EDM correlations in SUSY

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Motivation

EDMs of fundamental particles have not been observed,

BUT...

(1) remarkable sensitivity to NEW PHYSICS

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

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

(2) experimental progress

$d_e \rightarrow 10^{-30}$ e·cm
$d_n \rightarrow 10^{-28}$ 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

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

$$\Downarrow$$

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

$\left\{ \begin{array}{l} F_{\mu\nu} = \text{photon field strength} \\ \Psi = \text{fermion} \end{array} \right.$

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

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

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

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

$\left\{ \begin{array}{l} G_{\mu\nu} = \text{gluon field strength} \\ \theta = \text{QCD } \theta\text{-term} \\ w = \text{Weinberg operator} \\ \tilde{d} = \text{colour EDM} \end{array} \right.$

Neutron EDM

NDA: Arnowitt,... '90

$$d_n \sim d_d - 0.25\, d_u + e\left(0.4\, \tilde{d}_d - 0.1\, \tilde{d}_u\right) + 0.3\ \mathrm{GeV} \cdot e W$$

All Wilson coefficients at the EW scale.

Sum rules: Pospelov, Ritz '01

$$d_n \sim d_d - 0.25\, d_u + e\left(\tilde{d}_d + 0.5\, \tilde{d}_u\right) + 0.1\ \mathrm{GeV} \cdot e W$$

Other models

⋮

strangeness → Ellis, Flores '96
Hisano, Shimizu '04

Thallium / electron EDM

Liu, Kelly '92
Bouchiat '75

$$d_{Tl} = -585\, d_e - C_S \cdot 43\ e \cdot \mathrm{GeV}$$

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

When $C_S \to 0$, $d_{Tl} \leftrightarrow d_e$ $\Rightarrow |d_e| < 1.5 \cdot 10^{-27}\ e\,\mathrm{cm}$

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)

Experimental results:

all negative ...

$d_{Tl} < 9 \times 10^{-25}$ e·cm (90% CL)

$d_{Hg} < 2 \times 10^{-28}$ e·cm (95% CL)

$d_n < 6 \times 10^{-26}$ e·cm (90% CL)

Note:

SM predictions are very small,

$d_n \sim 10^{-32}$ e·cm

...

EDMs in SUSY

Induced by new CP phases:

$$\Delta \mathcal{L} = \textcircled{\mu}\, \bar{\Psi}_{H_1} \Psi_{H_2} + \textcircled{B\mu}\, H_1 H_2 + h.c.$$

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

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

$\textcircled{\ldots}$ = complex

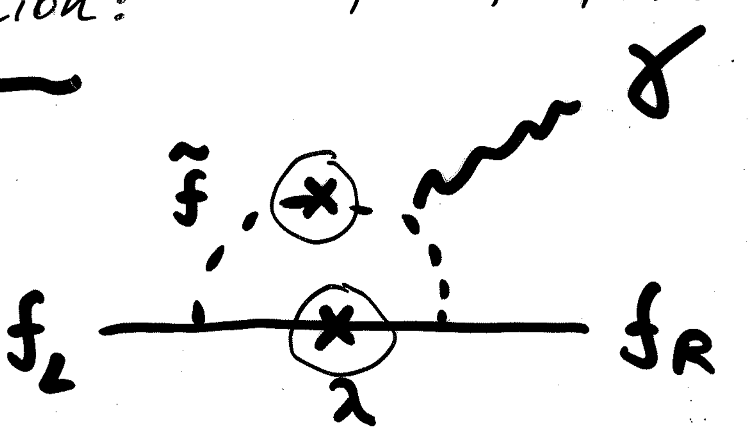
2 phases eliminated by $U(1)_R$, $U(1)_{PQ}$

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 <u>most minimalistic models</u>, e.g.

mSUGRA :

μ, A = complex!

This is due to holomorphicity of SUSY.

(Unlike the FCNC problem)

$\Downarrow$

EDMs are <u>special</u> observables, probe even minimal scenarios

Suppression of EDMs

① Small CP-phases , $\varphi \lesssim 10^{-2}$

(e.g. phase alignment $\varphi_M \simeq \varphi_A \simeq -\varphi_\mu$ + corrections)

② Heavy SUSY spectrum , $m \sim$ a few TeV

(motivated by a heavy Higgs → heavy stop)

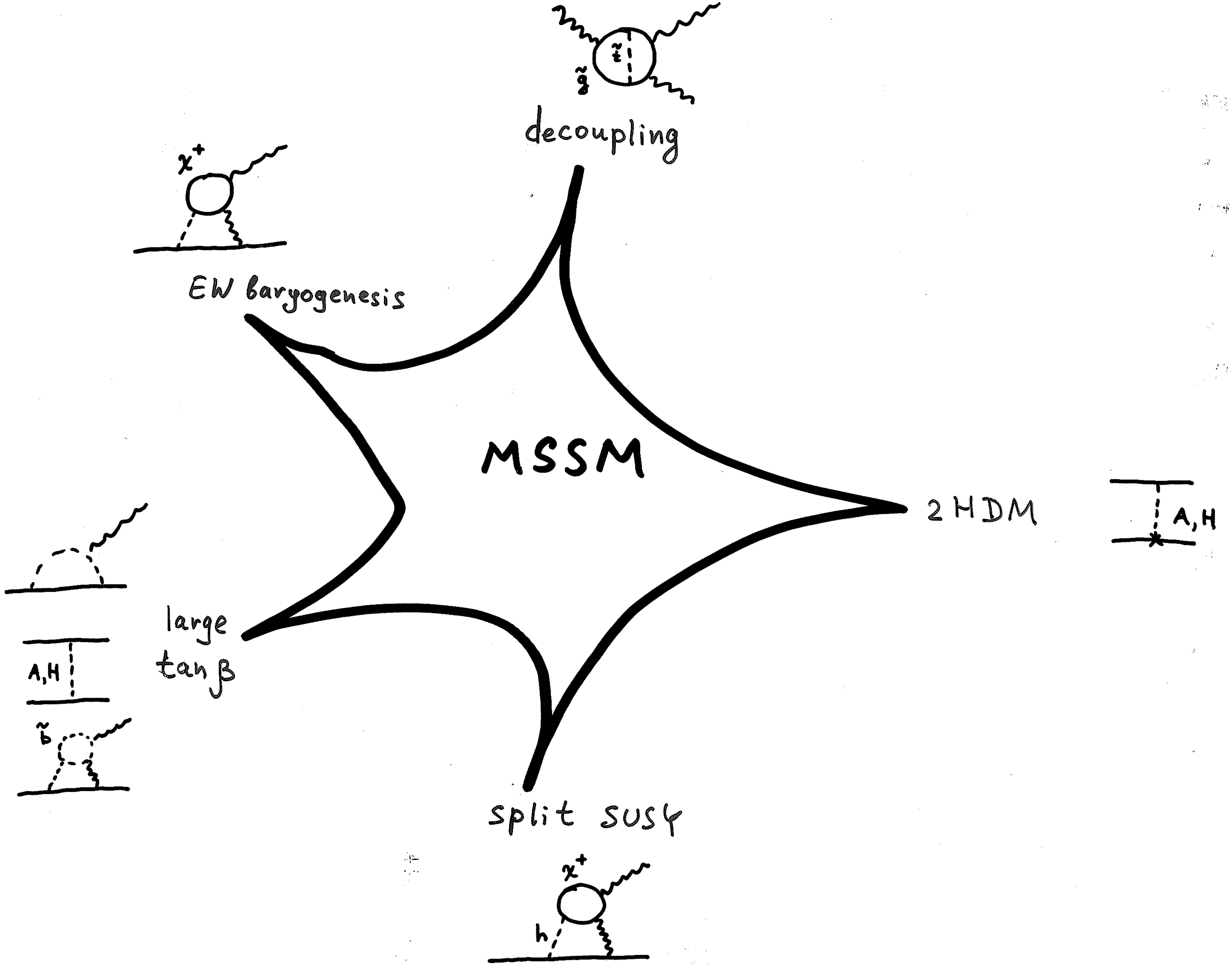
③ Decoupling , $\tilde{m}_{1,2} \gtrsim 10$ TeV

(but the stop mass $\lesssim$ TeV)

③′ Decoupling′ ≃ split SUSY

(only fermions are light, ≃ TeV)

The CP problem is difficult, but possible to avoid.


MSSM
decoupling
EW baryogenesis
large tan β
split SUSY
2HDM
A,H
h

EDM correlations

SUSY predicts certain correlations between

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

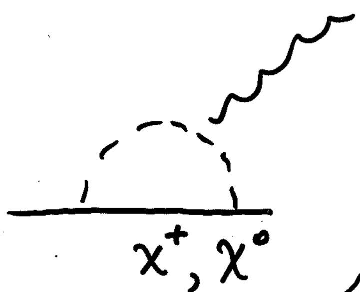
$\Downarrow$

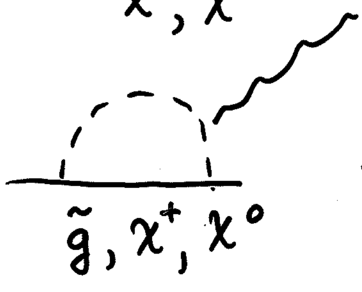
indirect signature of SUSY

Typically expect:

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

even though

$d_e \sim$ 

$d_n \sim$  $+ \ldots$

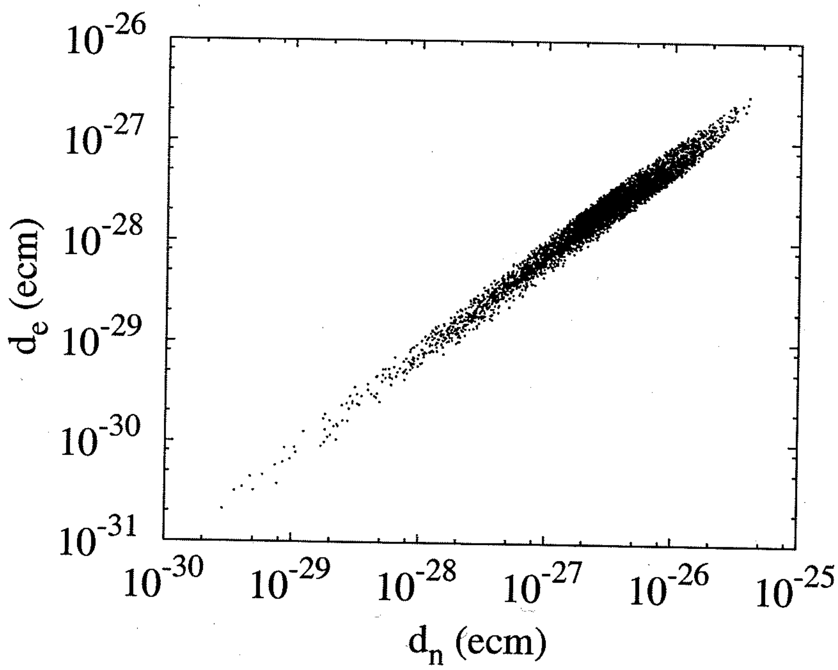
Abel, OL '05

$d_e - d_n$ 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!

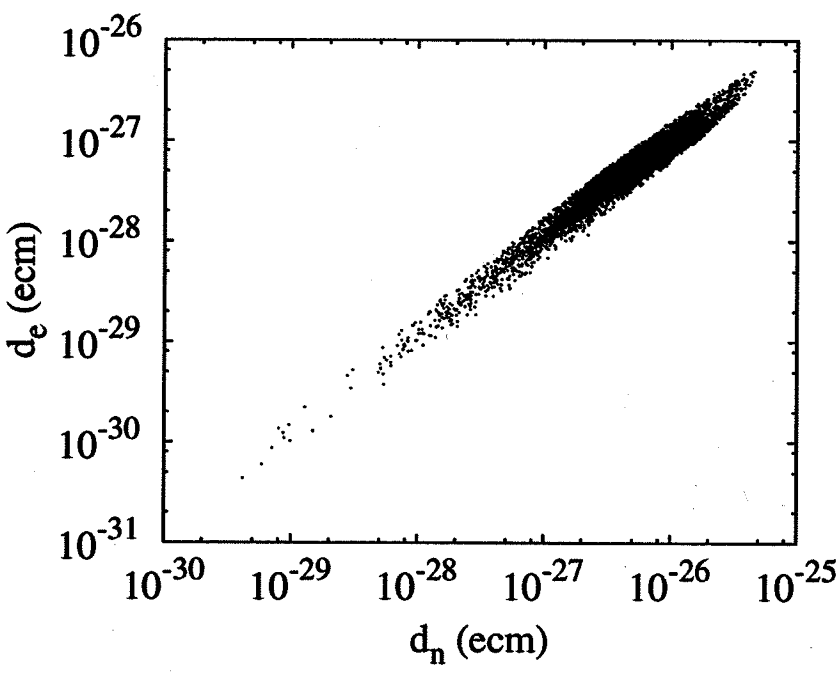
Note: persists for $\tan\beta \sim 35$; also for $m_{\tilde{q}} \neq m_{\tilde{\ell}}$ (GUT)

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!

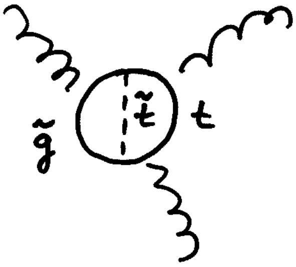
Decoupling

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

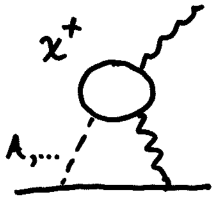
$\varphi_A, \varphi_\mu \in [-\pi, \pi]$

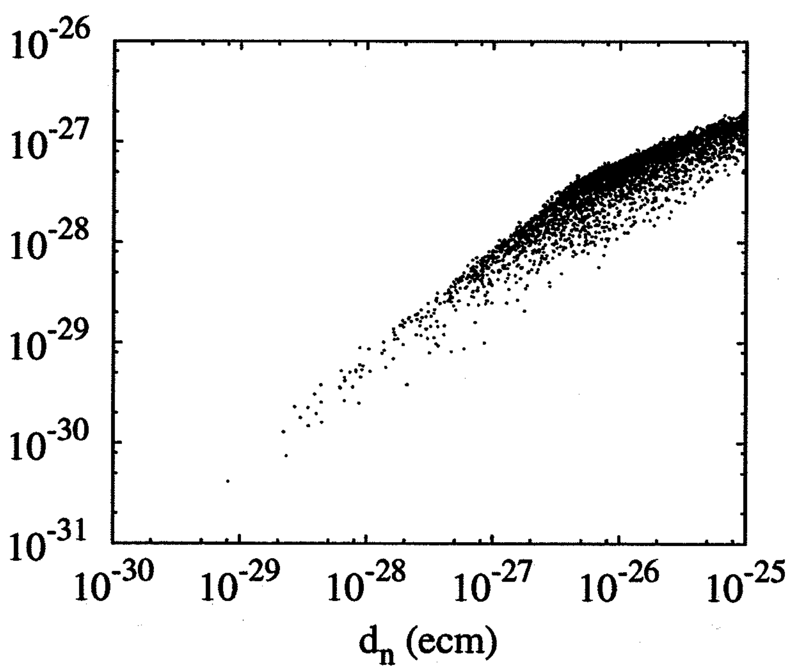
$m_{\tilde{q}_{1,2}} \to \infty$

Weinberg '89
Dai, ... '90

$d_n \sim$  $+ \ldots$

Chang, Keung, Pilaftsis '99

$d_e \sim$  $+$  $+ \ldots$



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

Should be observed soon!

Split SUSY

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

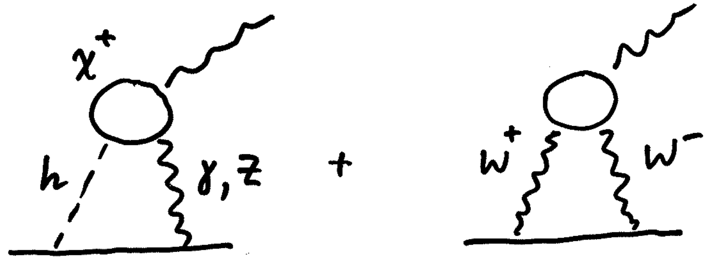
$|\mu| \in [200\ \text{GeV}, 1\ \text{TeV}]$

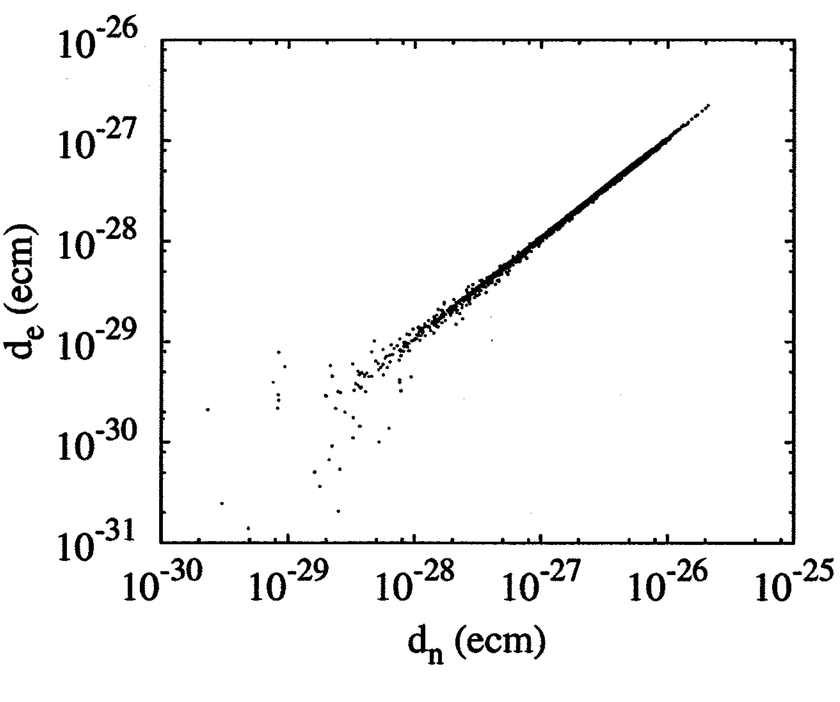
$m_h \in [100\ \text{GeV}, 300\ \text{GeV}]$

$M_{scalars} \to \infty$

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

$d_{n,e} \sim$





$d_n \sim 10\, d_e$

Observable!

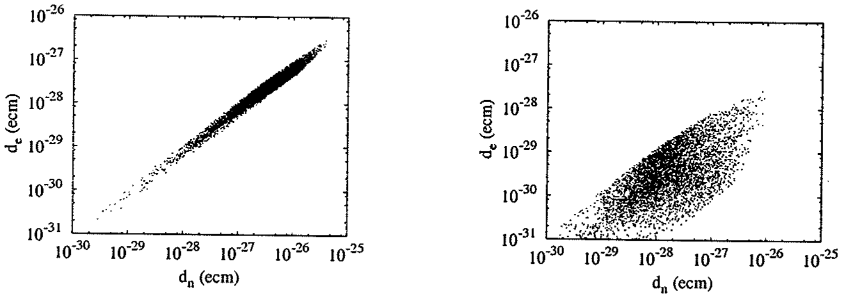


Figure 6: d_e vs d_n in mSUGRA with small phases, $\tan\beta = 5$. Left: $\phi_\mu \neq 0$, right: $\phi_A \neq 0$.

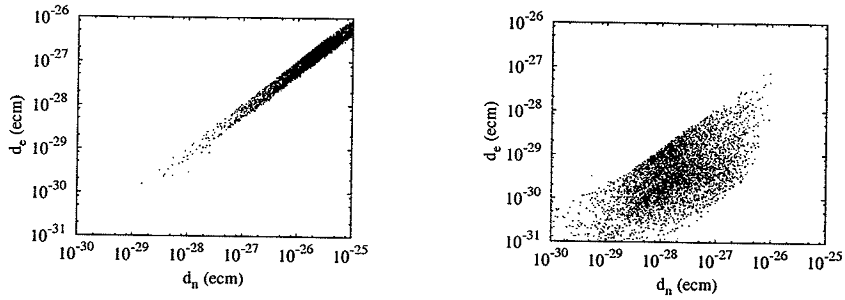


Figure 7: As in Fig.6, but for $\tan\beta = 35$.

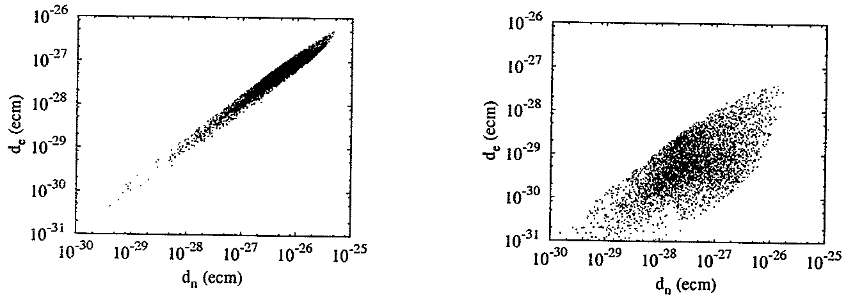


Figure 8: d_e vs d_n in mSUGRA with a heavy spectrum, $\tan\beta = 5$. Left: $\phi_\mu \neq 0$, right: $\phi_A \neq 0$.

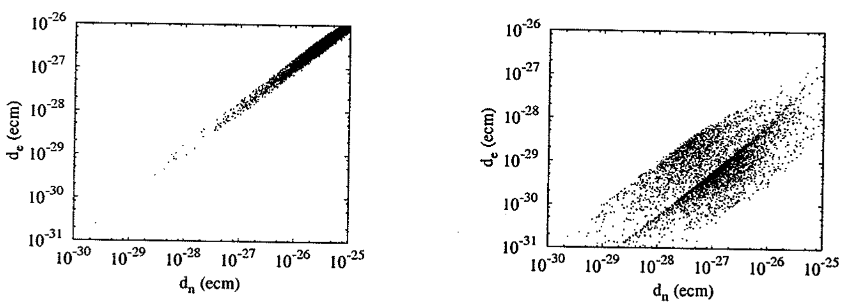


Figure 9: As in Fig.8, but for $\tan\beta = 35$.

d_n - d_e correlations

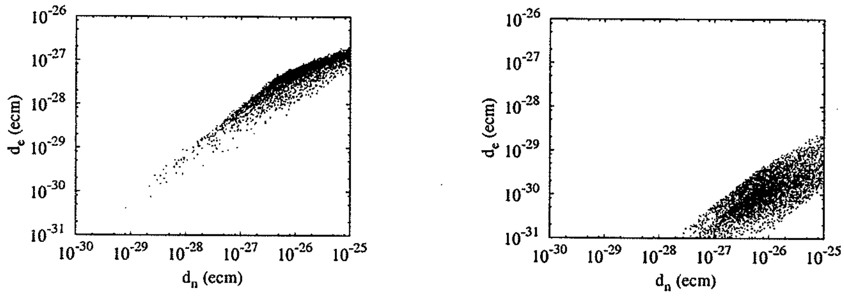


Figure 10: d_e vs d_n in the decoupling scenario, $\tan\beta = 5$. Left: $\phi_\mu \neq 0$, right: $\phi_A \neq 0$.

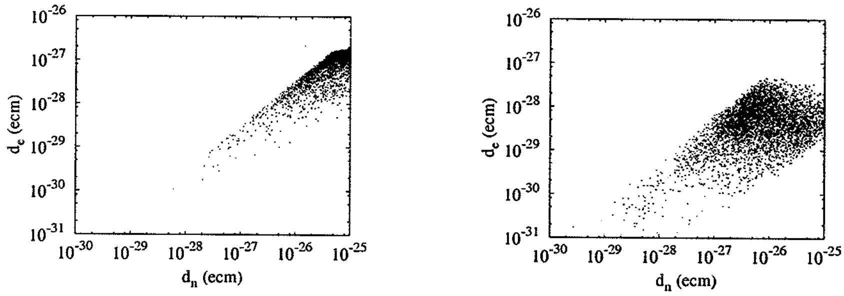


Figure 11: As in Fig.10, but for $\tan\beta = 35$.

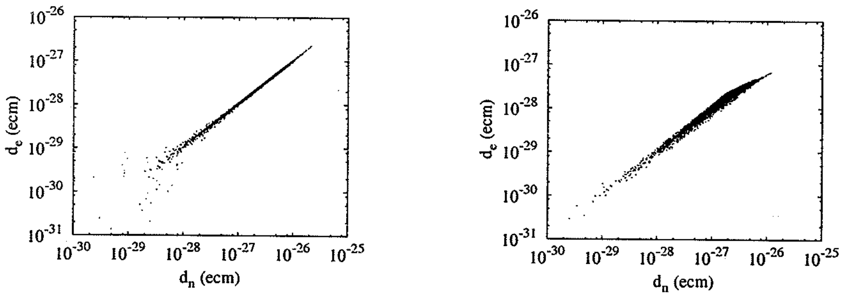


Figure 12: d_e vs d_n in split SUSY. Left: $\tan\beta = 5$, right: $\tan\beta = 35$.

Message:

typically $\underline{d_n \sim 10 \div 100\, d_e}$

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

Thus,

$d_e \gtrsim d_n$
$d_e \lll d_n$ $\Rightarrow$ SUSY disfavored

Also,

complementary to collider data:

$M_{SUSY} \lessgtr$ TeV , $\varphi_{CP} \sim 10^{-5}$
$M_{SUSY} \gtrsim 5$ TeV , $\varphi_{CP} \sim 1$
} out of colliders' reach

Conclusion:

- even in the minimal SUSY scenarios EDMs are observable within 5-... years

- $d_n - d_e$,... correlations →
  → indirect evidence for SUSY

- complementary to collider data