More on EDM correlations in SUSY

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1. S. Abel + OL, JHEP 0601, 133 (2006)
2. — " — , WG3 report

Motivation

EDMs of fundamental particles have not been observed,

BUT...

1. remarkable sensitivity to NEW PHYSICS

$$d_e \simeq \left(\frac{300\text{ GeV}}{M_{SUSY}}\right)^2 \sin\varphi_{CP} \times 10^{-25}\ e\cdot cm$$

$\Rightarrow M_{SUSY}$ up to 100 TeV for $d_e \sim 10^{-30}$ e·cm

2. experimental progress

$d_e \to 10^{-30}$ e·cm
$d_n \to 10^{-28}$ e·cm
} in a few years

3. complementary to collider data

E.g. $\varphi_{CP} \sim 10^{-5}$

4. probe fundamental sources of $\not{CP}$, possibly baryogenesis, ...

Relativistic EDMs

$$H_{\text{non-rel.}} = -d\,\vec{S}\cdot\vec{E}$$

$$\Downarrow$$

$$\mathcal{L}_{\text{rel.}} = -\frac{i}{2}\, d\, \bar{\Psi}\,(F\sigma)\,\gamma_5\,\Psi$$

$F_{\mu\nu}$ = photon field strength
Ψ = fermion

For composite objects (n, atoms, ...) also relevant

$$\mathcal{L}_{\not{CP}} = \frac{g^2}{32\pi^2}\,\theta\, G_{\mu\nu}\,\tilde{G}^{\mu\nu} + \frac{w}{3} f^{abc}\, G_a\, \tilde{G}_b\, G_c$$

$$-\frac{i}{2}\,\tilde{d}\,\bar{\Psi}\, g\,(G\sigma)\,\gamma_5\,\Psi$$

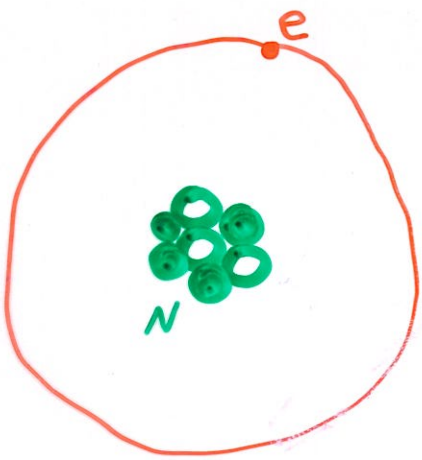
$$+\sum_{ij} C_{ij}\,(\bar{\Psi}_i\,\Psi_i)(\bar{\Psi}_j\, i\gamma_5\,\Psi_j).$$

$G_{\mu\nu}$ = gluon field strength
θ = QCD θ-term
w = Weinberg operator
$\tilde{d}$ = colour EDM

$$\text{EDM} = f(\theta, w, d, \tilde{d}, C_{ij})$$

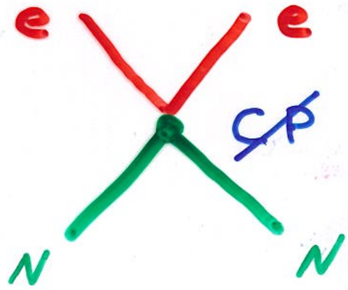
Example:

Tl atom



$$\mathcal{L} \sim \bar{e} i \gamma_5 e \, \bar{N} N$$

$$\Downarrow$$



Deforms the atom → EDM

$$d_{Tl} \simeq -585 \, d_e - C_S \cdot 43 \, e \cdot \text{GeV}$$

↘ $\mathcal{L} \sim C_S \, \bar{e} i \gamma_5 e \, \bar{N} N$

C_S can be more important than d_e (e.g. heavy superpartners)

Model - dependence

d_n	Model	Ref.
2.7	MIT bag model	Baluni
3.6	Current algebra	Crewther, ...
3.3	Effective chiral approach	Pich, ...
6.7	HBchPT	Borasoy
3.0	Chiral bag model	Musakhanov, ..
1.4	Cloudy bag model	Morgan, ...
1.2	Chiral quark-meson model	McGovern, ...
2.4	QCD sum rules	Pospelov, ...
1.4	perturbative chiral model	Kuckei, ...

(d_n in units of $|\Theta| \times 10^{-16}$ e·cm)

EDMs in SUSY

Induced by new CP phases:

$$\Delta \mathcal{L} = \mu \, \overline{\psi}_{H_1} \psi_{H_2} + B\mu \, H_1 H_2 + h.c.$$

$$+ \frac{1}{2}\left(m_3 \overline{\lambda}_3 \lambda_3 + m_2 \overline{\lambda}_2 \lambda_2 + m_1 \overline{\lambda}_1 \lambda_1 \right)$$

$$+ A^d_{ij} H_1 \tilde{q}_{L_i} \tilde{q}^*_{R_j} + \dots$$

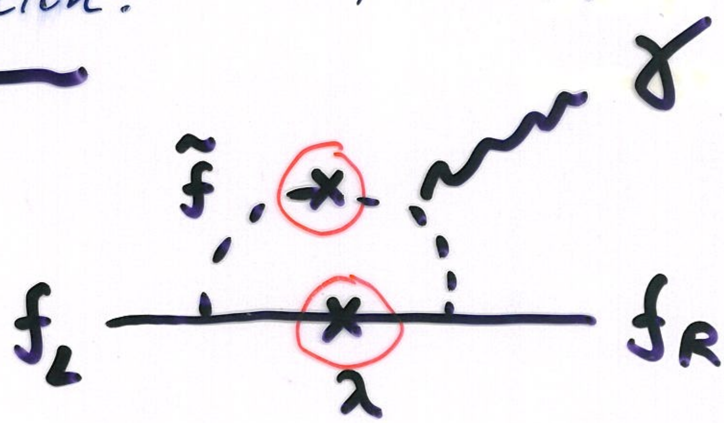
(...) = complex

2 phases eliminated by $U(1)_R$, $U(1)_{PQ}$

Physical phases: $\mathrm{Arg}(m_i^* A)$, $\mathrm{Arg}(B^* A)$, ...

Typical EDM contribution:

Ellis, Ferrara, Nanopoulos '82



$\varphi_{SUSY} \sim 10^{-2} \Leftarrow$

(CP problem)

The CP problem appears already in the most minimalistic models, e.g.

mSUGRA :

μ, A = complex!

This is due to holomorphicity of SUSY.

(Unlike the FCNC problem)

$\Downarrow$

EDMs are special observables, probe even minimal scenarios

① Small phases

E.g. phase alignment

$$\varphi_M = \varphi_A = -\varphi_\mu \qquad (+\text{ corrections})$$

$$\Downarrow$$

$$\varphi(M^* A) = \varphi(\mu A) = .. = 0$$

(dilaton domination + Giudice - Masiero)

② Decoupling

Nath '91
Kizukuri, Oshimo '92

$$\sim \; 1 / m^2_{\tilde{q}_{1,2}} \xrightarrow{\sim 10\text{ TeV}} 0$$

→ EDMs at 2 loops

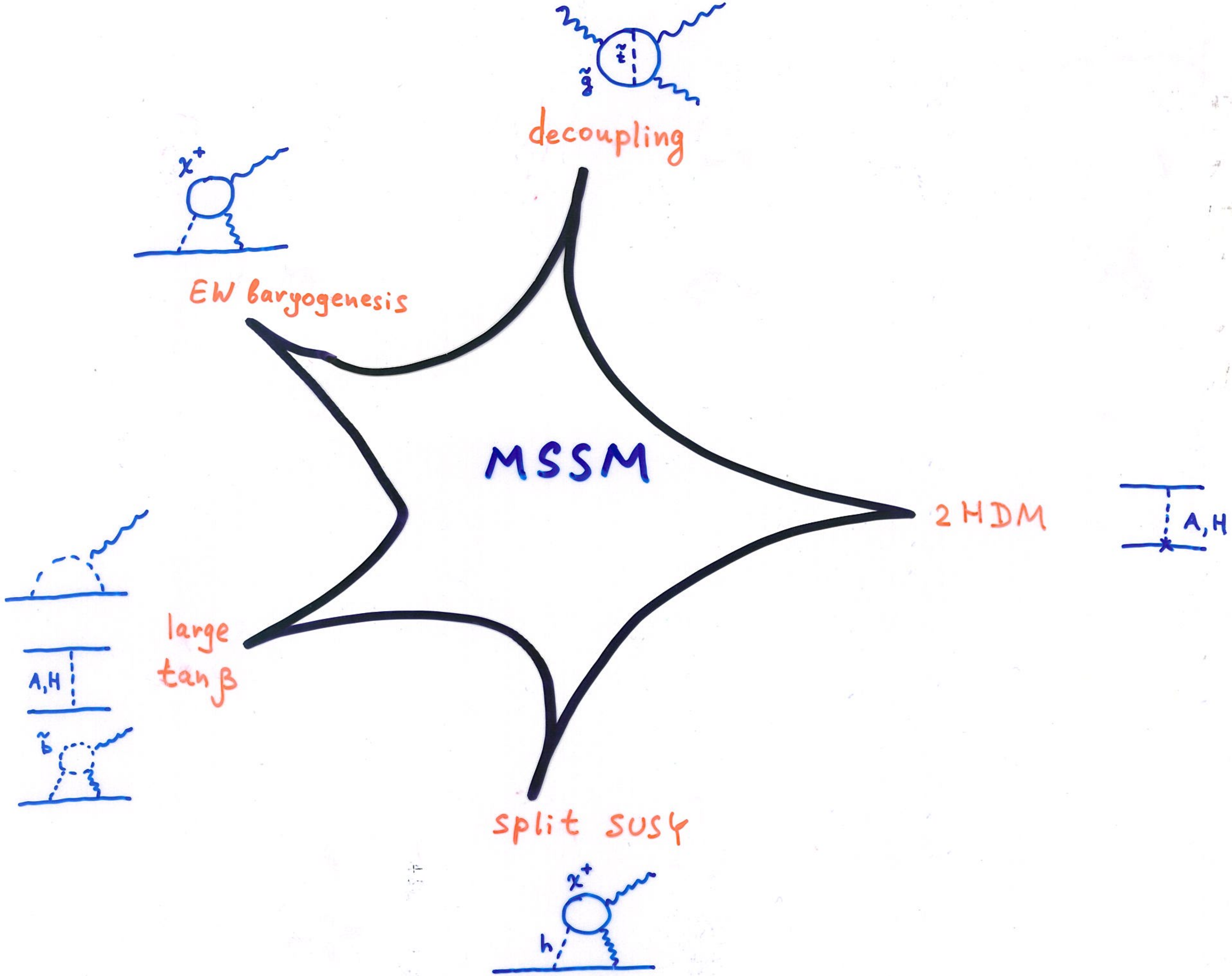
③ off diagonal ~~CP~~

$$\left.\begin{array}{l} A = A^+ \\ \mu = \mu^+ \\ .. \end{array}\right\} \text{ by symmetry } \begin{array}{l} \nearrow LR \\ \searrow \text{flavour} \end{array}$$

LR: Mohapatra, Senjanovich

flavour: Abel, Bailin, Khalil, OL

Like in the SM, small EDMs.


decoupling
g̃
t̃
EW baryogenesis
χ+
MSSM
2HDM
A,H
large tan β
A,H
b̃
split SUSY
χ+
h

EDM correlations

SUSY predicts certain correlations between

$$\underline{d_n \; , \; d_e} \; , \; (d_{Hg}, d_\mu, d_D, \ldots)$$

$\Downarrow$

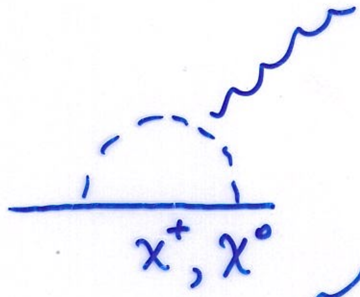
indirect signature of SUSY

Typically expect:

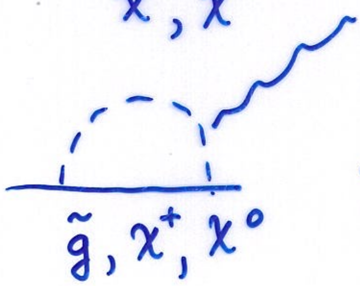
$$d_n \sim 10\, d_e \qquad \left(\frac{m_q}{m_e} \sim 10 \right)$$

even though

$d_e \sim$



$d_n \sim$



$+ \ldots$

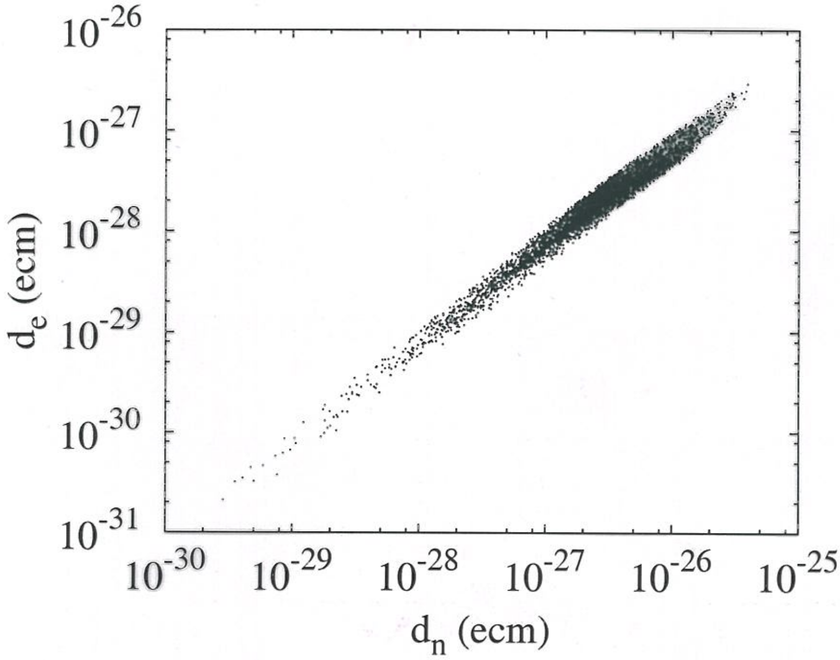
Abel, OL '05

$d_e - d_n$ correlation in mSUGRA

$m_0, m_{1/2}, |A| \in [200\ \text{GeV}, 1\ \text{TeV}]$

$\varphi_\mu \in [-\pi/500, \pi/500]$

$\tan\beta = 5$



$d_e \sim 10^{-1}\, d_n$

⇓

indirect evidence for SUSY!

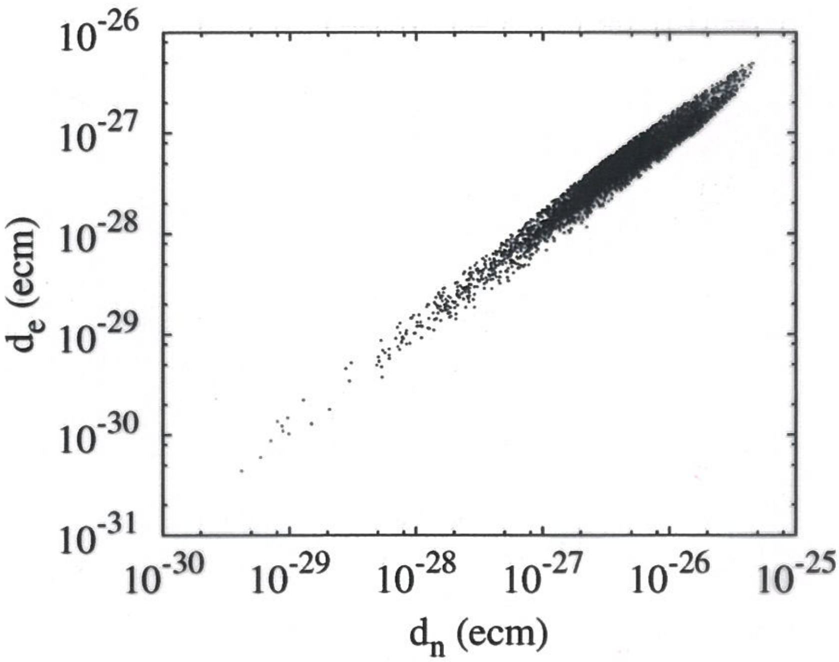
Note: persists for $\tan\beta \sim 35$; also for $m_{\tilde{q}} \neq m_{\tilde{l}}$ (GUT)

Heavy mSUGRA

$m_0, m_{1/2}, |A| \in [2\,\text{TeV}, 10\,\text{TeV}]$

$\varphi_A, \varphi_\mu \in [-\pi, \pi]$

A very similar picture:



Most points are in the observable range!

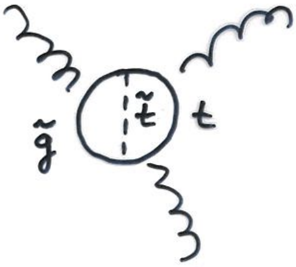
Decoupling

$m_{\tilde{q}_3}, m_{1/2}, |A| \in [200 \text{ GeV}, 1 \text{ TeV}]$

$\varphi_A, \varphi_\mu \in [-\pi, \pi]$

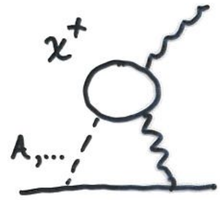
$m_{\tilde{q}_{1,2}} \to \infty$

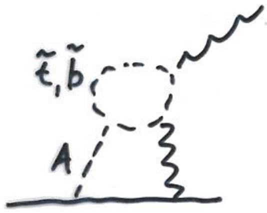
Weinberg '89
Dai, ... '90

$d_n \sim$ 

$+ \ldots$

Chang, Keung, Pilaftsis '99

$d_e \sim$ 

$+$ 

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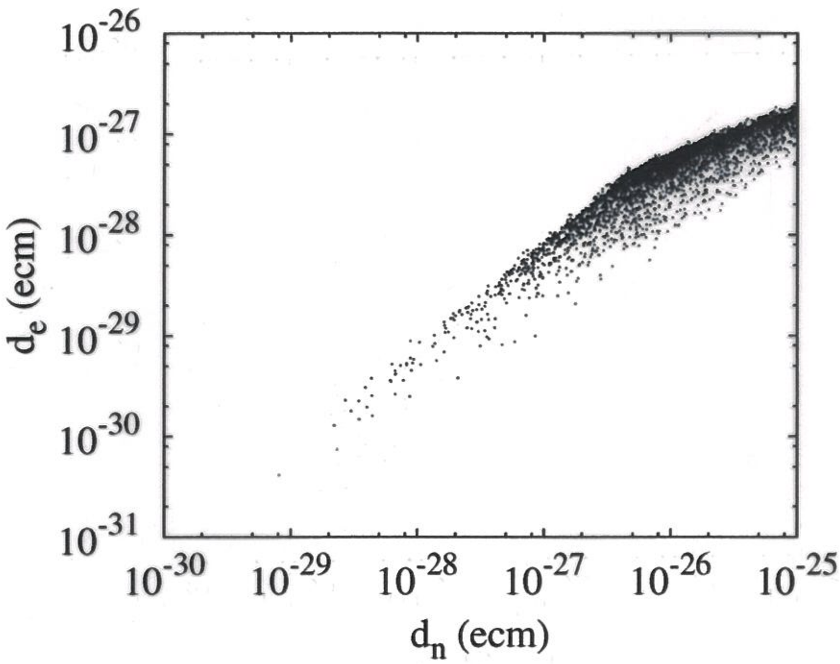


$d_n \sim 10 \div 100\, d_e$

Should be observed soon!

Split SUSY

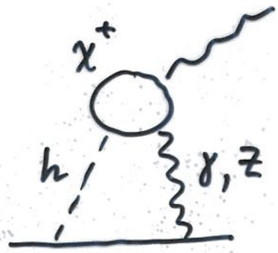
$M_{1,2,3} \in [200 \text{ GeV}, 1 \text{ TeV}]$

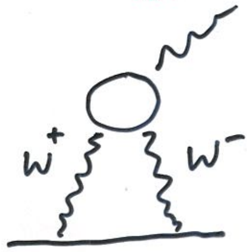
$|\mu| \in [200 \text{ GeV}, 1 \text{ TeV}]$

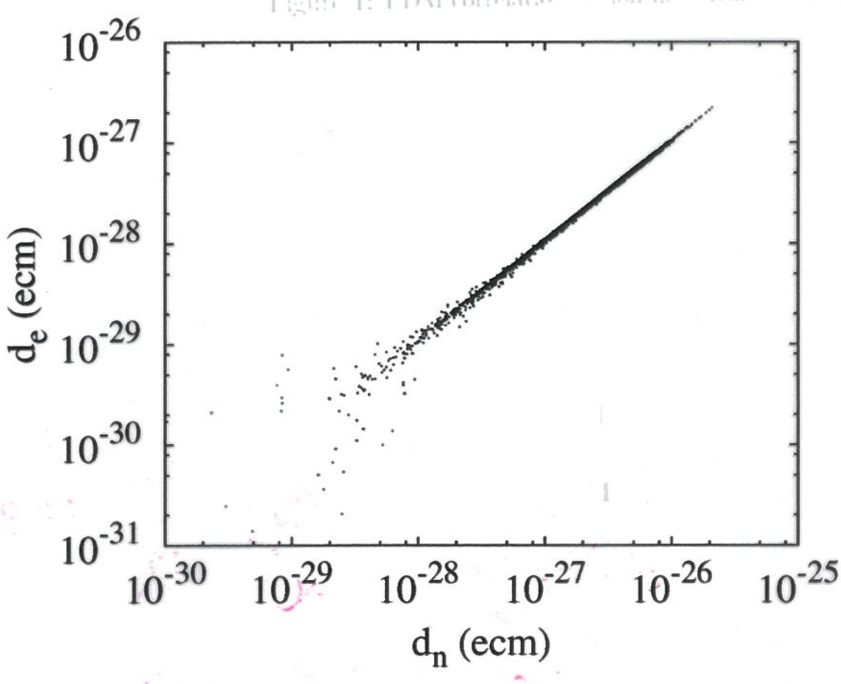
$m_h \in [100 \text{ GeV}, 300 \text{ GeV}]$

$M_{scalars} \to \infty$

Chang,...'02
Giudice, Romanino '05
...

$d_{n,e} \sim$ 

$+$ 



$d_n \sim 10\, d_e$

Observable!

Non-universal SUSY

$m_{squark} \neq m_{slepton}$

$M_{1,2} \neq M_3$

phases : $\varphi_\mu, \varphi_A, \varphi_{M_3}$

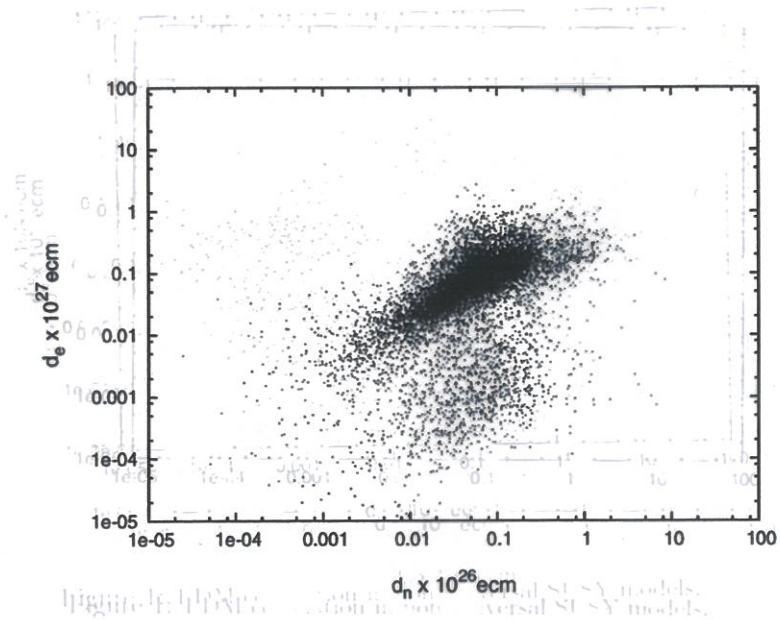


Figure 1: EDM correlation in non-universal SUSY models.

90% : $d_n/d_e \sim 10 - 100$

10% : $d_n/d_e \sim 10^2 - 10^4$

Reason:

① φ_μ dominates

② 

$\sim \frac{m_q}{m_e}$ 

unless there are large mass hierarchies

Non-universal SUSY

Random scan : all mass parameters $\in$ [300 GeV, 5 TeV]
complete non-universality
($m_{\tilde{q}_3} \neq m_{\tilde{q}_{1,2}}$, ...)

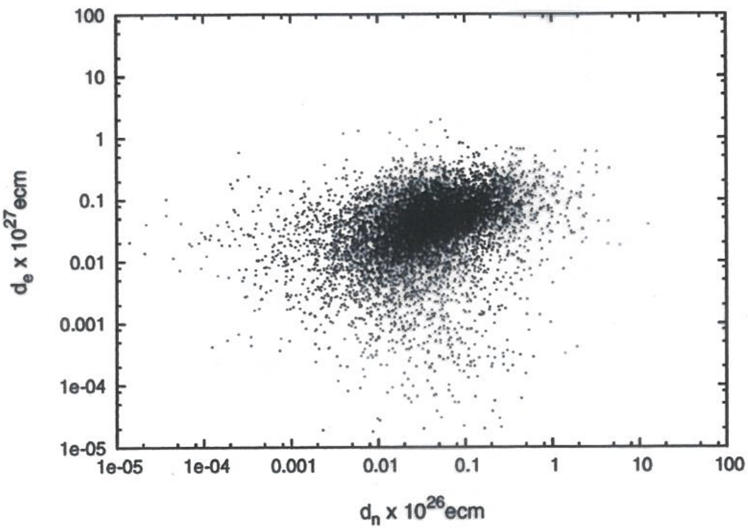


Figure 1: EDM correlation in non-universal SUSY models.

Message:

typically $d_n \sim 10 \div 100\, d_e$

(rather insensitive to $\tan\beta$, universality assumptions, ...)

Thus,

$d_e \gtrsim d_n$
$d_e \lll d_n$ $\Rightarrow$ SUSY disfavored (at least common models)

Also,

complementary to collider data:

$M_{SUSY} \lesssim$ TeV , $\varphi_{CP} \sim 10^{-5}$
$M_{SUSY} \gtrsim 5$ TeV , $\varphi_{CP} \sim 1$

} out of colliders' reach

Conclusions

- if there's low energy SUSY, EDMs should be observed in the next ~ 5 years
  ($d_n > 10^{-28}$ e.cm , $d_e > 10^{-30}$ e.cm)

- SUSY predicts $d_e - d_n$ correlations
  (typically $d_n \sim 10\, d_e$)

- EDM measurements are complementary to collider data
  (e.g. $\varphi_{CP} \sim 10^{-5}$)