Can measurements of Electric Dipole Moments determine the seesaw parameters?

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This seminar is based on

Y. F. and M. Peskin, **PRD70 (04) 095001**

D. Demir and Y. F., JHEP510 (05) 68

Outline

- CP-violation and EDMs
- EDMs in the MSSM
- EDMs in the seesaw mechanism embedded in the MSSM
- Prospects for measurements
- Conclusions

Importance of CP symmetry

- CP-Violation is one of Sakharov's conditions for creation of the baryon asymmetry of the universe.

(Violation of CP is closely connected to the fact that you and me are made of matter rather than antimatter.)

Nonzero EDM=CP-violation=T-violation

T-violation (quantum mechanics)

$$d\vec{S}\cdot\vec{E}+\mu\vec{S}\cdot\vec{B}$$

T operator:

$$\vec{S}\longrightarrow-\vec{S}$$

$$\vec{E}\longrightarrow\vec{E}$$

$$\vec{B}\longrightarrow-\vec{B}$$

Field theoretical outlook

- CP-violating:

$$d\bar{\psi}\,[\gamma^\mu,\gamma^\nu]\,\gamma^5\psi F_{\mu\nu}$$

- CP-conserving:

$$\mu\bar{\psi}[\gamma^\mu,\gamma^\nu]\psi F_{\mu\nu}$$

CP-violation in the Standard Model

- CKM matrix (quark mixing) contains a CP-violating phase.
- In fact, CP-violating effects have been detected in the Kaon and B-meson sector.

EDMs in the Standard Model

$$d_e \sim 10^{-38}\ e\ \mathrm{cm}$$

- Bernrether and Suzuki, Rev Mod. Phys. 63 (1991) 313

$$|d_e| < 1.4 \times 10^{-27}\ e\ \mathrm{cm}$$

EDMs in the Standard Model

d_n ranges from 10^{-31} e cm to 10^{-33} e cm [2]

- Shabalin, Sov Phys Usp 26 (83) 297; Gavela et al., PLB109 (82) 215; Khriplocich and Zhitneitsky, PLB109 (82) 490.

$$|d_n| < 3.0 \times 10^{-26} \; e \; \text{cm}.$$

Is there any other source of CP-violation in the SM?

- Theta term

$$\theta \tilde{G}_{\mu\nu} G^{\mu\nu} = \theta \epsilon_{\mu\nu\sigma\rho} G^{\mu\nu} G^{\sigma\rho}$$

- We will assume some Peccei-Quinn mechanism is at work.

CP-violation in the context of MSSM

General MSSM includes 44 sources of CP-violation:

$$V_{soft} = \sum_{ij} \tilde{f}_i^\dagger \tilde{f}_j m_{ij}^2 + M_1 \tilde{B}\tilde{B} + M_2 \tilde{W}\tilde{W} + M_3 \tilde{g}\tilde{g} + etc$$

Flavor changing neutral current bounds

- Hayasaka *et al.* , **PLB613 (05) 20**

$$\mathrm{Br}(\tau \to e\gamma) < 3.9 \times 10^{-7}$$

- Aubert, **PRL95 (05) 41802**

$$\mathrm{Br}(\tau \to \mu\gamma) < 6.8 \times 10^{-8}$$

Neutral current flavor changing bounds

- PDG:

$$\mathrm{Br}(\mu \to e\gamma) < 1.2 \times 10^{-11}$$

No deviation from SM in $\mathrm{Br}(b \to s\gamma)$

Constrained MSSM or mSUGRA

$$W = Y_\ell^{ij} \epsilon_{\alpha\beta} H_d^\alpha E_i L_j^\beta - \mu \epsilon_{\alpha\beta} H_d^\alpha H_u^\beta,$$

$$\begin{aligned}
\mathcal{L}_{soft} &= -m_0^2 (\tilde{L}_i^\dagger \tilde{L}_i + \tilde{E}_i^\dagger \tilde{E}_i + H_d^\dagger H_d + H_u^\dagger H_u) \\
&- \frac{1}{2} m_{1/2} (\tilde{B}\tilde{B} + \tilde{W}\tilde{W} + \tilde{g}\tilde{g} + \text{H.c.}) \\
&- (\frac{1}{2} \epsilon_{\alpha\beta} b_H \mu H_d^\alpha H_u^\beta + A_\ell^{ij} \epsilon_{\alpha\beta} H_d^\alpha \tilde{E}_i \tilde{L}_j^\beta + \text{H.c.})
\end{aligned}$$

MSSM+RN

- In the MSSM, just like in the SM, neutrinos are massless.

- An economic way to assign tiny masses to neutrinos: embed the seesaw mechanism

in the MSSM.

Three right-handed neutrino supermultiplets: N_i

Superpotential in the presence of the right-handed neutrinos

$$W = Y_\ell^{ij}\epsilon_{\alpha\beta}H_d^\alpha E_i L_j^\beta - Y_\nu^{ij}\epsilon_{\alpha\beta}H_u^\alpha N_i L_j^\beta + \frac{1}{2}M_{ij}N_iN_j - \mu\epsilon_{\alpha\beta}H_d^\alpha H_u^\beta,$$

- Without loss of generality we can go to a basis that Y_ℓ^{ij} and M_{ij} are real diagonal.

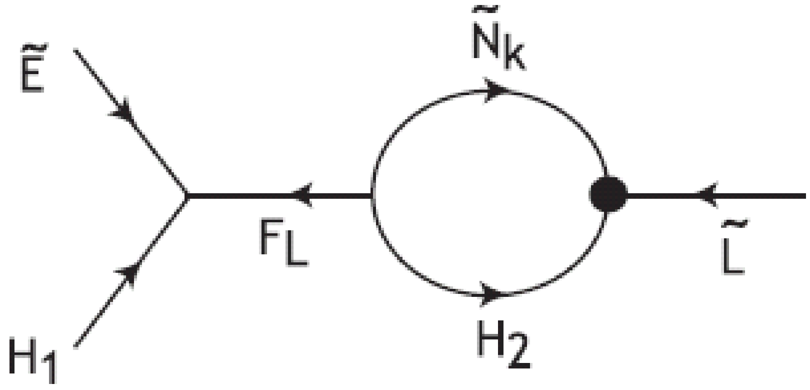
Soft susy breaking potential in the presence of the right-handed sneutrinos

$$
\begin{aligned}
= \;& -m_0^2(\tilde{L}_i^\dagger \tilde{L}_i + \tilde{E}_i^\dagger \tilde{E}_i + \tilde{N}_i^\dagger \tilde{N}_i + H_d^\dagger H_d + H_u^\dagger H_u) \\
- \;& \frac{1}{2} m_{1/2}(\tilde{B}\tilde{B} + \tilde{W}\tilde{W} + \tilde{g}\tilde{g} + \mathrm{H.c.}) \\
- \;& (\frac{1}{2}\epsilon_{\alpha\beta} b_H \mu H_d^\alpha H_u^\beta + \mathrm{H.c.}) - (A_\ell^{ij}\epsilon_{\alpha\beta} H_d^\alpha \tilde{E}_i \tilde{L}_j^\beta - A_\nu^{ij}\epsilon_{\alpha\beta} H_u^\alpha \tilde{N}_i \tilde{L}_j^\beta + \mathrm{H.c.}) \\
- \;& (\frac{1}{2} B_\nu M_i \tilde{N}^i \tilde{N}^i + \mathrm{H.c.}).
\end{aligned}
$$

$$A_\ell \;=\; a_0 Y_\ell \;\text{ and }\; A_\nu \;=\; a_0 Y_\nu$$

Radiative correction to charged lepton A-term

$$\delta(A_\ell)_{ij} = a_0 Y_{\ell i}(\delta Z_A)_{ij}$$



$$\delta Z_A^{ij} = -\frac{1}{(4\pi)^2}(Y_\nu^{ki})^* Y_\nu^{kj}\left[\log\frac{M_{\mathrm{GUT}}^2}{M_k^2} + 1\right]$$

Radiative corrections to the masses of the slepton doublet

$$(\delta m_{\tilde{L}}^2)^{ij} = -\frac{2m_0^2}{(4\pi)^2}(Y_\nu^{ki})^* Y_\nu^{kj} \left[\log \frac{M_{\mathrm{GUT}}^2}{M_k^2}\right]$$

$$-\frac{a_0^2}{(4\pi)^2}(Y_\nu^{ki})^* Y_\nu^{kj} \left[\log \frac{M_{\mathrm{GUT}}^2}{M_k^2} + 1\right]$$

- As shown in Y. F., **PRD69 (04) 073009**,

the neutrino B-term can also induce a correction to the slepton masses as well as

$(A_\ell)_{ij}$

Can we determine the parameters of seesaw?

- Right-handed neutrinos are believed to be too heavy to be produced by man or cosmic ray.
- Sources of information:

$$m_\nu = Y_\nu^T (\langle H_u \rangle^2 / M) Y_\nu$$

$$(m^2_{\tilde{L}})_{ij}$$

Is there any other source of information?

- $(Y_\nu)_{ij}$ add 6 new CP-violating phases which

Induces EDMs for charged leptons.

Duta and Mohapatra, PRD68 (03)113008

Is this conclusive?

- There are other sources of CP-violation:
- Phases of

$$B_\nu \qquad \mu \qquad a_0$$

Can we discriminate between the sources of CP-violation?

- D. Demir and Y. F., JHEP 0510 (05) 68:

- Each of these sources contribute differently to

$$d_\ell \quad d_n \quad d_{Hg} \quad d_D$$

- Complex Y_ν: only d_e
- Complex a_0 and μ: d_e, d_n d_{Hg}, d_D

Considering limited accuracy, is it possible to discern the source of EDM?

Calculation of d_n suffers from large uncertainty

- SU(3) chiral Lagrangian: Hisano and Shimizu, PRD70 (04) 93001

$$d_n = (1.6\tilde{d}_u + 1.3\tilde{d}_d + 0.26\tilde{d}_s)$$

- QCD sum rules:

Pospelov and Ritz,

PRD63 (01) 7

$$d_n = (1 \pm 0.5)\frac{|\langle\bar{q}q\rangle|}{(225\ \mathrm{MeV})^3}\times$$

$$\left[0.55e(\tilde{d}_d + 0.5\tilde{d}_u) + 0.7(d_d - 0.25d_u)\right]$$

- Following Hisano et al., PLB604 (04) 216 and Falk et al., NPB560 (99) 3, We will interpret d_{Hg} as $|\tilde{d}_d - \tilde{d}_u| < 2 \times 10^{-26}$ cm.
- Notice that d_{Hg} receives a non-negligible contribution from electron EDM

- Proposal in Semertzidis, hep-ex/0308063

- $|d_D|$ as small as $(1-3)\times 10^{-27}\ e\ cm$ can be probed.

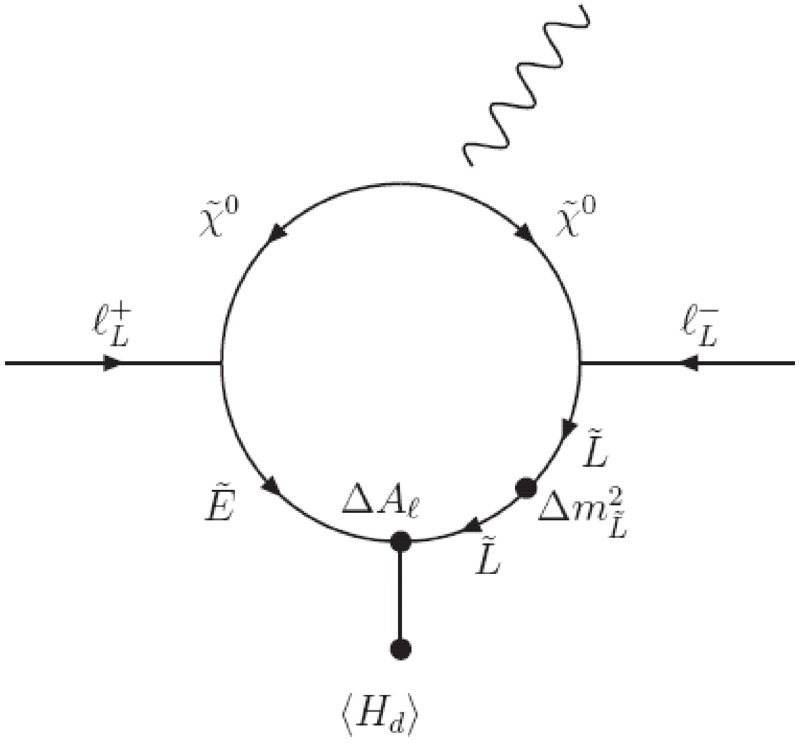
- Lebedev et al., PRD70 (04) 016003

$$d_D(d_q,\tilde{d}_q) \simeq -e(\tilde{d}_u - \tilde{d}_d)\,5^{+11}_{-3}$$

The contribution of Y_ν to d_e

- Hisano et al., PLB437 (98) 351; Romanino and Strumia, NPB622 (02) 73; Ellis et al., PLB528 (02) 86; I. Masina, NPB671 (03) 432.

- Y. F. and M. Peskin, PRD 70 (04) 095001



$$\mathrm{Im}[(\Delta A_\ell \Delta m_{\tilde{L}})_{ii}] \neq 0$$

Can we discriminate between different sources of CP-violation?

To answer, we have drawn scatter plots

Input parameters for mSUGRA

- It is not a correct practice to set all masses equal to $M_{susy.}$

- Stark et al, **JHEP 0508 (05) 059.**

$$m_{1/2} \quad m_0 \quad \tan\beta \quad a_0$$

Assigning values to Y_ν

$$m_\nu = Y_\nu^T (\langle H_u \rangle^2 / M) Y_\nu$$

$$(\delta m^2_{\tilde{L}})^{ij} = -\frac{2m_0^2}{(4\pi)^2}(Y_\nu^{ki})^* Y_\nu^{kj} \left[\log \frac{M^2_{\mathrm{GUT}}}{M_k^2}\right]$$

$$- \frac{a_0^2}{(4\pi)^2}(Y_\nu^{ki})^* Y_\nu^{kj} \left[\log \frac{M^2_{\mathrm{GUT}}}{M_k^2} + 1\right]$$

Bounds on the Yukawa coupling

$$Y_\nu^T \frac{1}{M} Y_\nu (v^2 \sin^2\beta)/2 = U \cdot \Phi \cdot M_\nu^{Diag} \cdot \Phi \cdot U^T$$

Φ is $diag[1, e^{i\phi_1}, e^{i\phi_2}]$

U = Unitary mixing matrix

$$M_\nu^{Diag} = diag[m_1, \sqrt{m_1^2 + \Delta m_{21}^2}, \sqrt{m_1^2 + \Delta m_{31}^2}]$$

Bounds from LFV processes

$$h \equiv Y_\nu^\dagger \mathrm{Log}\frac{M_{GUT}}{M} Y_\nu = \begin{bmatrix} a & 0 & d \\ 0 & b & 0 \\ d^* & 0 & c \end{bmatrix}$$

$$\mathrm{Br}(\mu \to e\gamma) < 1.2 \times 10^{-11}$$

$$\mathrm{Br}(\tau \to \mu\gamma) < 6.8 \times 10^{-8}$$

$$\mathrm{Br}(\tau \to e\gamma) < 3.9 \times 10^{-7}$$

How to interpret the bounds on d_{Hg} d_D

- Bound from d_{Hg} :

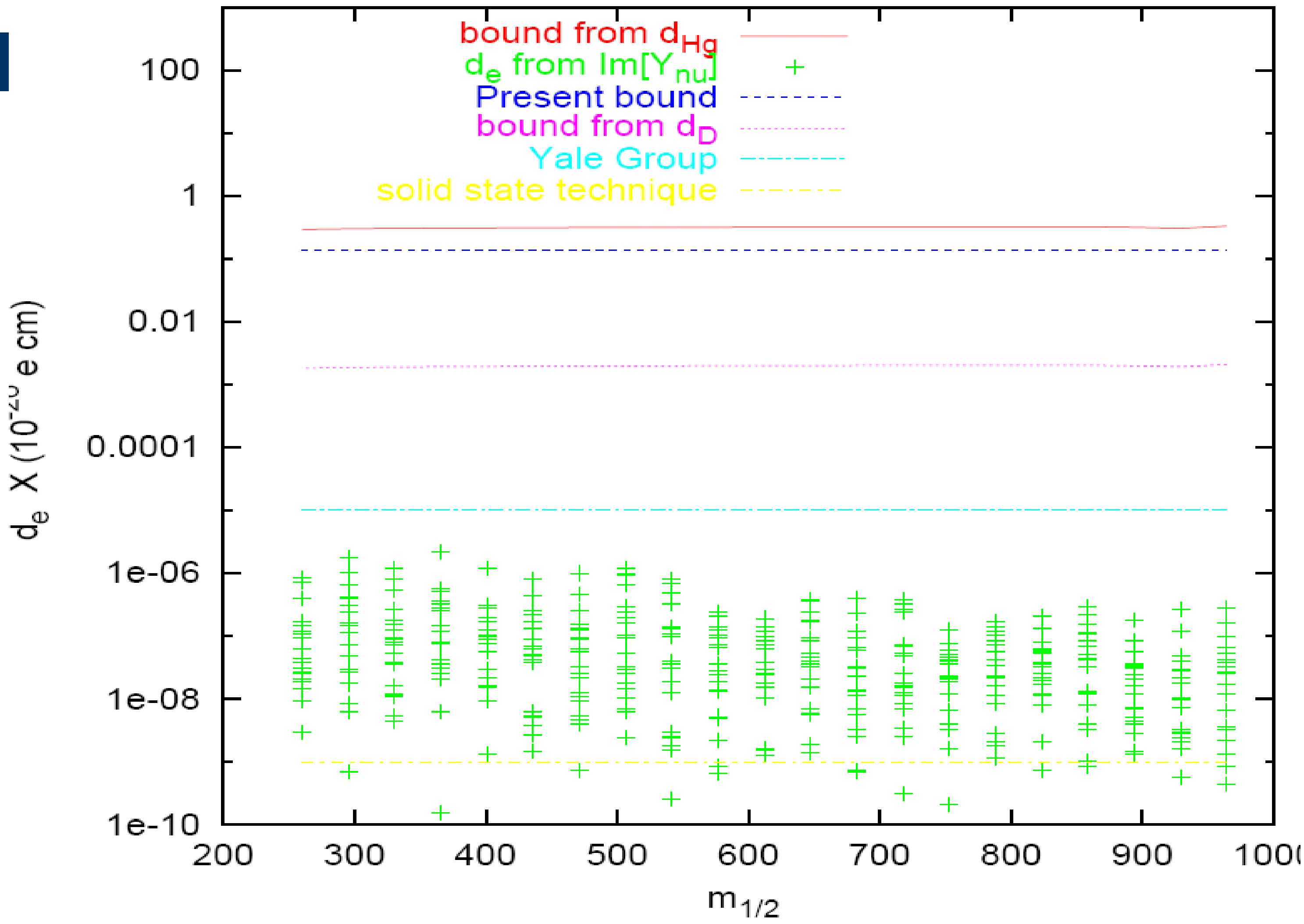
$$\tilde{d}_d - \tilde{d}_u < 2 \times 10^{-26}\ \mathrm{cm}$$

- (To be) Bound from d_D :

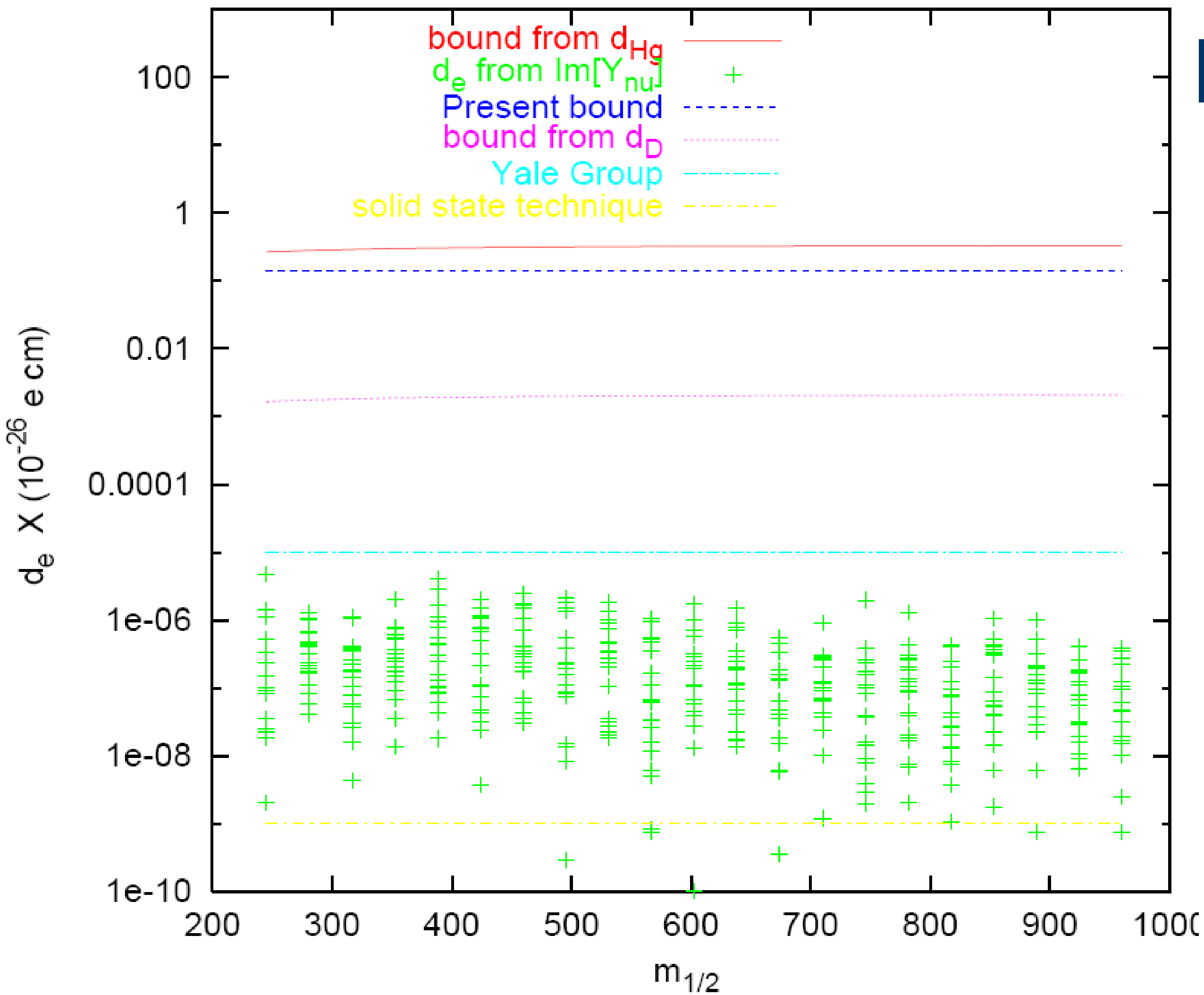
$$\tilde{d}_d - \tilde{d}_u < 2 \times 10^{-28}\ \mathrm{cm}$$

$\mathrm{Im}[a_0] = 0$

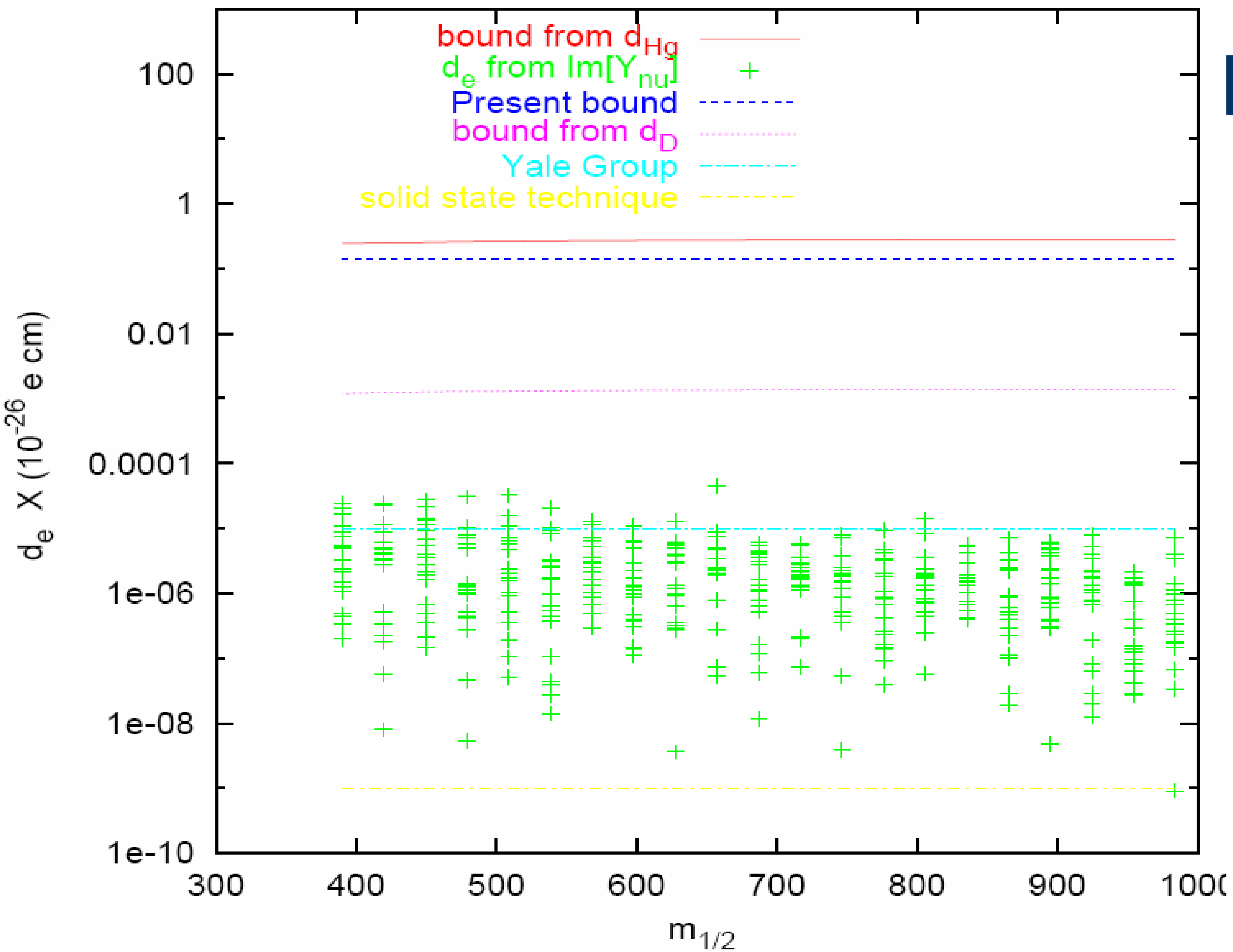
$a_0 = 0, \tan\beta = 10$



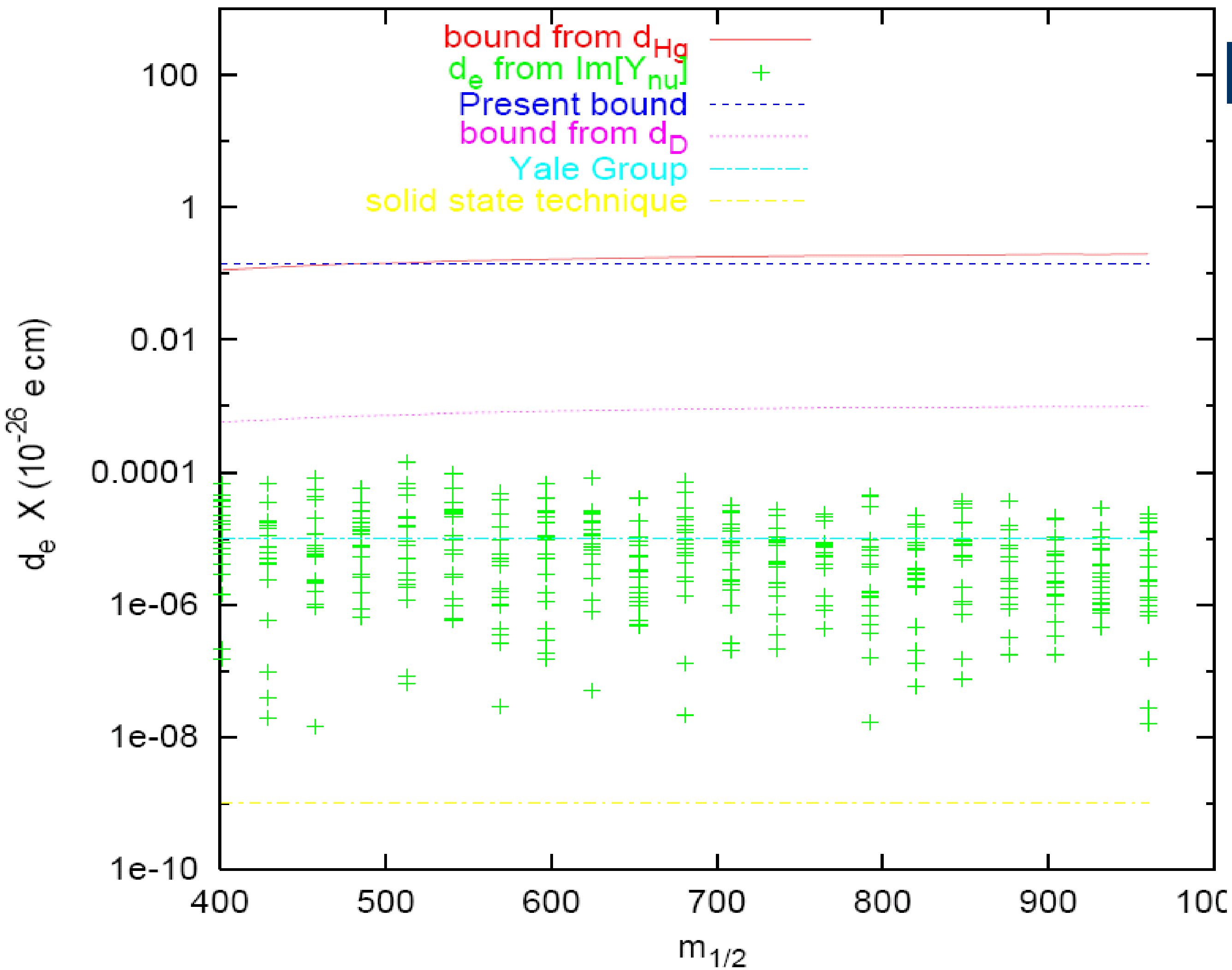
$$\mathrm{Im}[a_0] = 0 \qquad a_0 = 0,\ \tan\beta = 20$$



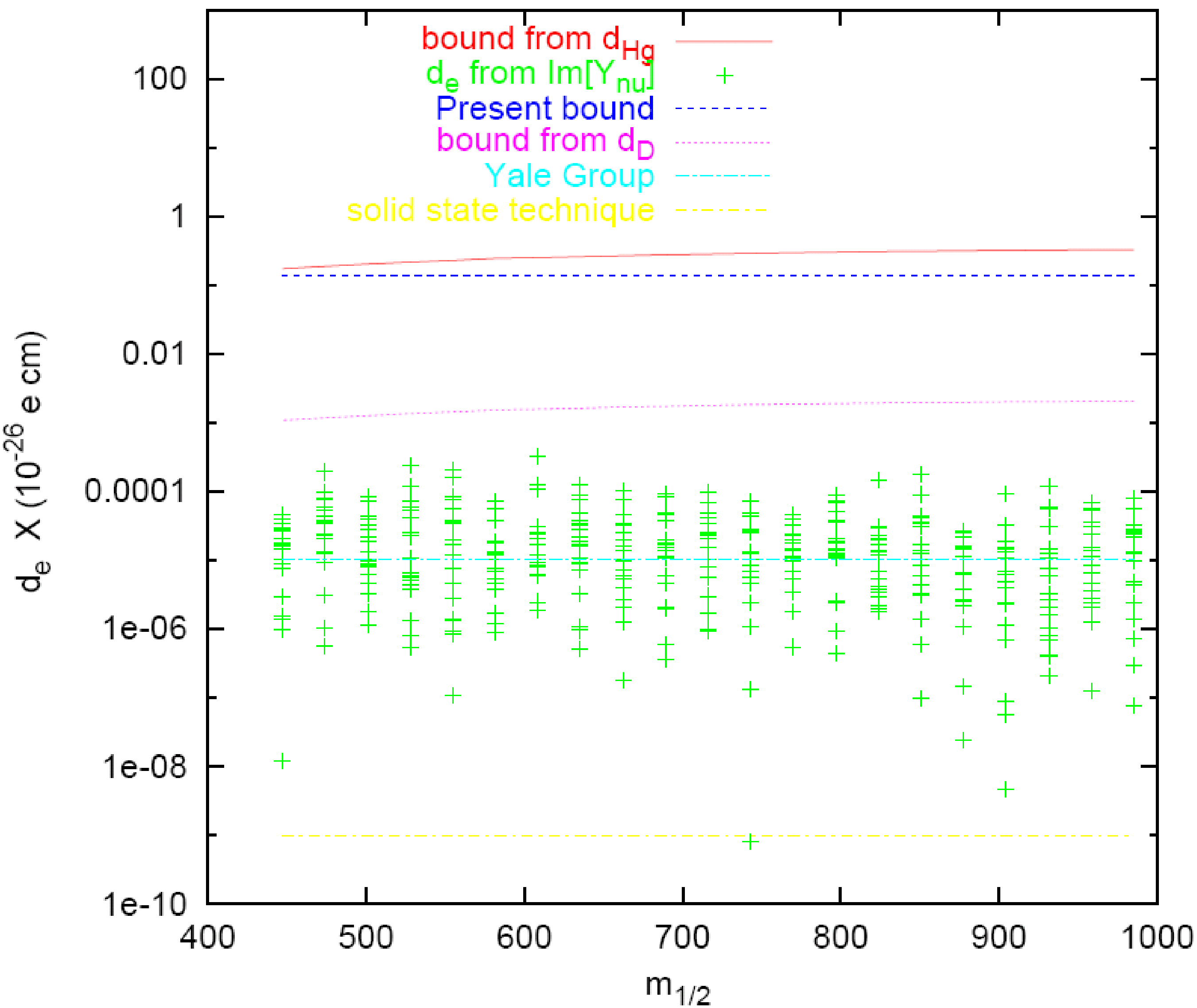
$\mathrm{Im}[\mu] = 0 \qquad a_0 = 1000\ \mathrm{GeV},\ \tan\beta = 10$



$\mathrm{Im}[\mu] = 0$ $\quad a_0 = 1000\ \mathrm{GeV},\ \tan\beta = 20$



$\mathrm{Im}[a_0] = 0 \qquad a_0 = 2000\ \mathrm{GeV},\ \tan\beta = 20$



Conclusions

- For small values of tan(β) [tan(β)<10] and

a_0 (a_0<1000 GeV), d_e is beyond the reach of the ongoing Yale experiment.

(Kawall et al., AIP Conf. Proc. 698 (04) 192)

However, can be probed by solid state techniques.

(Lamoreaux, nucl-ex/0109014)

Conclusions

- For larger values $\tan(\beta)$ and/or a_0, the Yale group may be able to detect the effects of complex Y_ν on d_e.

However, we will not be able to discriminate between different effects.

Answer to the question raised in the title of the talk

Let us suppose non-zero d_e is detected.

To discern the effects of phases of μ and a_0,

and thus to be able to extract information on Y_ν

and M, from d_e, $|\tilde{d}_d - \tilde{d}_u| \sim 10^{-28} - 10^{-29}\ e\ \mathrm{cm}$

has to be probed which is beyond the reach of the even proposed experiments.