EDMs as probes of SUSY

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OUTLINE:

- 0* Warning: here Lepton EDM (LEDM)
- 1* Constraints from LEDMs on slepton masses
- 2* LEDMs from RGE-induced CPV Sources
  - See-Saw
  - See-Saw + minSU(5)
  - Semi-Realistic SO(10)

  ⇔ potentially observable LFV!
- 3* Outlook

Beyond SM & ALL from DIPOLE OPERATOR

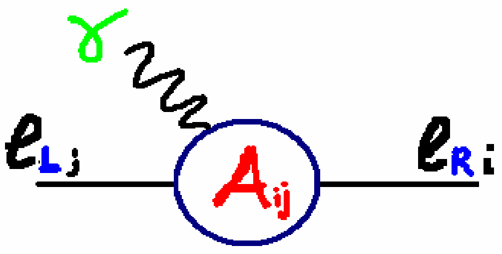
$$BR(\ell_i \to \ell_j \gamma) \propto |A_{ij}|^2$$

$$\delta a_{\ell_i} = Re A_{ii}$$

$$d_{\ell_i} = Im A_{ii}$$

NewPhys

$$\mathcal{L}_{d=5} = \frac{1}{2}\,\bar{\psi}_{Ri}\, A_{ij}\, \psi_{Lj}\, \sigma^{\mu\nu} F_{\mu\nu} + h.c.$$



e.m.charge chir flip

adim coupl of NP with lept encodes F&CP violations

$$\approx \frac{e\, m_i}{(4\pi)^2} \frac{\Gamma_{ij}}{M^2}$$

1-loop NP

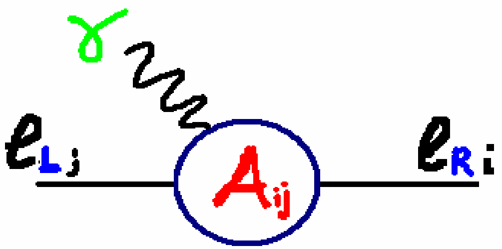
loop factor

NP mass scale

$$BR(\ell_i \to \ell_j \gamma) \propto |A_{ij}|^2$$

$$\delta a_{\ell_i} = Re A_{ii}$$

$$d_{\ell_i} = Im A_{ii}$$



lep-slept misalignment

$$\approx \frac{e\, m_i}{(4\pi)^2} \frac{\Gamma_{ij}}{M^2_{SUSY}}$$

SUSY

Loops w/ Sleptons & Gauginos

$$(\tilde{L}_e^* \; \tilde{L}_\mu^* \; \tilde{L}_\tau^*)\, \mathcal{M}^2_{\tilde{L}} \begin{pmatrix} \tilde{L}_e \\ \tilde{L}_\mu \\ \tilde{L}_\tau \end{pmatrix} + (\tilde{e}_R^* \; \tilde{\mu}_R^* \; \tilde{\tau}_R^*)\, \mathcal{M}^2_{\tilde{e}_R} \begin{pmatrix} \tilde{e}_R \\ \tilde{\mu}_R \\ \tilde{\tau}_R \end{pmatrix} + \left[(\tilde{e}_L^* \; \tilde{\mu}_L^* \; \tilde{\tau}_L^*)\, \mathcal{M}^2_{LR} \begin{pmatrix} \tilde{e}_R \\ \tilde{\mu}_R \\ \tilde{\tau}_R \end{pmatrix} + h.c. \right]$$

Mass Insertion: $\bar{m}_L^2 (\mathbb{1} + \delta^{LL})$ $\quad \bar{m}_R^2 (\mathbb{1} + \delta^{RR})$ $\quad \hat{m}_\ell (\hat{a}_\ell^* - \mu \tan\beta) + \bar{m}_L \bar{m}_R \delta^{LR}$

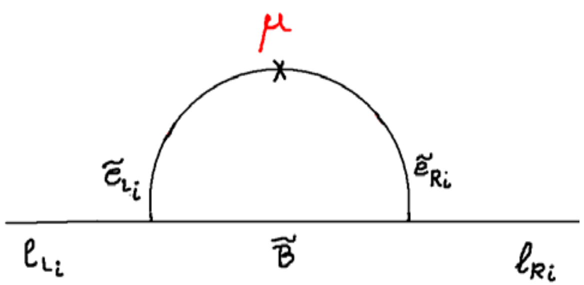
FC

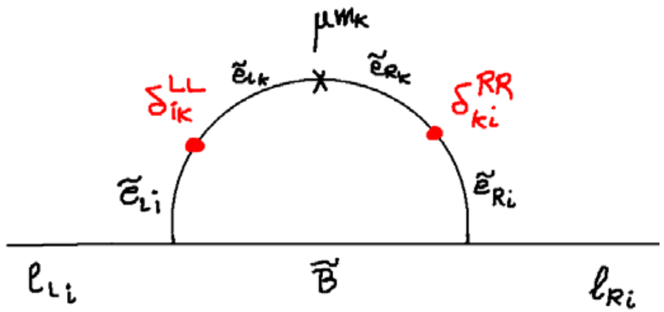
Expansion in powers of the FV δ's

$$BR(\ell_i \to \ell_j \gamma) \propto |A_{ij}|^2 = f_{LL}\,|\delta^{LL}_{ji}|^2 + f_{RR}\,|\delta^{RR}_{ji}|^2 + f_{LR}\,|\delta^{LR}_{ji}|^2 + f_{RL}\,|\delta^{RL}_{ji}|^2 + \ldots$$

$$\delta a_{\ell_i} = Re A_{ii} = f_\mu\, m^2_{\ell_i}\, Re\mu + \ldots$$

$$d_{\ell_i} = Im A_{ii} = \underbrace{f_\mu\, m_{\ell_i}\, Arg\mu + f_a m_{\ell_i} Im a_i}_{\text{FC}} + \underbrace{f_{LLRR} Im(\delta^{LL} m_\ell \delta^{RR})_{ii} + \ldots}_{\text{FV}}$$





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No canc: pr lim in mSugra in susy region preferred by g_μ with tgβ=10

[For more details see e.g.: IM&Savoy, ph/0211283]

$\mu \to e\gamma$ ⇨	$\lvert\delta^{LL}_{21}\rvert \leq 10^{-3}$	$\lvert\delta^{RR}_{21}\rvert \leq (10^{-2} - 1)$	
d_e ⇨	$Arg\mu \leq 2\times10^{-3}$	$Im a_e / m_R \leq 0.2$	$Im(\delta^{LL} m_l \delta^{RR})_{ee} / m_\tau \leq 10^{-5}$
d_μ@10^{-23}ecm ⇨	$Arg\mu \leq 10^{-1}$	-	$Im(\delta^{LL} m_l \delta^{RR})_{\mu\mu} / m_\tau \leq 10^{-1}$

$$BR(\ell_i \to \ell_j \gamma) \propto |A_{ij}|^2 = f_{LL} |\delta^{LL}_{ji}|^2 + f_{RR} |\delta^{RR}_{ji}|^2 + f_{LR} |\delta^{LR}_{ji}|^2 + f_{RL} |\delta^{RL}_{ji}|^2 + \ldots$$

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Scaling $d_e/m_e = d_\mu/m_\mu$

Scaling violation (in general)

No canc: pr lim in mSugra in susy region preferred by g_μ with $tg\beta=10$

[For more details see e.g.: IM&Savoy, ph/0211283]

$\mu \to e\gamma$ ⇨ $|\delta^{LL}_{21}| \leq 10^{-3}$ $|\delta^{RR}_{21}| \leq (10^{-2} - 1)$

d_e ⇨ $Arg\mu \leq 2\times10^{-3}$ $Im a_e/m_R \leq 0.2$ $Im(\delta^{LL} m_l \delta^{RR})_{ee}/m_\tau \leq 10^{-5}$

would need d_μ@2×10^{-25} ecm

Measure of d_μ = scaling violation → **Focus on CPV sources which violate scaling**

a-term and FV δ's a source of EDM

At low energy

$$a = a^{(0)} + a^{(rad)}$$

$$\delta = \delta^{(0)} + \delta^{(rad)}$$

in soft masses at M_{Pl}

Assume INHIBITION mechanism at work (e.g.mSUGRA)

radiatively induced running from M_{Pl} to m_{susy} by FV&CPV YUKAWAS of Heavy States

LFV exp's are testing the rad !!!

What about EDM exp's ?

1) See-Saw: ν^c

$$L_{SS} = \nu^c Y_\nu \nu H_D^u + \nu^c M_R \nu^c$$

Dirac ν-Yukawa coupling

ν^c mass matrix

2) GUTs: ν^c + H_T

Heavy colored Higgs Triplets (inducing p-decay)

e.g. in SU(5):

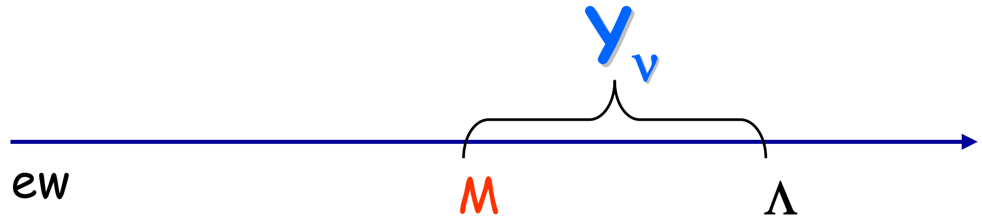
$5 = (H_D, H_T)$ $\bar{5} = (\bar{H}_D, \bar{H}_T)$

See-Saw

[RomaninoStrumia; EllisHisanoLolaRaidalShimizu; MSavoy; FarzanPeskin; ....]

See-Saw ν^c-deg

Solve RGE approx



LFV: at 1° order

(basis Ye=diag)

['86 BorzumatiMasiero]

$$1 \gg \delta^{LL}_{ij} \propto (Y_\nu^\dagger Y_\nu)_{ij} \ln \frac{\Lambda}{M}$$

strong impact on SS models!

EDM needs Im(non-herm)$_{ii}$

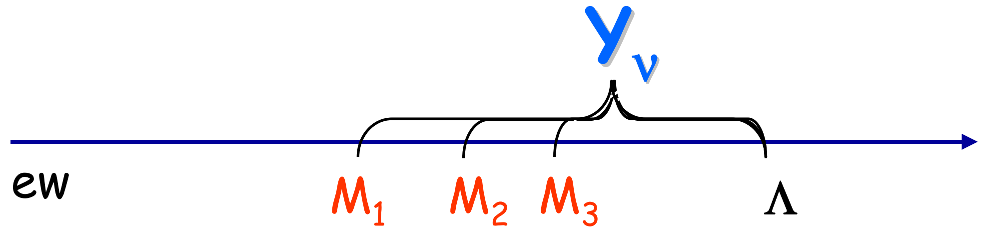
-> go at 4° order $Im(Y_\nu^\dagger Y_\nu [Y_\nu^\dagger Y_\nu, Y_\ell^\dagger Y_\ell] Y_\nu^\dagger Y_\nu)_{ii}$

a negligible effect…

deg->hier : EDM get STRONGLY enhanced, LFV not

See-Saw ν^c-hier

Solve RGE approx



LFV: at 1° order

$$\delta^{LL}_{ij} \propto \sum_{k=1,2,3} Y^{\dagger}_{\nu\, ik} \ln \frac{\Lambda}{M_k} Y_{\nu\, kj} = (C^k)_{ij}$$

strong impact on SS models!

EDM

FC: at 2° order
['01 EllisHisanoLolaRaidalShimizu]

$$\mathrm{Im}(a_i) \propto \sum_{k>k'} \frac{\ln(M_k/M_{k'})}{\ln(\Lambda/M_{k'})} \mathrm{Im}(C^k C^{k'})_{ii}$$

FV: at 3° order✪ tgβ³
['03 IM]

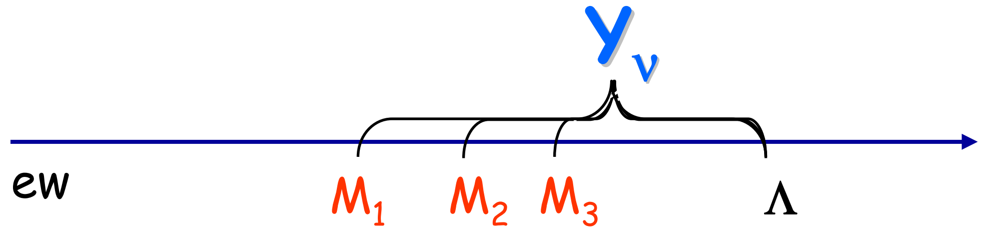
$$\mathrm{Im}(\delta^{RR} m_\ell \delta^{LL})_{ii} \propto \sum_{k>k'} \widetilde{\ln}^{k}_{k'} \mathrm{Im}(C^k m_\ell^2 C^{k'})_{ii}$$

<u>dominant for tgβ>10</u>

[formulae written as in IM&Savoy, ph/0501166]

See-Saw ν^c-hier

Solve RGE approx



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g_μ-2 region with tgβ=20

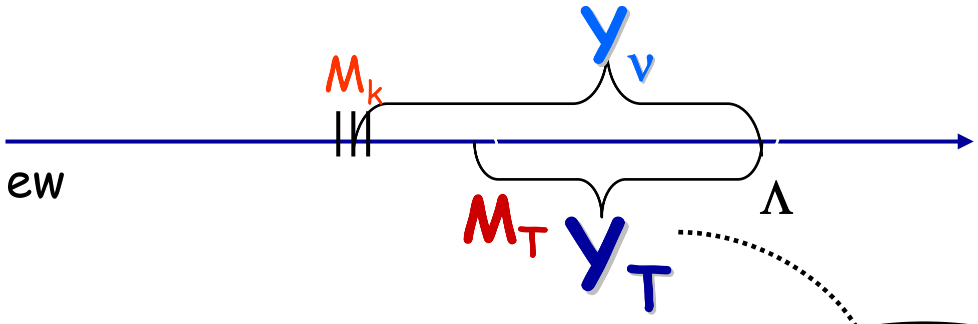
d^{SS}_μ ⊙ 10^{-25}ecm below planned...

d^{SS}_e ⊙ 1/2x10^{-27}ecm **At hand!** Strong SS-model dependence

See-Saw + minSU(5)

[BarbieriHallStrumia; Hisano&ManyManyJapanese; ....]

See-Saw+mSU(5)



from $U^{cT}\, y_u^T\, E^{cT}\, H_{T_u}$

LFV at 1° order:

$$\delta^{LL}_{ij} \propto \sum_k Y^\dagger_{\nu\, ik} \ln \frac{\Lambda}{M_k} Y_{\nu kj} = C_{ij}$$

not changed

$$\delta^{RR}_{ij} \propto (Y_u^T Y_u^*)_{ij} \ln \frac{\Lambda}{M_T}$$

not significant (now)

EDM ['03 IM]

⑥

FC: at 2° order

$$\mathrm{Im}(a_i) \propto \sum_{k>k'} \frac{\ln(M_k/M_{k'})}{\ln(\Lambda/M_{k'})} \mathrm{Im}(C^k C^{k'})_{ii}$$

same as only See-Saw

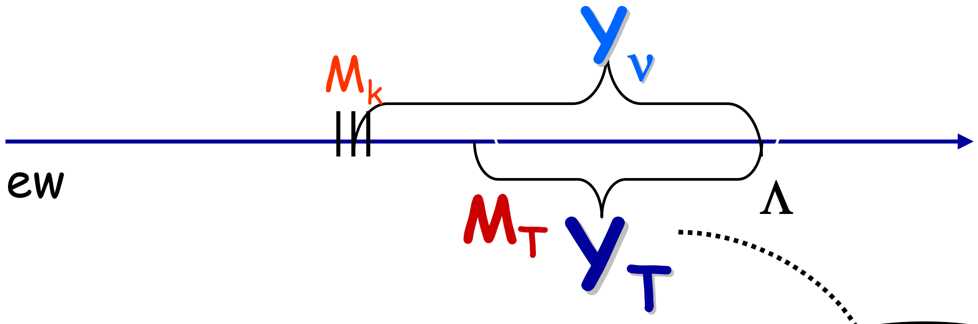
FV: at 2° order ✪ tgβ

$$\mathrm{Im}(\delta^{RR} m_\ell \delta^{LL})_{ii} \propto \mathrm{Im}(C m_\ell Y_u^T Y_u^*)_{ii} \ln \frac{\Lambda}{M_T}$$

MIXED

See-Saw+mSU(5)

even w/ν^c-deg



LFV at 1° order:

$$\delta^{LL}_{ij} \propto \sum_k Y^\dagger_{\nu\, ik} \ln \frac{\Lambda}{M_k} Y_{\nu kj} = C_{ij}$$

not changed

from $U^{cT}\ y_u{}^T\ E^{cT}\ H_{Tu}$

$$\delta^{RR}_{ij} \propto (Y_u^T Y_u^*)_{ij} \ln \frac{\Lambda}{M_T}$$

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EDM ['03 IM]

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$$\mathrm{Im}(a_i) \propto \sum_{k>k'} \frac{\ln(M_k/M_{k'})}{\ln(\Lambda/M_{k'})} \mathrm{Im}(C^k C^{k'})_{ii}$$

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$$\mathrm{Im}(\delta^{RR} m_\ell \delta^{LL})_{ii} \propto \mathrm{Im}(C m_\ell Y_u^T Y_u^*)_{ii} \ln \frac{\Lambda}{M_T}$$

g_μ region , tgβ=20
$M_T=2\times10^{16}$ GeV
$M_3=10^{15}$ GeV

d^{SS5}_μ ⊙ 5×10^{-25}ecm below planned...

d^{SS5}_e ⊙ 10^{-25}ecm ABOVE present! → $\mathrm{Im}\,(e^{-i\beta} C_{13}) < 0.1$

N.B. minSU(5) ruled out by p-decay induced by H_T
(that requires $M_T >> M_{GUT}$)

More realistic GUTs

e.g. in **SO(10)** p-decay rate can be suppressed by introducing more Higgs triplets with particular mass matrix

What predictions for d_e ?

[IM&Savoy, hep-ph/0309067]

Semi-Realistic SO(10)

Introduce: $16_i \qquad 10^u_H = (H^u_D, H^u_T) + (\bar{H}^u_D, \bar{H}^u_T) \qquad 10^d_H = (H^d_D, H^d_T) + (\bar{H}^d_D, \bar{H}^d_T)$

Fermion Masses u-quarks & Dirac-ν $Y_u = Y_\nu$ d-quarks & ch-lept $Y_d = Y_e$

→ T-Yukawas determined

Masses of **DOUBLETS**

$$\begin{array}{c|cc} & H^u_D & H^d_D \\ \hline \bar{H}^d_D & e.w. & 0 \\ \bar{H}^u_D & 0 & M_{GUT} \end{array}$$

TRIPLETS (splitting problem)

$$\begin{array}{c|cc} & H^u_T & H^d_T \\ \hline \bar{H}^d_T & \multicolumn{2}{c}{?} \\ \bar{H}^u_D & & \end{array} \times M_{GUT}$$

deg

$$\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$$

cpD (as D-W!)

$$\begin{pmatrix} 0 & 1 \\ 1 & r \end{pmatrix}$$

r<1

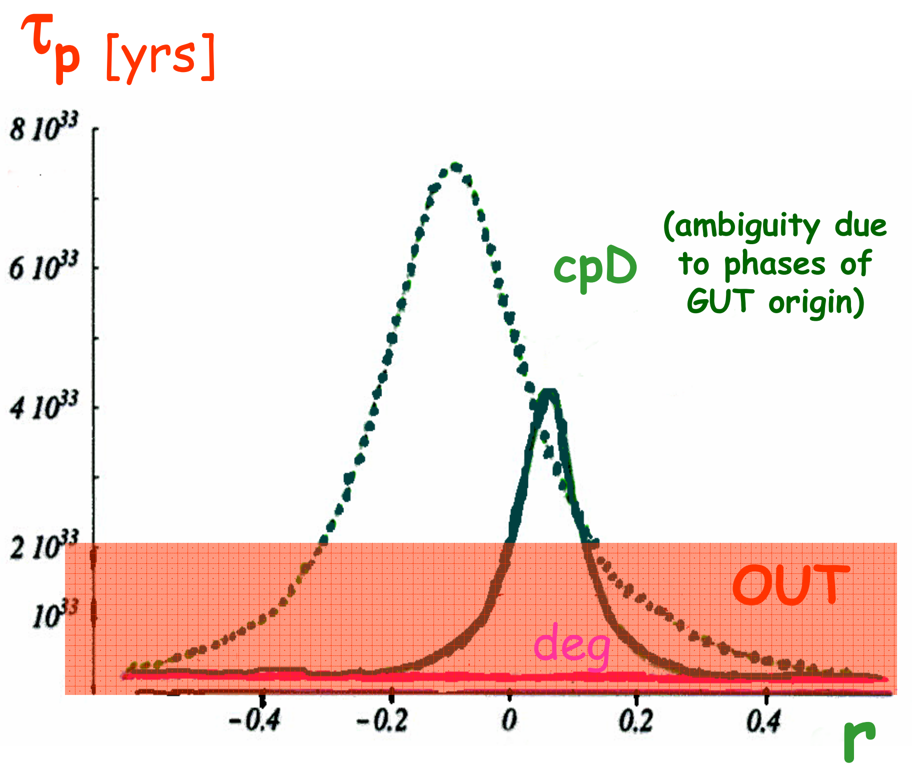
$p \to K^+ \nu$ VS d_e

From d=5 op generated by TRIPLET exchange
['82: Weinberg, Sakai, Yanagida, ...]

τ_p depends A LOT on M_T-structure

deg: KO cpD: SAFE

g_μ region& tgβ=3



$p \to K^+ \nu$ VS d_e

From d=5 op generated by TRIPLET exchange
['82: Weinberg, Sakai, Yanagida, ...]

τ_p depends A LOT on M_T-structure

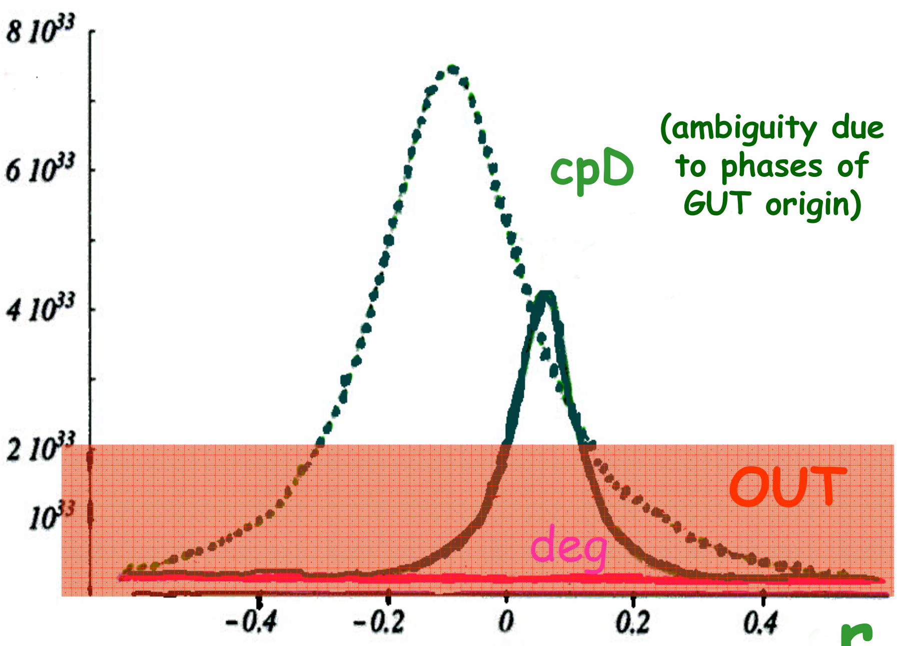
deg: KO   cpD: SAFE

From RGE where contributions of the many heavy states sum up

d_e INSENSITIVE to M_T-structure

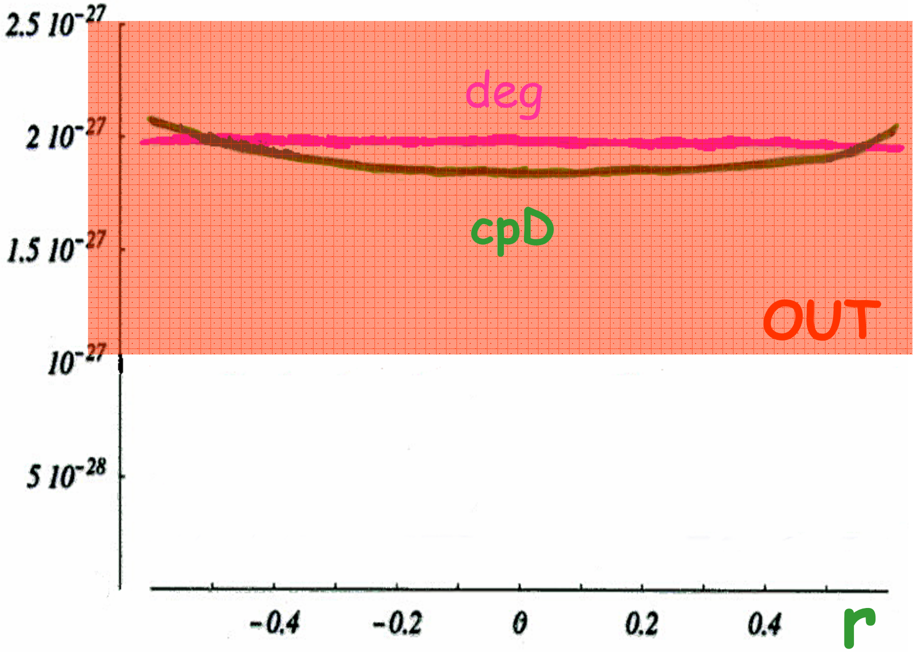
g_μ region& tgβ=3

τ_p [yrs]



d_e [ecm]

With (naturally) O(1) phase:



Complementary in constraining SUSY GUTs

In this model $$\frac{d_\mu}{d_e} \sim \left|\frac{V_{ts}}{V_{td}}\right|^2 \approx 25$$ **d_μ < planned**

When d_μ > planned ?

May happen in L-R symm GUT models

[see: '00 BabuDuttaMohapatra]

Outlook

EDMs are effective probes of TeV-scale NP beyond SM

in particular SUSY

Even thought it is interesting to compare their sensitivities by considering just ONE CPV source (like Argμ in SUSY) in general EDMs probe many different CPV sources

➡ This is the case for RGE-induced LEDMs
where CPV sources are Heavy State's Yukawas

- See-Saw: EDMs generically below exp sensitivity
- GUTs: EDMs possibly at hand

Planned EDM exp's have a strong impact on susy/seesaw/GUTs