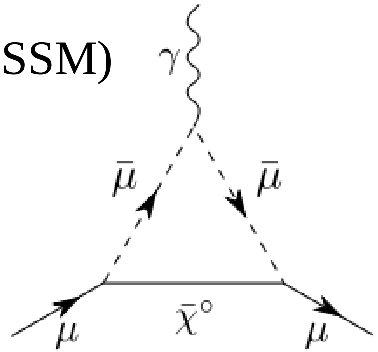
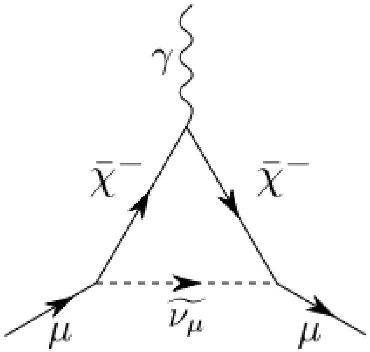
Deviation of the muon magnetic moment → **New Physics**

INTRODUCTION

- New Physics → Supersymmetry (SUSY)
- Minimal Supersymmetric Standard Model (MSSM)
- $\delta a_\mu \approx a_\mu^{MSSM}$

$$a_\mu^{MSSM} = a_\mu^{MSSM}\left(\tilde{\chi}^0\right) + a_\mu^{MSSM}\left(\tilde{\chi}^\pm\right)$$





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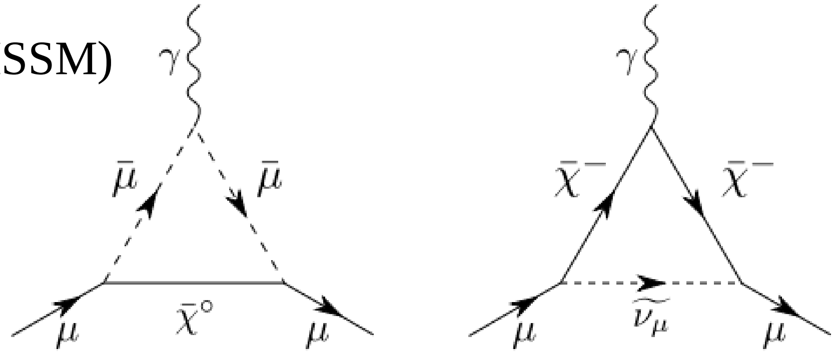

- $$\delta a_\mu \approx a_\mu^{MSSM}$$

$$a_\mu^{MSSM} = a_\mu^{MSSM}\left(\tilde{\chi}^0\right) + a_\mu^{MSSM}\left(\tilde{\chi}^\pm\right)$$

- MSSM → μ problem → U(1)' Model

Gauge Extended Supersymmetric Model
$$SU(3)\otimes SU(2)\otimes U(1)\otimes U(1)'$$

- $$\delta a_\mu \approx a_\mu^{U(1)'}$$

$$a_\mu^{U(1)'} = a_\mu^{U(1)'}\left(\tilde{\chi}^0\right) + a_\mu^{U(1)'}\left(\tilde{\chi}^\pm\right)$$

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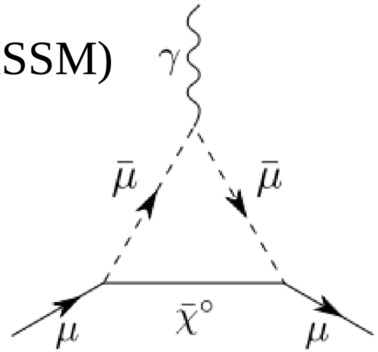

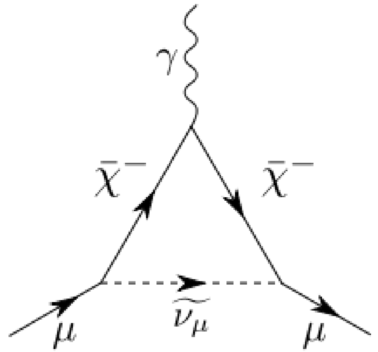

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- MSSM → μ problem → U(1)' Model

Gauge Extended Supersymmetric Model
$SU(3) \otimes SU(2) \otimes U(1) \otimes U(1)'$

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$$a_{\mu}^{U(1)'} = a_{\mu}^{U(1)'}\left(\tilde{\chi}^{0}\right) + a_{\mu}^{U(1)'}\left(\tilde{\chi}^{\pm}\right)$$

- If this discrepancy (δa_{μ}) is actual and SUSY exists then which U(1)' model could be the most viable one?

Goal of the Study

- We studied δa_μ in different U(1)' models (Generic & E_6 based U(1)' models):
  - To probe the model reactions
  - To **find constraints** on the large parameter space of these models

- By using the constrained parameter space,
  - we **made predictions** for m_h and m_{Z_2} which can be illuminating for future measurements.

lightest Higgs boson mass (m_h)

additional Z boson mass (m_{Z_2})

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THE MODELS

PROPERTIES \ MODELS	SM Standard Model	MSSM Minimal Supersymmetric Model	U(1)' MODEL Gauge-Extended MSSM
Gauge group	$SU(3)\otimes SU(2)\otimes U(1)$	$SU(3)\otimes SU(2)\otimes U(1)$	$SU(3)\otimes SU(2)\otimes U(1)\otimes U(1)'$
Gauge fields	$G_{1,2....,8}, W_{1,2,3}$ & B_μ	$G_{1,2....,8}, W_{1,2,3}$ & B_μ	$G_{1,2....,8}, W_{1,2,3}, B_\mu$ & B'_μ
Higgs fields	$H=\begin{pmatrix} H^+ \\ H^0 \end{pmatrix}$	$H_u=\begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix}$ $H_d=\begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix}$	$H_u=\begin{pmatrix} H_u^+ \\ H_u^0 \end{pmatrix}$ $H_d=\begin{pmatrix} H_d^0 \\ H_d^- \end{pmatrix}$ S
Gauge bosons	$G_{1,2....,8}, W^\pm, Z, A_\mu$	$G_{1,2.....,8}, W^\pm, Z, A_\mu$	$G_{1,2.....,8}, W^\pm, Z, Z', A_\mu$
Higgs bosons	h	h, H, A & $H^\pm$	h, H, H', A & $H^\pm$

U(1)' Models

μ Problem of MSSM

$$W = -\mu H_u . H_d + h_u Q . H_u U + h_d Q . H_d D + h_e L . H_d E$$

- has a dimension
- its scale → arbitrary

dimensionless

- μ must be fixed to the EW scale!

U(1)’ Models

μ Problem of MSSM

$$W = -\mu H_u.H_d + h_u Q.H_u U + h_d Q.H_d D + h_e L.H_d E$$

- has a dimension
- its scale → arbitrary

dimensionless

- μ must be fixed to the EW scale!

Generic U(1)’ Models

- come from *low-energy*
- motivated by μ problem alone,
- There is one additional gauge group and singlet S

$$\mu_{eff} = h_s \langle S \rangle$$

$$W \ni \mu_{eff} H_u.H_d = h_s \langle S \rangle H_u.H_d$$

$h_s \to$ dimensionless

$\langle S \rangle \approx$ EW scale

E_6 based U(1)’ Models

- come from *high-energy*
- motivated by μ problem
- motivated by string theory of SUSY GUTS

$$E(6) \to SO(10) \otimes U(1)_\psi \to SU(5) \otimes U(1)_\chi \otimes U(1)_\psi \to$$

$$\to G_{SM} \otimes U(1)'$$

$$U(1)' = \cos\theta_{E_6} U(1)_\psi - \sin\theta_{E_6} U(1)_\chi$$

θ_{E_6} (mixing angle)

the breaking direction

in $U(1)_\chi \otimes U(1)_\psi$ space

- For different values of θ_{E_6} there are different $U(1)'$ models based on E(6) groups. $\theta_{E_6} \to [0, \pi]$

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    - **Predictions** for m_h and M_{Z_2}
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Parameters

Collider Bounds on the Higgs and Sparticle Masses $m_h > 114.4 GeV$ $m_{\tilde{t}_1} > 180 GeV$ $m_{\tilde{b}_1} > 240 GeV$ $m_{\tilde{\chi}_1^0} > 50 GeV$ $m_{\tilde{\chi}_1^\pm} > 170 GeV$	Mass of the Gauginos $50 < M_1 < 500\ GeV$ $50 < M_2 < 500\ GeV$ $50 < M_1^{'} < 2000\ GeV$
Scalar Quark Masses : Two cases: 1) $m_{\tilde{q}} \leq 2\ TeV$ 2) $m_{\tilde{q}} \leq 1\ TeV$	Z' boson mass : $M_{Z2} > 700\ GeV$ $M_{Z2} \leq 3\ TeV$ Mixing angle : $\lvert\theta_{Z-Z'}\rvert < 10^{-3}$
Trilinear Couplings $A_t,\ A_b,\ A_s,\ A_\mu \leq 1\ TeV$	Squark Soft Mass-Squareds $m_{\tilde{Q}}, m_{\tilde{t}_R}, m_{\tilde{b}_R} \approx [0,1]\ TeV$
Higgsino Yukawa Coupling : $0.1 < h_s < 0.8$	Singlet VEVs : $v_s \leq 10\ TeV$ to obtain large M_{Z2} values $M_{Z2} \approx 3\ TeV$
Muon Anomalous Magnetic Moment: We discard $a_\mu < 0$ regions → $\delta a_\mu > 0$	Charges under U(1)' symmetry: $Q_u, Q_d, Q_Q, Q_L \Rightarrow [-1, 1]$ Q_s, Q_U, Q_D, Q_E →from gauge invariance condition

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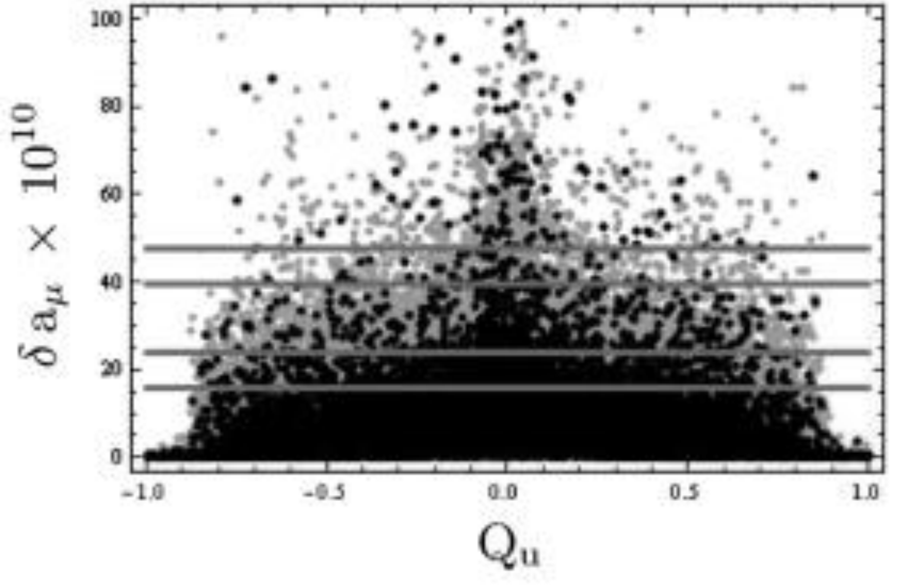
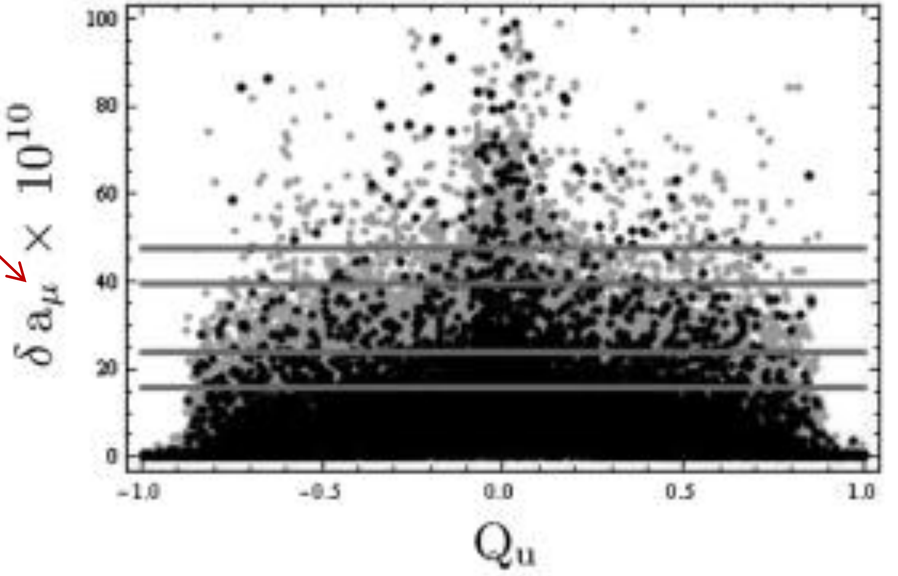
❖ Explanation of Figure Structure



❖ Explanation of Figure Structure

$\delta a_\mu \times 10^{10}$

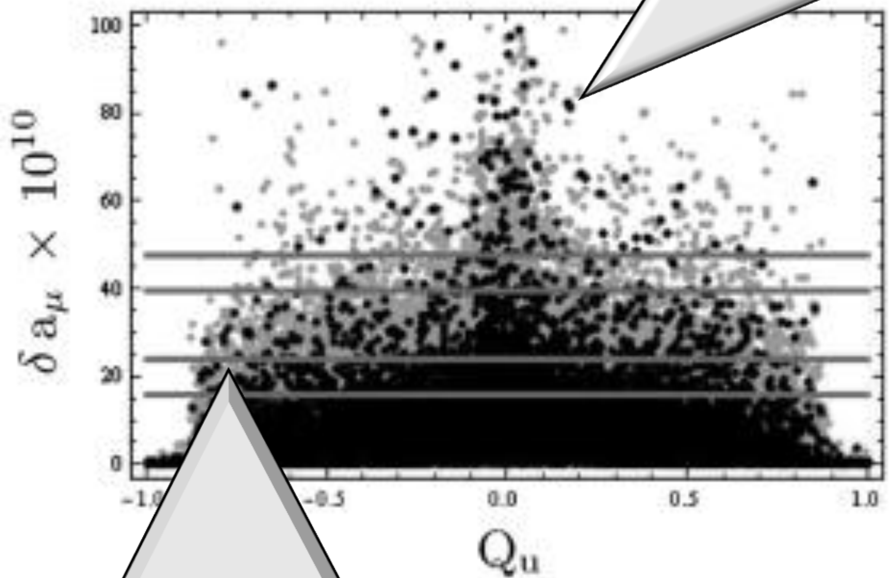


Free Parameters:

$$Q \quad \& \quad M_{Z_2} \quad \& \quad \tan\beta = \frac{v_u}{v_d}$$

❖ Explanation of Figure Structure

Black dots correspond to values when $m_{\tilde{f}} \leq 1\ TeV$



Grey dots correspond to values when $m_{\tilde{f}} \leq 2\ TeV$

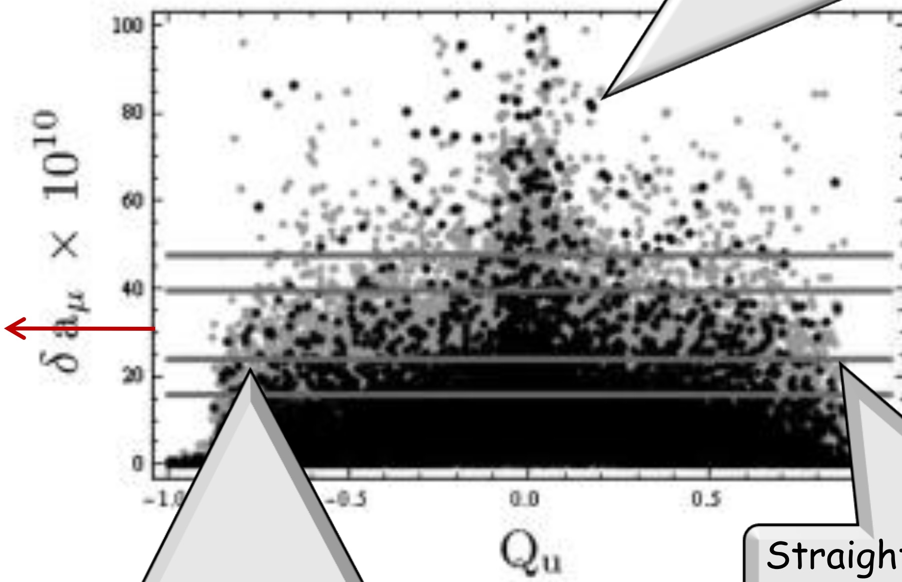
❖ Explanation of Figure Structure

Black dots correspond to values when $m_{\tilde{f}} \leq 1\ TeV$

$1\ \sigma$ ✓

$2\ \sigma$

$\delta a_{\mu} = (31.6 \pm 7.9) \times 10^{-10}$



Straight grey lines → 1σ, 2σ values

Grey dots correspond to values when $m_{\tilde{f}} \leq 2\ TeV$

δa_μ versus Q_i where $i = u, d, s, Q, U, D$; $\delta a_\mu = (31.6 \pm 7.9) \times 10^{-10}$

Generic U(1)' models

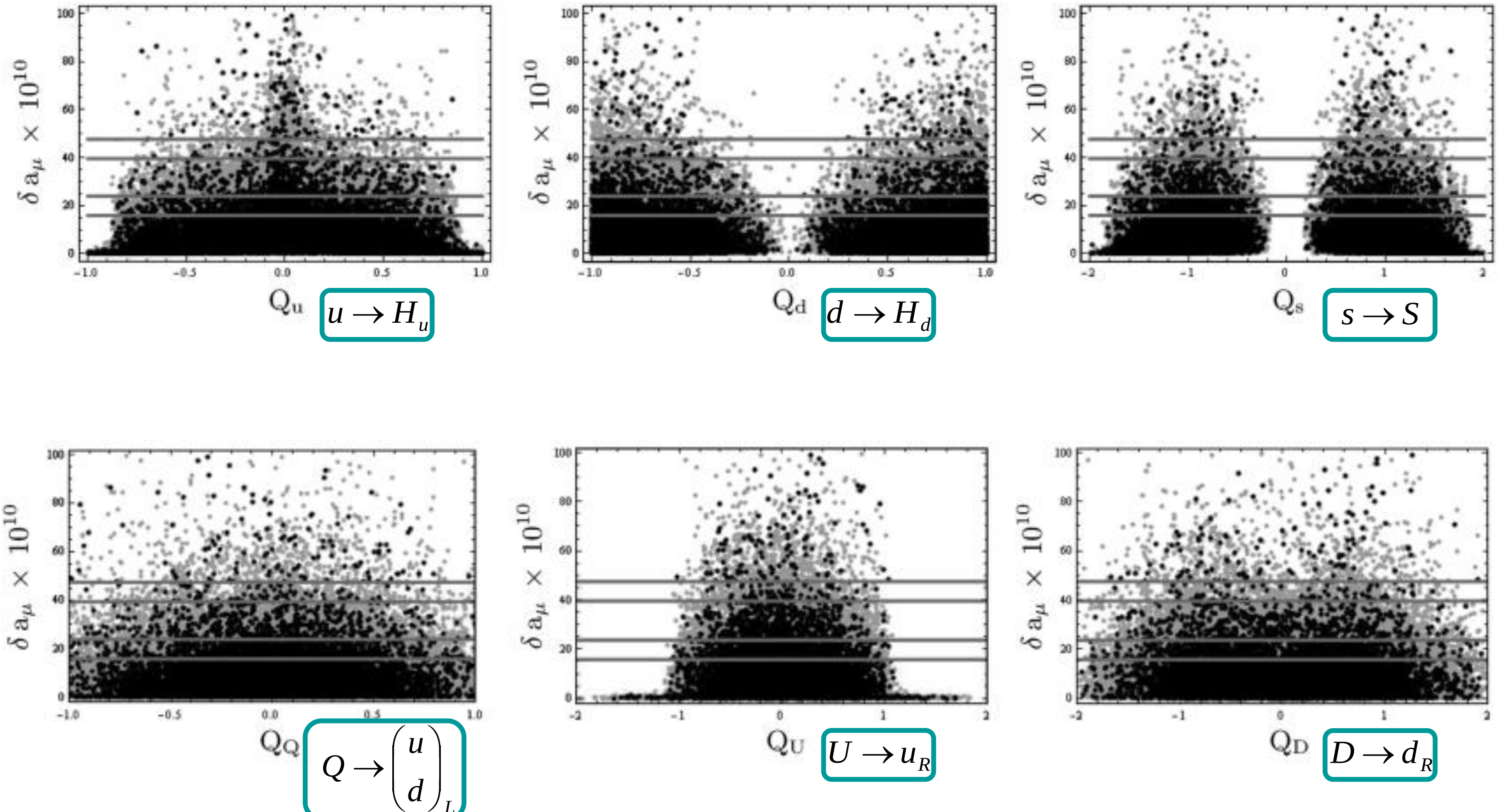


Fig-1: The allowed ranges of the U(1)' charges vs δa_μ **in generic U(1)' models**.

δa_μ *versus* Q_i *where* $i = u, d, s, Q, U, D$; $\delta a_\mu = (31.6 \pm 7.9) \times 10^{-10}$

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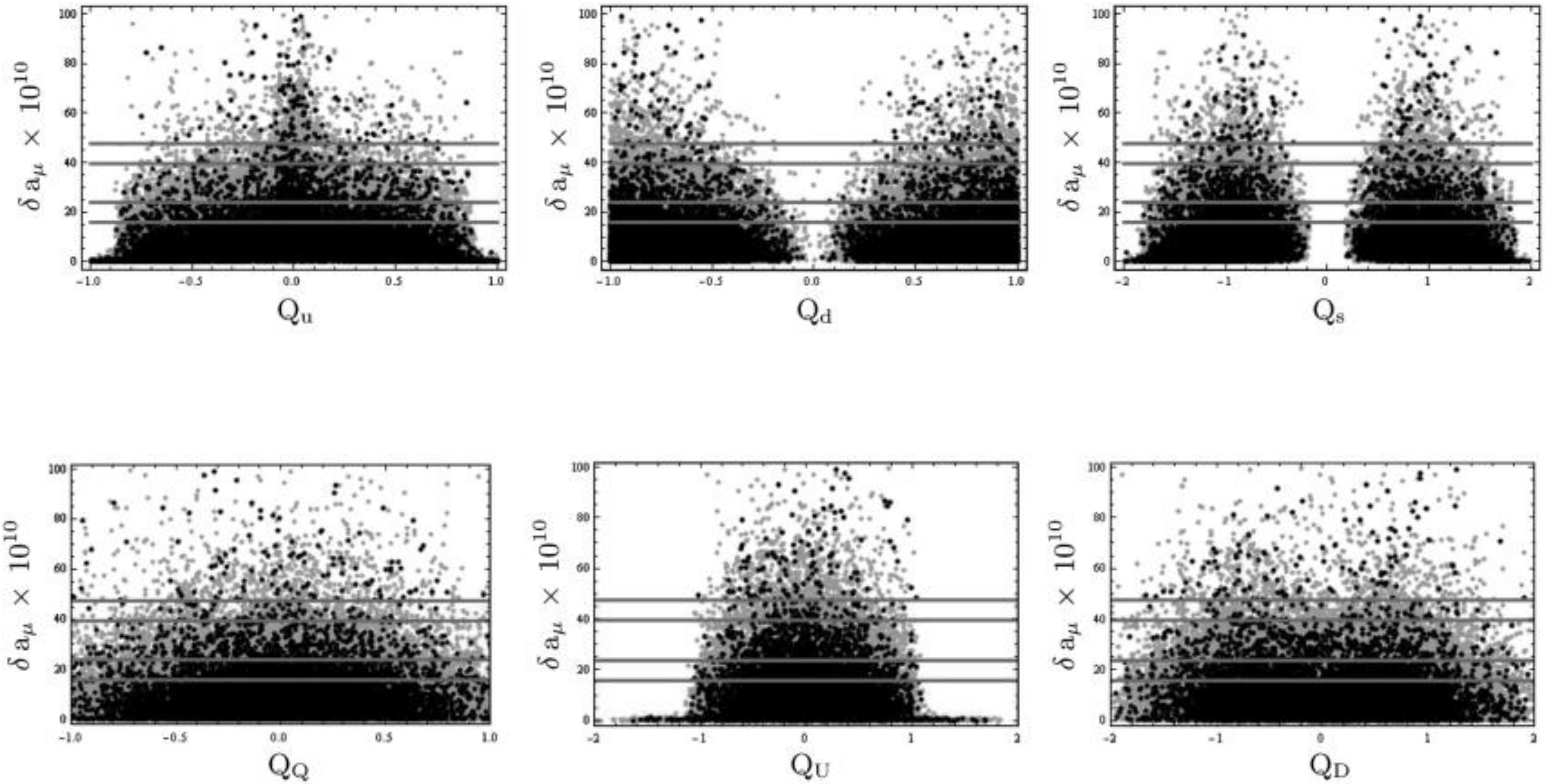

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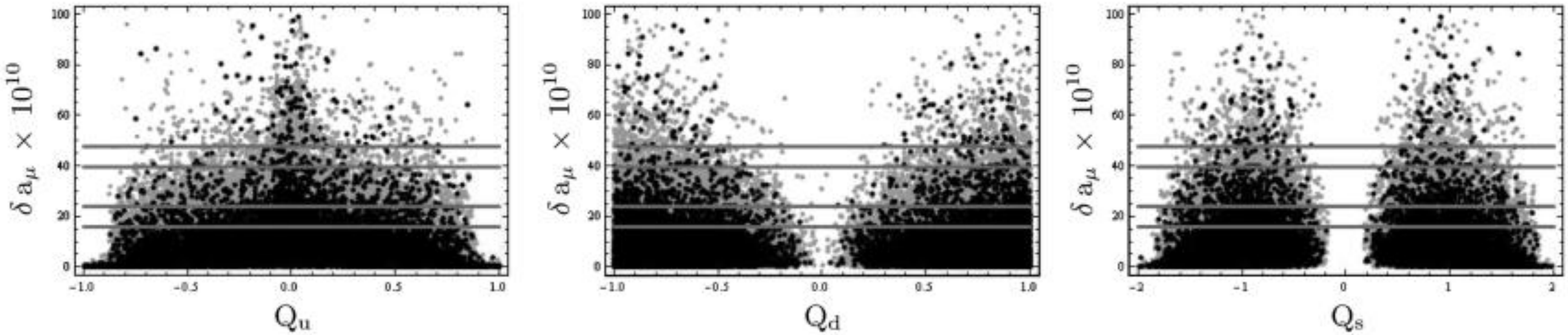
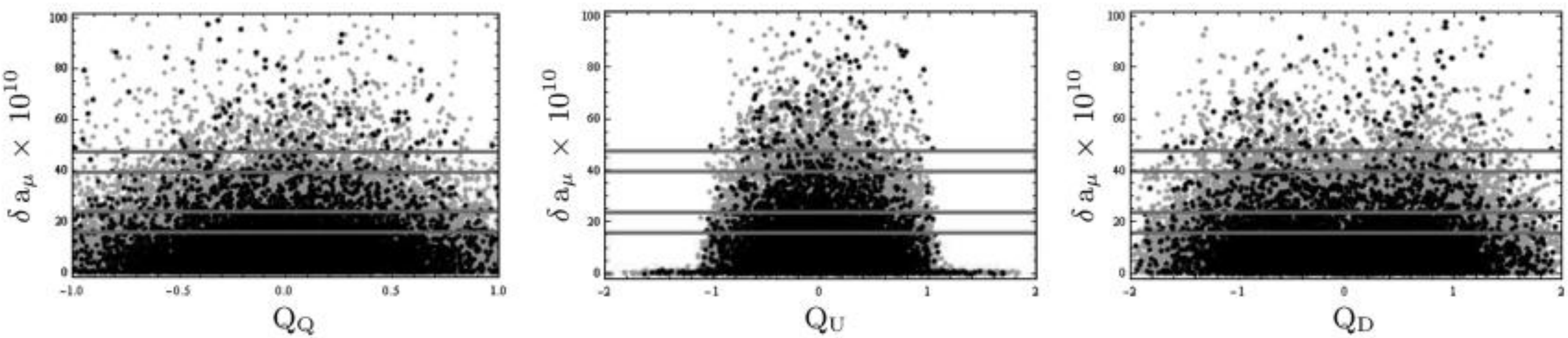


Symmetry for positive and negative U(1)' charges



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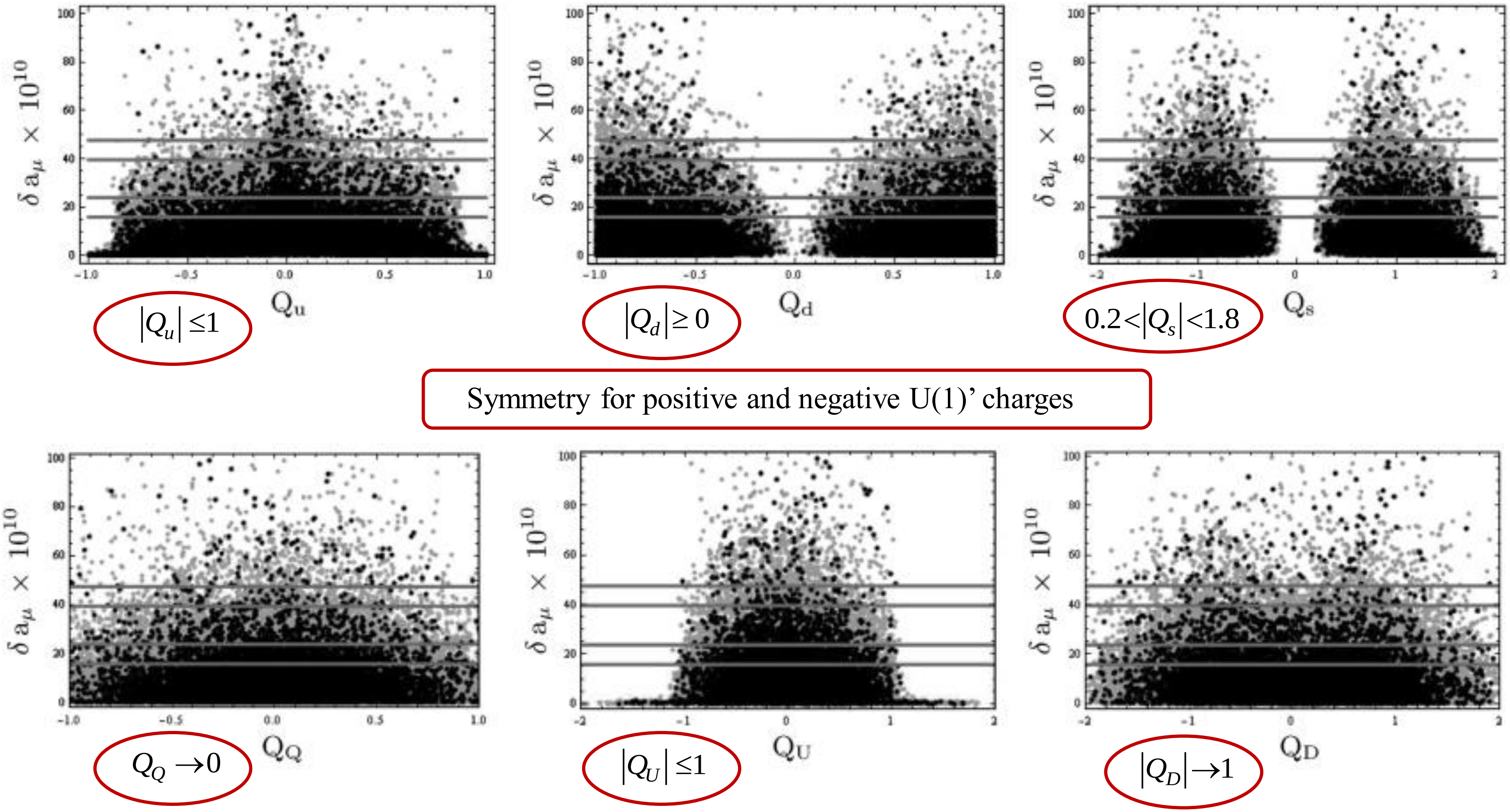

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E_6 based U(1)' models

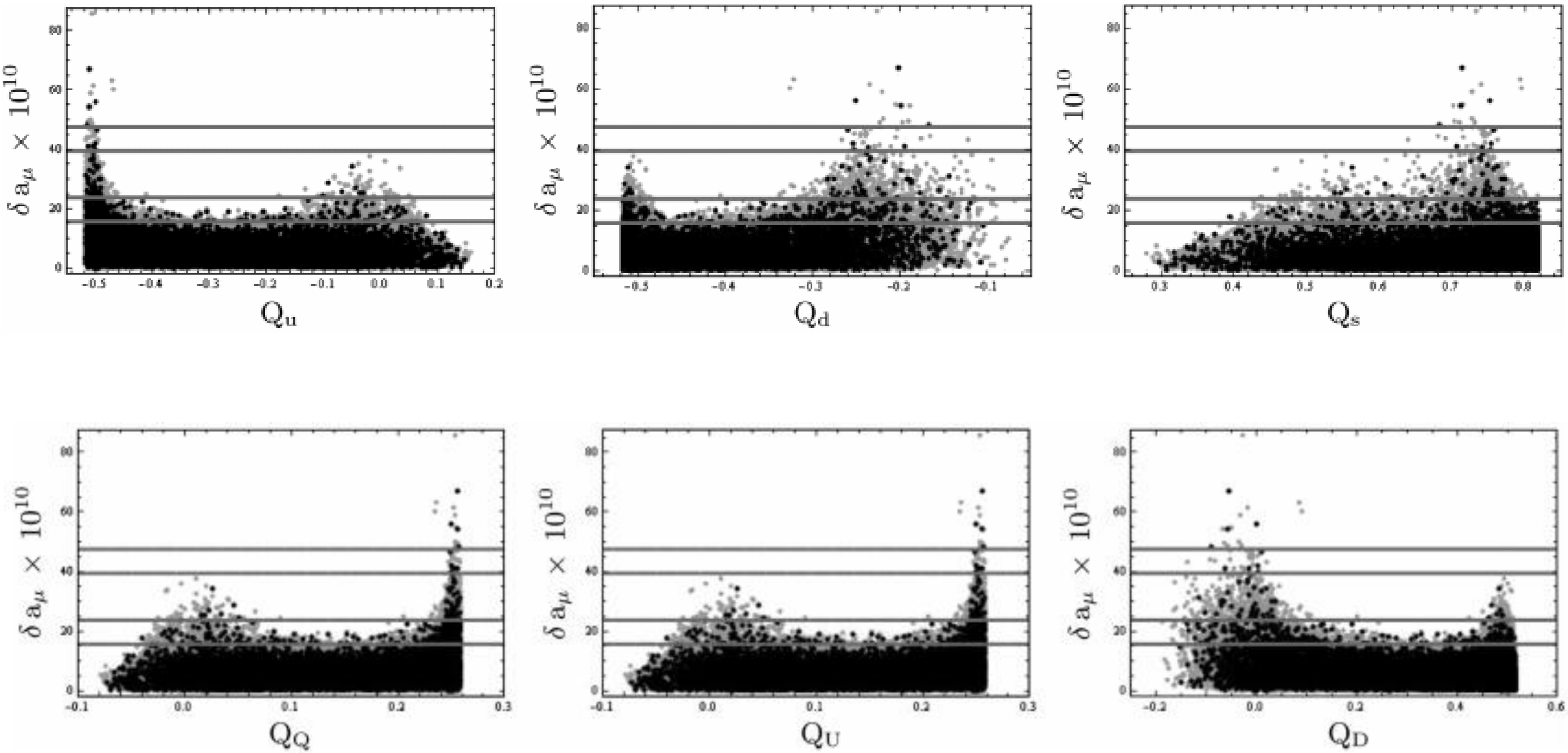

Fig-2: The allowed ranges of the U(1)' charges vs δa_μ **in supersymmetric** E_6 **models**.

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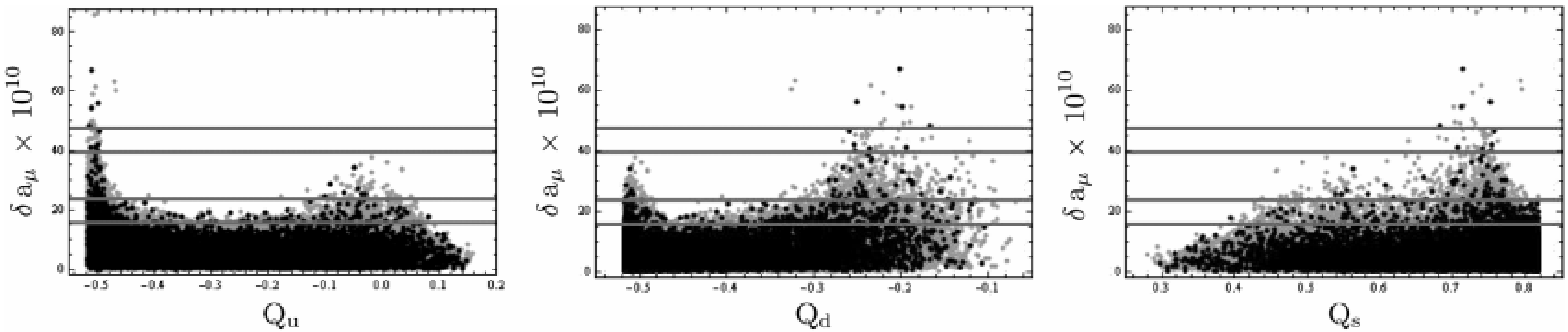
E_6 based U(1)' models



Two favorite regions satisfying the muon anomaly restrictions (for 1σ bounds)

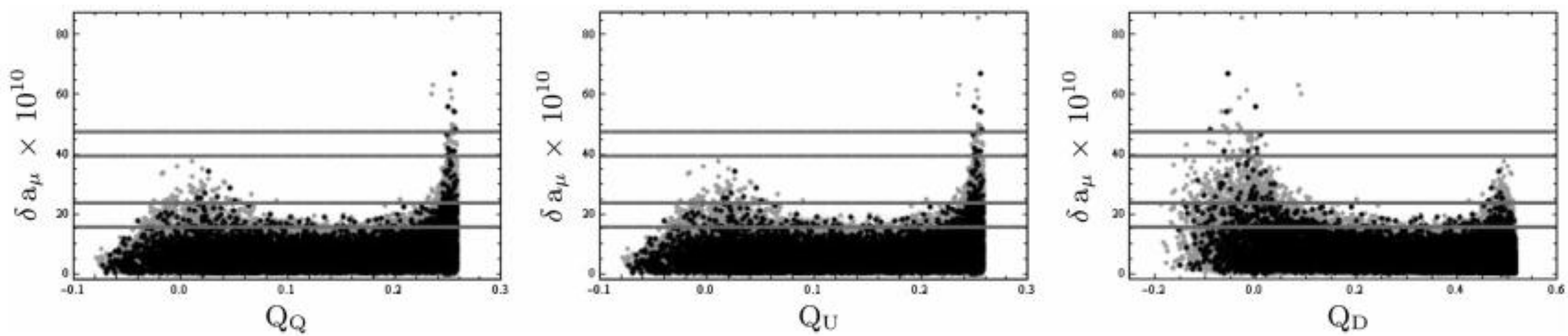


Fig-2: The allowed ranges of the U(1)' charges vs δa_μ **in supersymmetric** E_6 **models**.

❖ δa_μ *versus* $\tan\beta$ & m_h *versus* $\tan\beta$

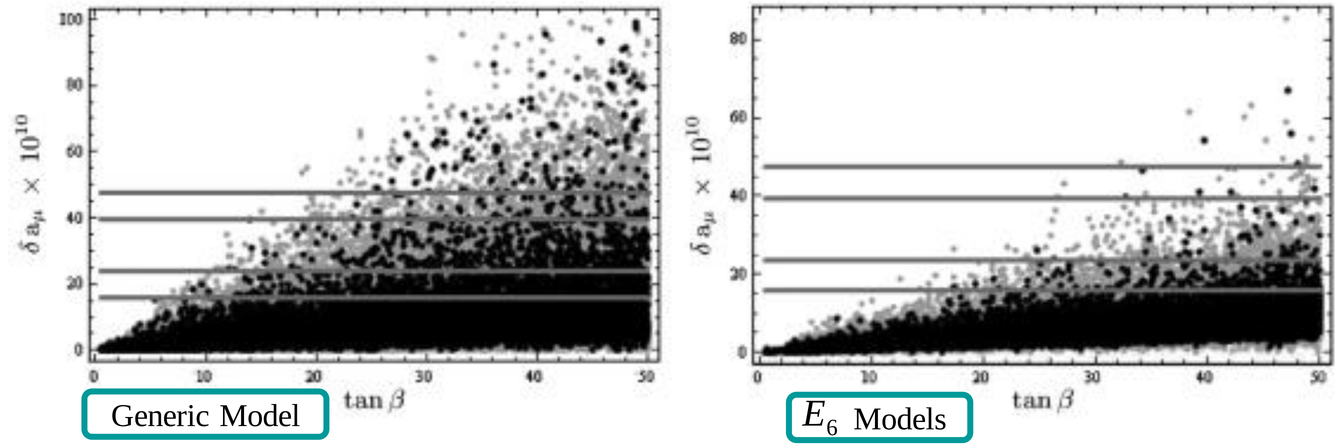
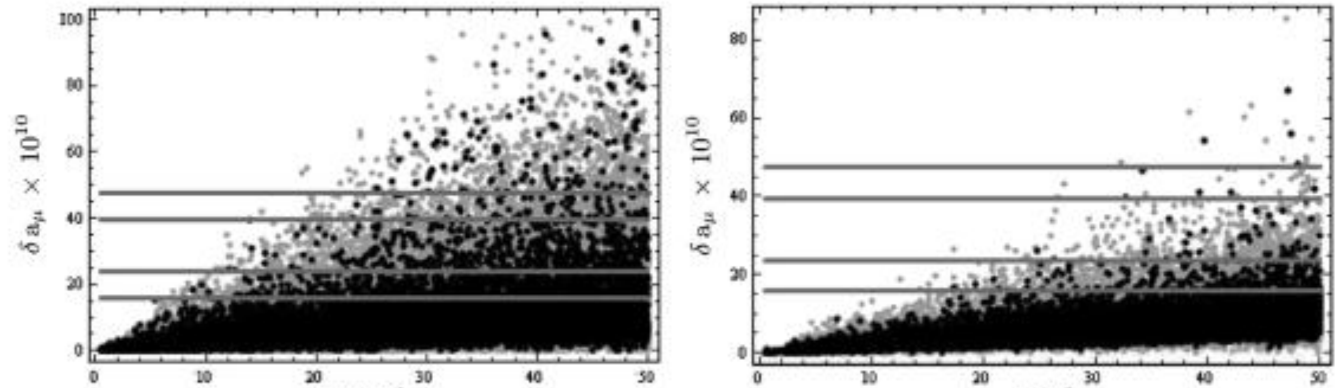


Fig-4: The evolution of $\tan\beta$ against δa_μ.

❖ δa_μ *versus* $\tan\beta$ & m_h *versus* $\tan\beta$



Generic Model

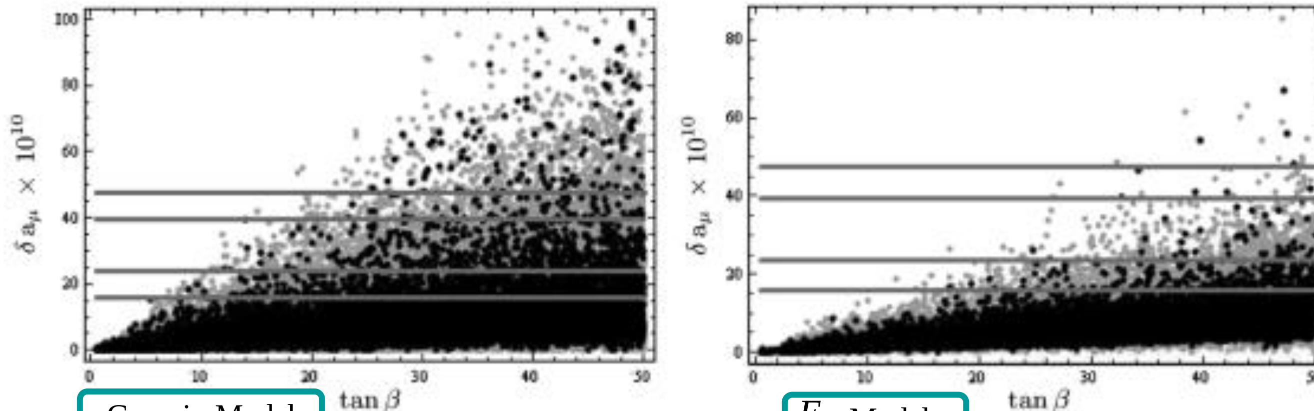
E_6 Models

$\tan\beta >_{\approx} 10$

Fig-4: The evolution of $\tan\beta$ against δa_μ.

$\tan\beta >_{\approx} 15$

δa_{μ} *versus* $\tan\beta$ & m_h *versus* $\tan\beta$



Generic Model

E_6 Models

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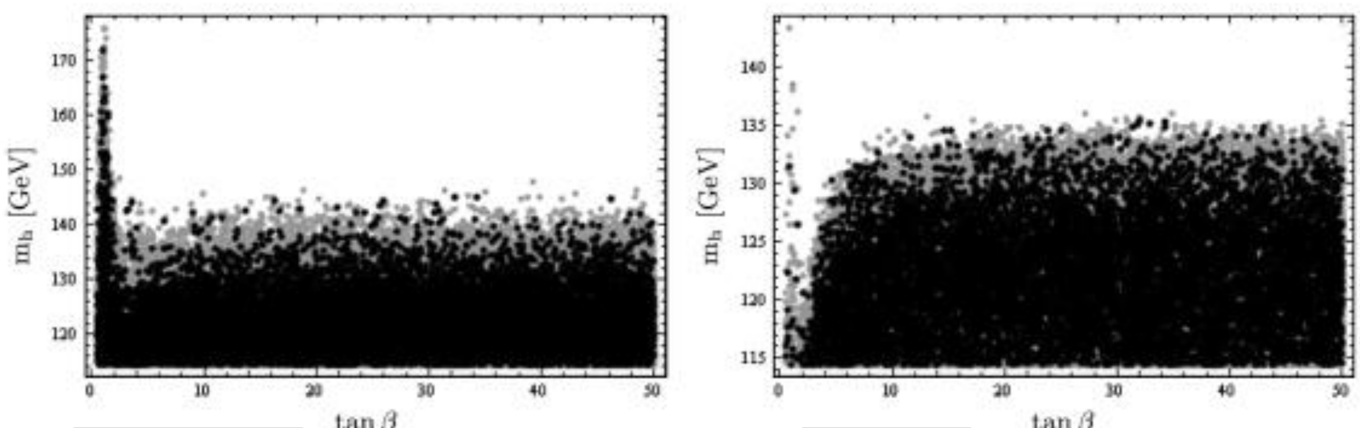
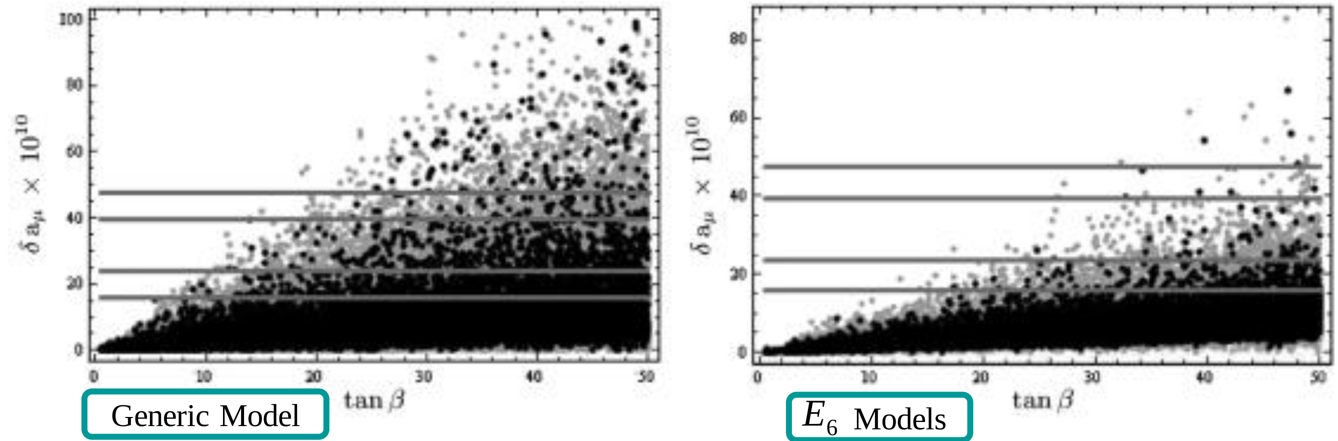


Generic Model

E_6 Models

Fig-3: The allowed ranges of $\tan\beta$ vs m_h .

δa_μ *versus* $\tan\beta$ & m_h *versus* $\tan\beta$



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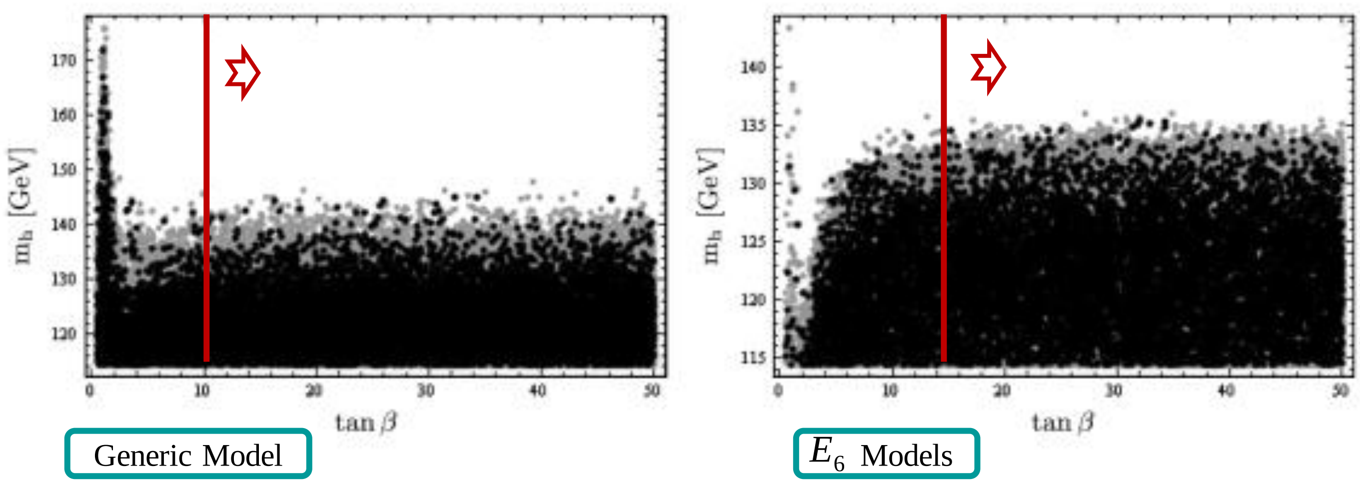

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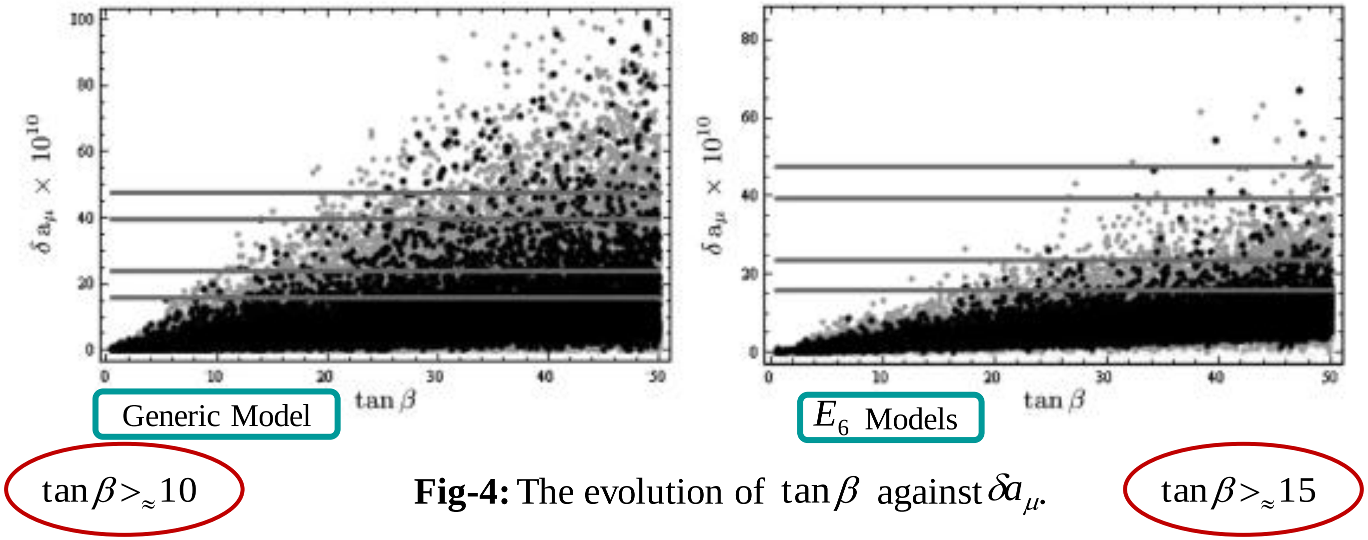

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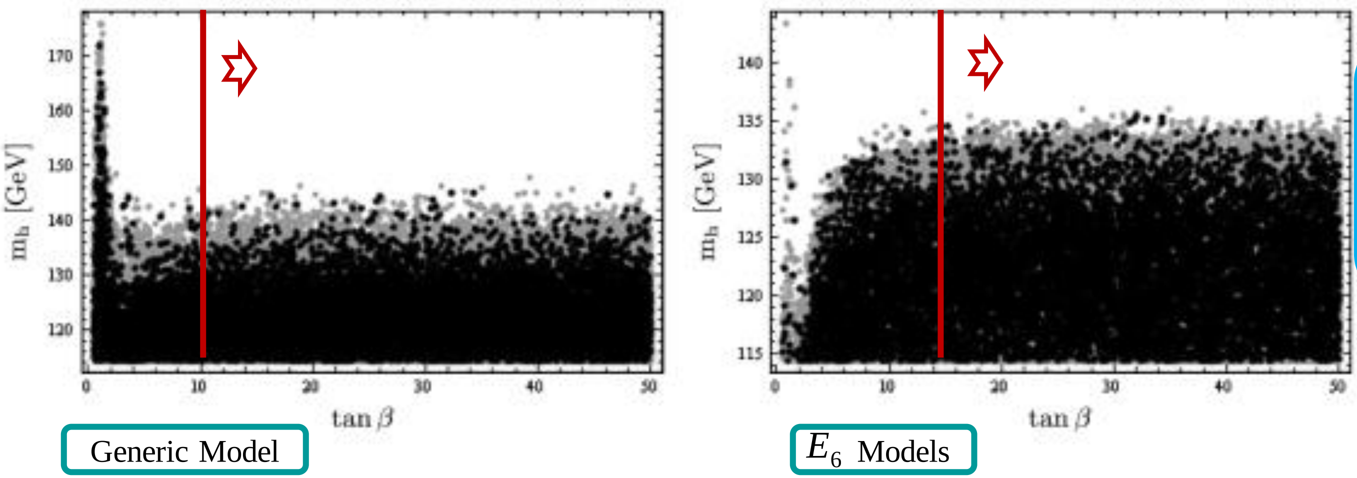
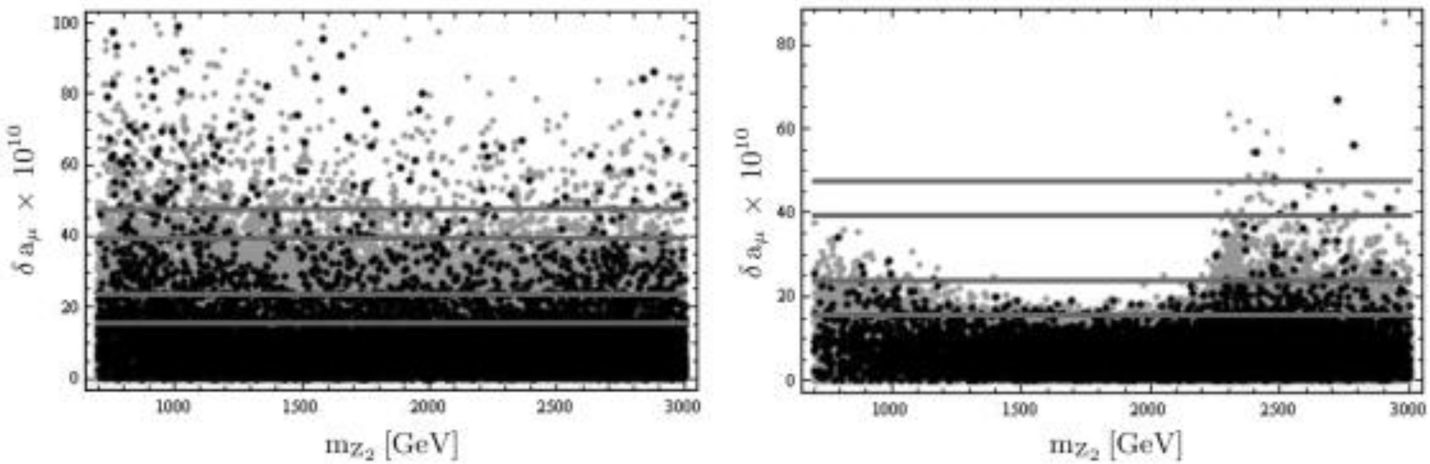


In U(1)' models very large values of m_h are not allowed due to restrictions coming from δa_μ .

Fig-3: The allowed ranges of $\tan\beta$ vs m_h .

δa_μ *versus* m_{Z_2}



Generic Model

E_6 Models

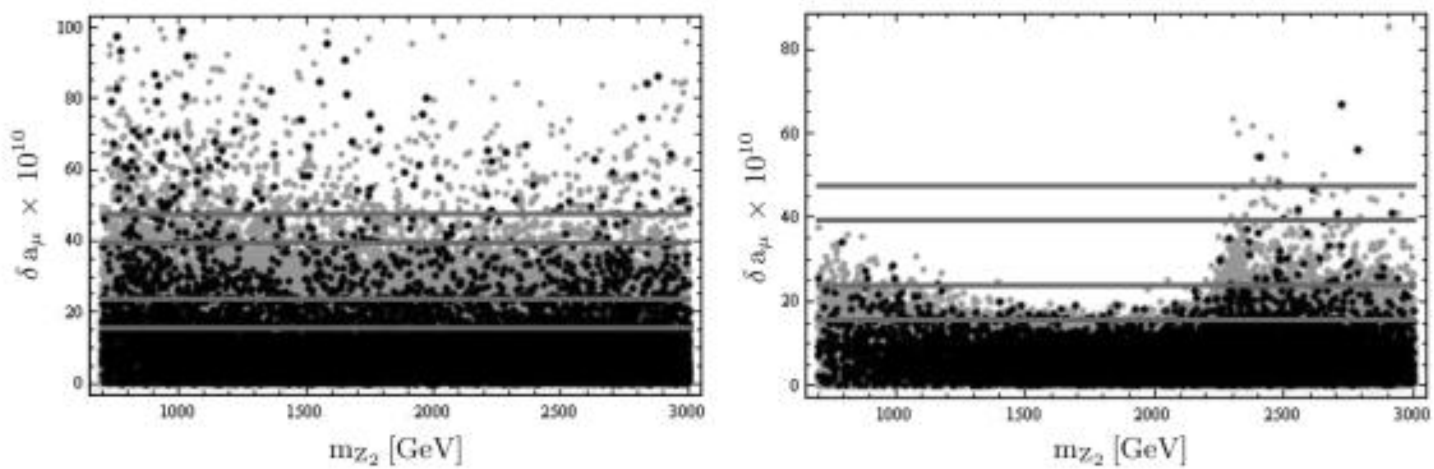
Fig-5: The allowed ranges of m_{Z_2} vs δa_μ.

δa_μ versus m_{Z_2}

Not sensitive to m_{Z_2}

$m_{Z_2} \approx 1\ TeV$

$m_{Z_2} \approx 2{,}5\ TeV$



Generic Model

E_6 Models

Fig-5: The allowed ranges of m_{Z_2} vs δa_μ.

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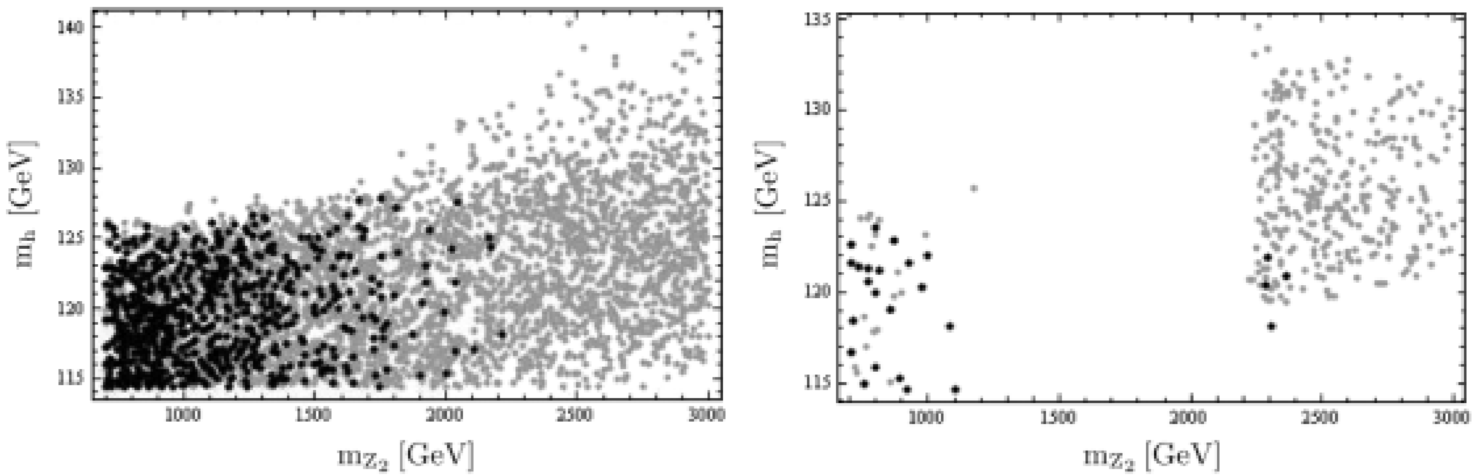
m_h *versus* m_{Z_2}



Generic Model

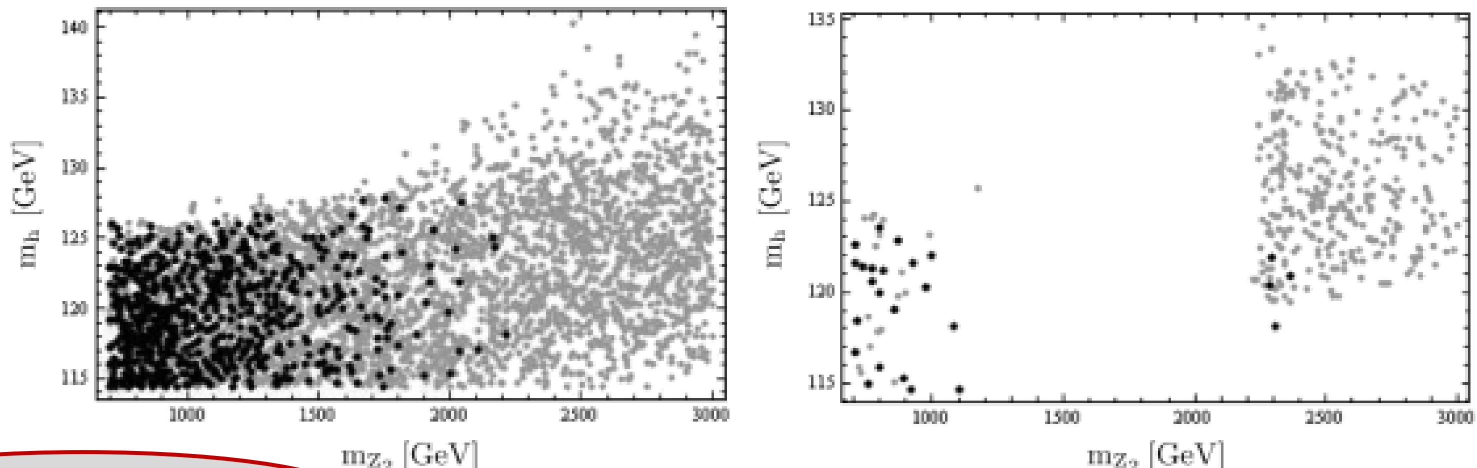
E_6 Models

Fig-8: The allowed ranges of m_h against m_{Z_2} .

m_h versus m_{Z_2}

if $m_{\tilde{q}} \leq 2\ TeV$ (Grey dots)

$m_h^{max} \lesssim 140\ GeV$



if $m_{\tilde{q}} \leq 1\ TeV$ (Black dots)

Generic Model

E_6 Models

$m_h^{max} \lesssim 128\ GeV$

$m_{Z_2} \lesssim 2.3\ TeV$

Fig-8: The allowed ranges of m_h against m_{Z_2} .

❖ m_h versus m_{Z_2}

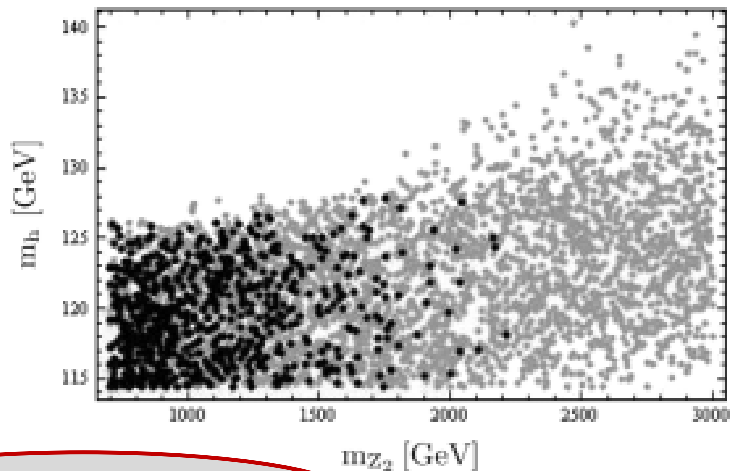
if $m_{\tilde{q}} \leq 2\ TeV$ (Grey dots)

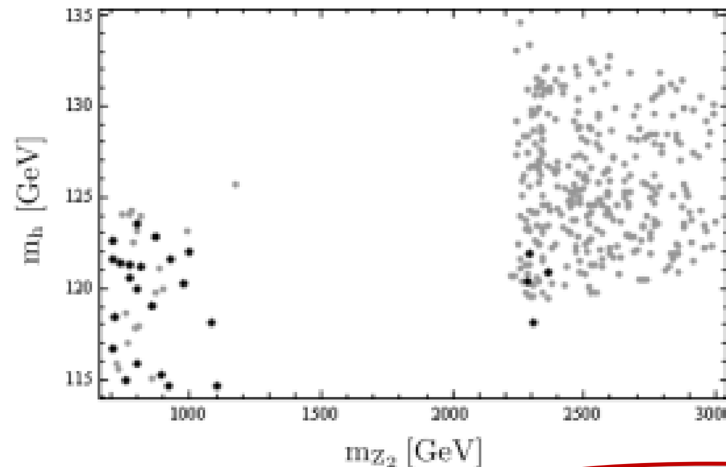
$m_h^{max} \lesssim 140\ GeV$

if $m_{\tilde{q}} \leq 2\ TeV$ (Grey dots)

$m_h^{max} \lesssim 135\ GeV$

$m_{Z_2} \approx 1\ TeV$ & $m_{Z_2} \geq 2.2\ TeV$





Generic Model

E_6 Models

if $m_{\tilde{q}} \leq 1\ TeV$ (Black dots)

$m_h^{max} \lesssim 128\ GeV$

$m_{Z_2} \lesssim 2.3\ TeV$

if $m_{\tilde{q}} \leq 1\ TeV$ (Black dots)

$m_h^{max} \lesssim 125\ GeV$

$m_{Z_2} \approx 1\ TeV$ & $m_{Z_2} \geq 2.2\ TeV$

Fig-8: The allowed ranges of m_h against m_{Z_2} .

INTRODUCTION | THE MODELS | **ANALYSIS** | CONCLUSION

❖ m_h versus m_{Z_2}

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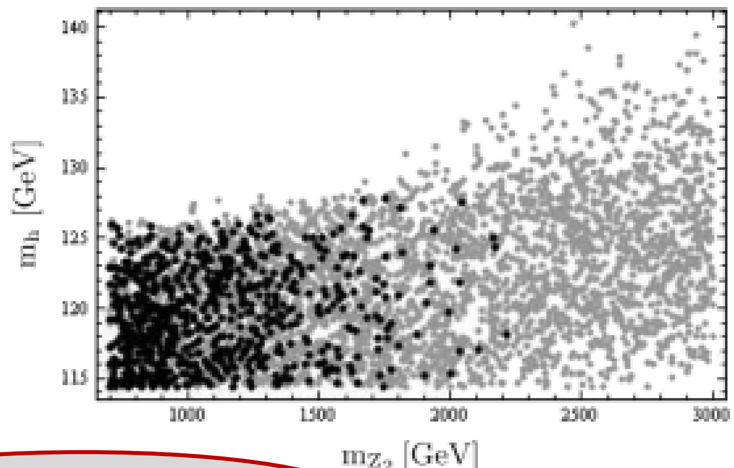

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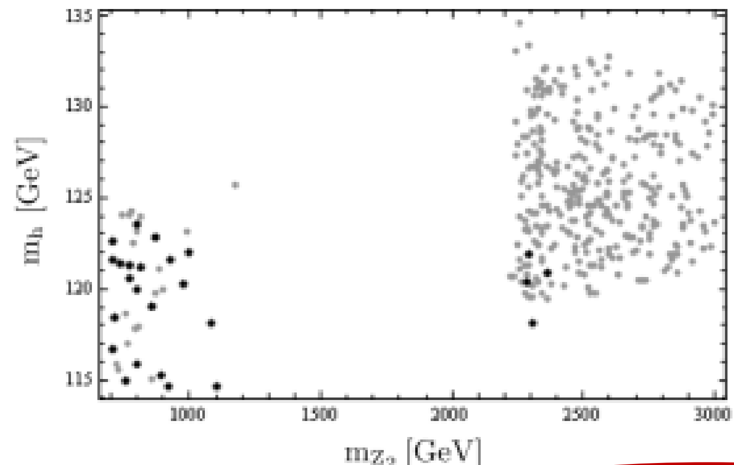

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In U(1)' models very large values of m_h are not allowed due to restrictions coming from δa_μ .

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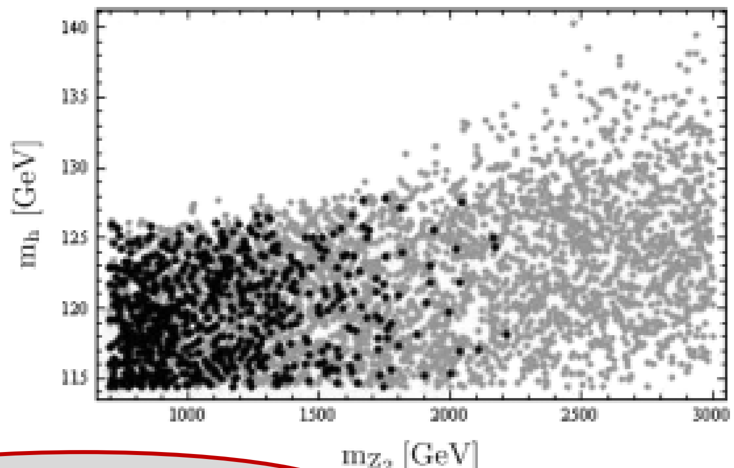

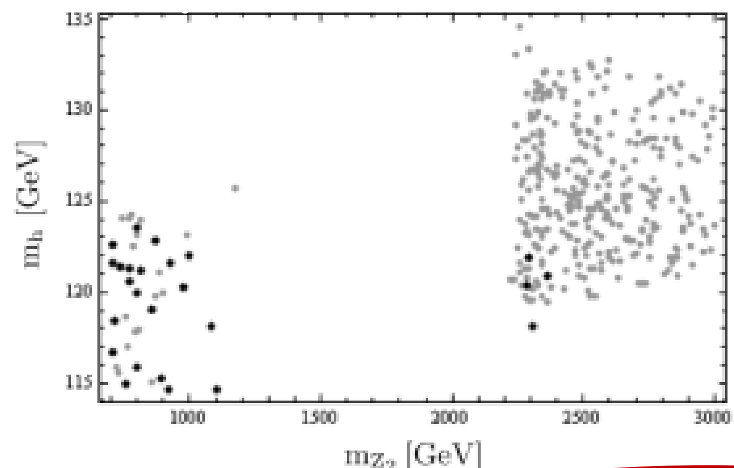

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Conclusion

- As a result of this work we showed that U(1)' models can explain the 3-4 σ discrepancy between $a_{\mu}^{\exp}$ and a_{μ}^{SM}.
- We used this discrepancy to find contraints on the parameters of the U(1)' models (generic and E_6 based models).
- We obtained predictions for m_h and m_{Z_2} in generic and E_6 models.
- We observed that E_6 based U(1)' models are more sensitive to δa_u than generic U(1)' model.

Acknowledgements

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"Muon anomalous magnetic moment constraints on supersymmetric U(1)' models"

Phys. Rev. D 82, 055009(2010).

by *E. Cincioglu*, *Z. Kirca*, *H. S.*, *S. Solmaz*, *L. Solmaz, and Y. Hicyilmaz.*

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THANKS FOR YOUR ATTENTION