Measurement of edm for a fast decaying particle

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Measuring the edm of a fast decaying particle

1. The EDM of a fundamental particle

2. A new test of CP violation for Hyperon production

3. Tauon edm measurement at $e^+e^- \to \tau^+ \tau^-$

4. Theoretical model studies

1. The EDM of a fundamental particle

Classically a EDM $\vec{D} = \int d^3x\vec{x}\rho(\vec{x})$ interacts with an electric field $\vec{E}$

The interaction energy is given by $H = \vec{D}\cdot\vec{E}$, allowed by P and T symmetries.

Under P, $\vec{D} \to -\vec{D}$ and $\vec{E} \to -\vec{E}$, H conserves both P and T.

A fundamental particle, $\vec{D}$ is equal to $d\vec{S}$, $H_{edm} = d\vec{S}\cdot\vec{E}$.

Since under P, $\vec{S} \to \vec{S}$ and under T, $\vec{S} \to -\vec{S}$

H_{edm} violates both P and T, CPT is conserved, CP is also violated!

Quantum field theory, $H_{edm} = -i\frac{1}{2}d\bar{\psi}\sigma^{\mu\nu}\psi\tilde{F}_{mu\nu} = -i\frac{1}{2}d\bar{\psi}\sigma^{\mu\nu}\gamma_5\psi F_{\mu\nu}$

In non-relativestic limit H_{edm} reduce to $d\frac{\vec{\sigma}}{2}\cdot\vec{E} = d\vec{S}\cdot\vec{E}$.

One easily sees that H_{edm} violates P and T, violates CP, but conserve CPT.

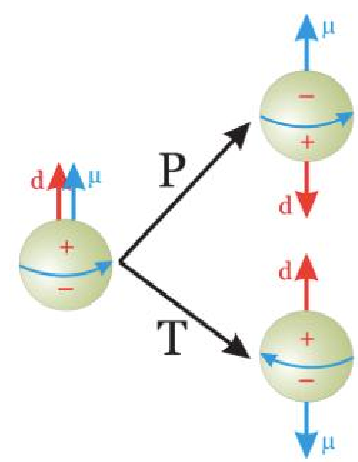
A non-zero fundamental particle EDM, violates P, T and CP!

Magnetic Dipole conserves P and T

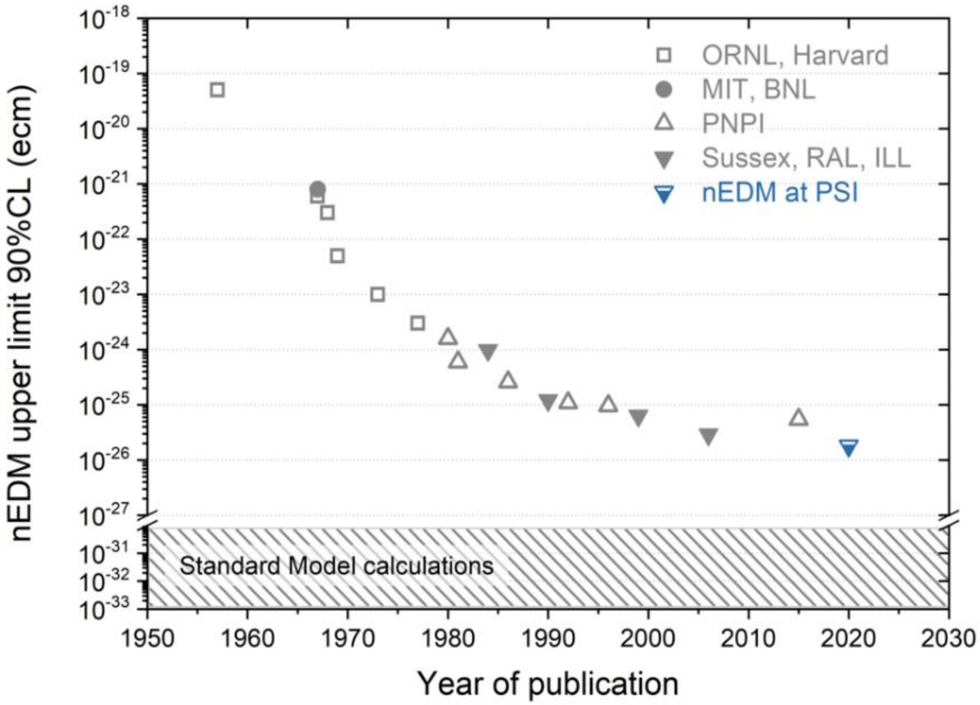
$H_{mdm} = d_m\vec{S}\cdot\vec{B}$,

Under P: $\vec{B} \to \vec{B}$ and under T: $\vec{B} \to -\vec{B}$

Relativistic expression: $d_m\bar{\psi}\sigma^{\mu\nu}\psi F_{\mu\nu}$.



History of Neutron EDM measurement



The first measreuiment started by Smith, Purcell, and Ramsey in 1951 (and published in 1957) obtaining a limit of $|d_n| < 5\times10-20$ e· cm

1957, Landau realized edm of a fundamental particle violates CP

In order to extract the neutron EDM, one measures the Larmor precession of the neutron spin in the presence of parallel and antiparallel magntic and electric fields.

$$h\nu = 2\mu_n B \pm 2d_n E$$

$$d_n = \frac{h\,\Delta\nu}{4E}$$

No measurement of a fundamental particle EDM, yet!

Current 90% C.L. limits on EDM:

Proton $|d_p| < 2.1 \times 10^{-25}$ ecm, electron $|d_e| < 1.1 \times 10^{-29}$ ecm

Neutron $|d_n| < 1.8 \times 10^{-26}$ ecm, muon $|d_\mu| < 1.8 \times 10^{-19}$ ecm

tauon $Re(d_\tau)$ -2.2 to 0.45×10^{-17} ecm, $Im(d_\tau)$ -2.5 to 0.08×10^{-17} ecm

Lambda $|d_\Lambda| < 1.5 \times 10^{-16}$ ecm, Other hyperons, no measurements

Neutron lives long enough, can watch Lomor precission, and switch electric field direction to measure.

Electron EDMs are usually not measured on free electrons, but instead on bound, unpaired valence electrons inside atoms and molecules. In these, one can observe the effect of $U = -\mathbf{d}_e \cdot \mathbf{E}$ as a slight shift of spectral lines.

But for fast decaying particles like hyperon and tauon other methods are needed, usually through interaction in decay or production processes.

Quark model for EDM

$$B = \begin{pmatrix} \Sigma^0/\sqrt{2} + \Lambda/\sqrt{6} & \Sigma^+ & p \\ \Sigma^- & -\Sigma^0/\sqrt{2} + \Lambda/\sqrt{6} & n \\ \Xi^- & \Xi^0 & -2\Lambda/\sqrt{6} \end{pmatrix}$$

d_B	QM	Reduced Results	d_B	NR QCD & QM	Reduced Results
d_p^{qEDM}	$\frac{1}{3}(4d_u - d_d)$	—	d_p^{qCDM}	$-\frac{1}{3}(4Q_d f_d - Q_u f_u)$	—
d_n^{qEDM}	$\frac{1}{3}(4d_d - d_u)$	—	d_p^{qCDM}	$-\frac{1}{3}(4Q_u f_u - Q_d f_d)$	—
$d_{\Sigma^+}^{\text{qEDM}}$	$\frac{1}{3}(4d_u - d_s)$	$-\frac{1}{3}d_s$	d_p^{qCDM}	$-\frac{1}{3}(4Q_u f_u - Q_s f_s)$	$-\frac{1}{9}ef_s$
$d_{\Sigma^0}^{\text{qEDM}}$	$\frac{1}{3}(2d_u + 2d_d - d_s)$	$-\frac{1}{3}d_s$	d_p^{qCDM}	$-\frac{1}{3}(2Q_u f_u + 2Q_d f_d - Q_s f_s)$	$-\frac{1}{9}ef_s$
$d_{\Sigma^-}^{\text{qEDM}}$	$\frac{1}{3}(4d_d - d_s)$	$-\frac{1}{3}d_s$	d_p^{qCDM}	$-\frac{1}{3}(4Q_d f_d - Q_s f_s)$	$-\frac{1}{9}ef_s$
$d_{\Xi^0}^{\text{qEDM}}$	$\frac{1}{3}(4d_s - d_u)$	$\frac{4}{3}d_s$	d_p^{qCDM}	$-\frac{1}{3}(4Q_s f_s - Q_u f_u)$	$\frac{4}{9}ef_s$
$d_{\Xi^-}^{\text{qEDM}}$	$\frac{1}{3}(4d_s - d_d)$	$\frac{4}{3}d_s$	d_p^{qCDM}	$-\frac{1}{3}(4Q_s f_s - Q_d f_d)$	$\frac{4}{9}ef_s$
$d_{\Lambda^0}^{\text{qEDM}}$	d_s	d_s	d_p^{qCDM}	$-Q_s f_s$	$\frac{1}{3}ef_s$

EDM of neutron and electron in KM model

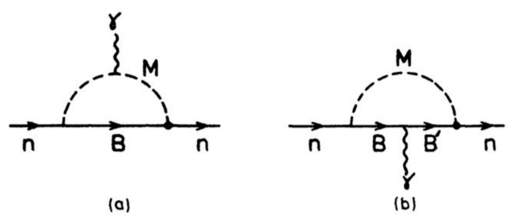
Quark EDM D_q and neutron EDM D_n, $D_n = (4D_d - D_u)/3$

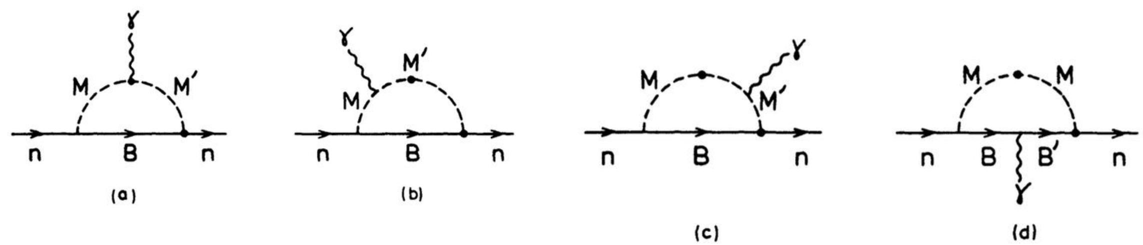
In KM model, quark EDM only generated at two electroweak and one strong loop level (3 loop effects)l, very small ~ 10^{-33} e.cm. (Shabalin, 1978, 1980)

In fact with two weak and one strong interaction vertices, EDM can also be generated!

(He, McKellar and Pakvasa, PLB197, 556(1987), J. Mod. Phys. A4, 5011(1989)

$$1.6 \times 10^{-31}\ \text{e.cm} \geq |D_n| \geq 1.4 \times 10^{-33}\ \text{e.cm}$$





Electron EDM is even smaller, generated at fourth loop level, $D_e < 10^{-38}$ecm

2. A new test of CP violation for Hyperon production

a

X-G He, J-P Ma, B. Mckellar, PRD 47(1993) 1744; X-G He and J-P Ma, PLB839(2023)137834
Yong Du, X-G He, J-P Ma, X-Y Du, PRD 110(2024)076019

Testing of P and CP symmetries with $e^+e^- \to J/\psi \to \Lambda\bar{\Lambda}$

$$\mathcal{A}^\mu = \bar{u}(k_1)\left[\gamma^\mu F_V + \frac{i}{2m_\Lambda}\sigma^{\mu\nu}q_\nu H_\sigma + \gamma^\mu\gamma_5 F_A + \sigma^{\mu\nu}q_\nu\gamma_5 H_T\right]v(k_2),$$

$$G_1^B = F_V^B + H_\sigma^B, \quad G_2^B = G_1^B - \frac{(k_1-k_2)^2}{4m_B^2}H_\sigma^B, \qquad H_T = \frac{2e}{3m_{J/\psi}^2}g_V d_\Lambda$$

$$\Lambda \to p + \pi \text{ or } \bar{\Lambda} \to \bar{p} + \pi.$$

$\hat{l}_p$, $l_{\bar{p}}$ and $\hat{k}$ momentum directions of p, $\bar{p}$ and Λ.

e+ e- -> J/Ψ Density matrix

$$\mathcal{T} = \epsilon^{\mu}\mathcal{A}_{\mu}, \quad R(\hat{\boldsymbol{p}}, \hat{\boldsymbol{k}}, \boldsymbol{s}_1, \boldsymbol{s}_2) = \mathcal{T}\mathcal{T}^{\dagger} = \rho^{ij}\mathcal{M}^{ij},$$

$$\mathcal{M}^{ij} = \mathcal{A}^{i}\mathcal{A}^{*j}, \quad \rho^{ij} = \epsilon^{i}\epsilon^{*j}. \quad \rho^{ij}(\hat{\boldsymbol{p}}) = \frac{1}{3}\delta^{ij} - i d_J \epsilon^{ijk}\hat{p}^{k} - \frac{c_J}{2}\left(\hat{p}^{i}\hat{p}^{j} - \frac{1}{3}\delta^{ij}\right),$$

d_J induced by Z exchange in SM   e+ e- ->Z -> J/Ψ

$$d_J = \frac{3 - 8\sin^2\theta_W}{32\cos^2\theta_W \sin^2\theta_W}\frac{M_{J/\psi}^2}{M_Z^2} \approx 2.53 \times 10^{-4},$$

$$\hat{\boldsymbol{p}} = \frac{\boldsymbol{p}}{|\boldsymbol{p}|}, \quad \hat{\boldsymbol{k}} = \frac{\boldsymbol{k}}{|\boldsymbol{k}|}, \quad \hat{\boldsymbol{n}} = \frac{\boldsymbol{p}\times\boldsymbol{k}}{|\boldsymbol{p}\times\boldsymbol{k}|}, \quad \omega = \hat{\boldsymbol{p}}\cdot\hat{\boldsymbol{k}}.$$

$$R\left(\hat{\boldsymbol{p}}, \hat{\boldsymbol{k}}, \boldsymbol{s}_1, \boldsymbol{s}_2\right) = a(\omega) + \boldsymbol{s}_1\cdot\boldsymbol{B}_1(\hat{\boldsymbol{p}}, \hat{\boldsymbol{k}}) + \boldsymbol{s}_2\cdot\boldsymbol{B}_2(\hat{\boldsymbol{p}}, \hat{\boldsymbol{k}}) + s_1^i s_2^j C^{ij}(\hat{\boldsymbol{p}}, \hat{\boldsymbol{k}}).$$

a, B_1, B_2 and C^{ij} are functions of $F_{V,A}$, $H_{\sigma, T}$

$$\boldsymbol{B_1}(\hat{\boldsymbol{p}},\hat{\boldsymbol{k}}) = \hat{\boldsymbol{p}} b_{1p}(\omega) + \hat{\boldsymbol{k}} b_{1k}(\omega) + \hat{\boldsymbol{n}} b_{1n}(\omega), \quad \boldsymbol{B_2}(\hat{\boldsymbol{p}},\hat{\boldsymbol{k}}) = \hat{\boldsymbol{p}} b_{2p}(\omega) + \hat{\boldsymbol{k}} b_{2k}(\omega) + \hat{\boldsymbol{n}} b_{2n}(\omega),$$

$$C^{ij}(\hat{\boldsymbol{p}},\hat{\boldsymbol{k}}) = \delta^{ij} c_0(\omega) + \epsilon^{ijk}\left(\hat{\boldsymbol{p}}^k c_1(\omega) + \hat{\boldsymbol{k}}^k c_2(\omega) + \hat{\boldsymbol{n}}^k c_3(\omega)\right) + \left(\hat{\boldsymbol{p}}^i\hat{\boldsymbol{p}}^j - \frac{1}{3}\delta^{ij}\right) c_4(\omega) + \left(\hat{\boldsymbol{k}}^i\hat{\boldsymbol{k}}^j - \frac{1}{3}\delta^{ij}\right) c_5(\omega)$$
$$+ \left(\hat{\boldsymbol{p}}^i\hat{\boldsymbol{k}}^j + \hat{\boldsymbol{k}}^i\hat{\boldsymbol{p}}^j - \frac{2}{3}\omega\delta^{ij}\right) c_6(\omega) + \left(\hat{\boldsymbol{p}}^i\hat{\boldsymbol{n}}^j + \hat{\boldsymbol{n}}^i\hat{\boldsymbol{p}}^j\right) c_7(\omega) + \left(\hat{\boldsymbol{k}}^i\hat{\boldsymbol{n}}^j + \hat{\boldsymbol{n}}^i\hat{\boldsymbol{k}}^j\right) c_8(\omega),$$

$$\begin{aligned}
a(\omega) &= E_c^2\left[|G_1|^2(1+\omega^2) + |G_2|^2 y_m^2(1-\omega^2)\right],\\
c_0(\omega) &= \frac{1}{3}a(\omega),\\
c_1(\omega) &= -4E_c^3\beta\omega\mathrm{Re}\left(H_T G_1^*\right),\\
c_2(\omega) &= 4E_c^3 y_m\beta\left\{\mathrm{Re}\left(H_T G_2^*\right) + \omega^2\mathrm{Re}\left[H_T(G_1-G_2)^*\right]\right\},\\
c_3(\omega) &= 0,\\
c_4(\omega) &= 2E_c^2|G_1|^2,\\
c_5(\omega) &= 2E_c^2\left[|G_1|^2 - y_m^2|G_2|^2 + |G_1-y_mG_2|^2\omega^2\right],\\
c_6(\omega) &= -2E_c^2\omega\left[|G_1|^2 - y_m\mathrm{Re}\left(G_1G_2^*\right)\right],\\
c_7(\omega) &= 2E_c^2\beta\left|\hat{\boldsymbol{p}}\times\hat{\boldsymbol{k}}\right|\mathrm{Im}\left(F_AG_1^*\right),
\end{aligned}$$

$$\begin{aligned}
c_8(\omega) &= 2E_c^2\left|\hat{\boldsymbol{p}}\times\hat{\boldsymbol{k}}\right|\left\{2d_Jy_m\mathrm{Im}\left(G_1G_2^*\right) - \beta\omega\mathrm{Im}\left[F_A\left(G_1-y_mG_2\right)^*\right]\right\},\\
b_{1n}(\omega) &= b_{2n}(\omega) = 2\left|\hat{\boldsymbol{p}}\times\hat{\boldsymbol{k}}\right|E_c^2\omega y_m\mathrm{Im}\left(G_1G_2^*\right),\\
b_{1p}(\omega) &= 2E_c^2\left\{2y_md_J\mathrm{Re}\left(G_1G_2^*\right) + \beta\omega\left[y_m\mathrm{Re}\left(F_AG_2^*\right) + 2E_c\mathrm{Im}\left(H_TG_1^*\right)\right]\right\},\\
b_{2p}(\omega) &= 2E_c^2\left\{2y_md_J\mathrm{Re}\left(G_1G_2^*\right) + \beta\omega\left[y_m\mathrm{Re}\left(F_AG_2^*\right) - 2E_c\mathrm{Im}\left(H_TG_1^*\right)\right]\right\},\\
b_{1k}(\omega) &= 2E_c^2\left\{2d_J\omega\left(|G_1|^2 - y_m\mathrm{Re}\left(G_1G_2^*\right)\right) + \beta\,\mathrm{Re}\left[F_A\left((1+\omega^2)G_1 - \omega^2y_mG_2\right)^*\right]\right.\\
&\qquad\left. -2E_c\beta\,\mathrm{Im}\left[H_T\left(\omega^2G_1 + (1-\omega^2)y_mG_2\right)^*\right]\right\},\\
b_{2k}(\omega) &= 2E_c^2\left\{2d_J\omega\left(|G_1|^2 - y_m\mathrm{Re}\left(G_1G_2^*\right)\right) + \beta\,\mathrm{Re}\left[F_A\left((1+\omega^2)G_1 - \omega^2y_mG_2\right)^*\right]\right.\\
&\qquad\left. +2E_c\beta\,\mathrm{Im}\left[H_T\left(\omega^2G_1 + (1-\omega^2)y_mG_2\right)^*\right]\right\},
\end{aligned}$$

On-shell production of J/Ψ and observables

$$e^-(p_1) + e^+(p_2) \to J/\psi \to \Lambda(k_1, s_1) + \bar{\Lambda}(k_2, s_2),$$

$$p_1^\mu = (E_c, \boldsymbol{p}), \quad p_2^\mu = (E_c, -\boldsymbol{p}), \quad k_1^\mu = (k^0, \boldsymbol{k}), \quad k_2^\mu = (k^0, -\boldsymbol{k}).$$

$$\Lambda \to p + \pi \ \text{ or } \ \bar{\Lambda} \to \bar{p} + \pi$$

$$\frac{d\Gamma_\Lambda}{d\Omega_p}(\boldsymbol{s}_1, \hat{\boldsymbol{l}}_p) \propto 1 + \alpha \boldsymbol{s}_1 \cdot \hat{\boldsymbol{l}}_p, \quad \frac{d\Gamma_{\bar{\Lambda}}}{d\Omega_{\bar{p}}}(\boldsymbol{s}_2, \hat{\boldsymbol{l}}_{\bar{p}}) \propto 1 - \bar{\alpha} \boldsymbol{s}_2 \cdot \hat{\boldsymbol{l}}_{\bar{p}}$$

$\hat{\boldsymbol{l}}_p$ and $\hat{\boldsymbol{l}}_{\bar{p}}$ is the direction of the momentum of the proton or anti-proton in the rest frame of Λ or $\bar{\Lambda}$

$$\mathcal{A}(\mathcal{O}) = \frac{\mathcal{N}_{\text{event}}(\mathcal{O} > 0) - \mathcal{N}_{\text{event}}(\mathcal{O} < 0)}{\mathcal{N}_{\text{event}}(\mathcal{O} > 0) + \mathcal{N}_{\text{event}}(\mathcal{O} < 0)} = \frac{1}{\mathcal{N}} \int \frac{d\Omega_k d\Omega_p d\Omega_{\bar{p}}}{(4\pi)^3} \Big(\theta(\mathcal{O}) - \theta(-\mathcal{O})\Big) \mathcal{W}(\Omega)$$

$$\langle \hat{\boldsymbol{l}}_b \cdot \hat{p} \rangle = \frac{4\alpha_B}{9\mathcal{N}} E_c^2 d_J \left(4y_m \mathrm{Re}\,(G_1 G_2^*) + |G_1|^2 \right),$$

$$\langle \hat{\boldsymbol{l}}_{\bar{b}} \cdot \hat{\boldsymbol{p}} \rangle = -\frac{4\bar{\alpha}_B}{9\mathcal{N}} E_c^2 d_J \left(4y_m \mathrm{Re}\,(G_1 G_2^*) + |G_1|^2 \right),$$

$$\langle \hat{\boldsymbol{l}}_b \cdot \hat{\boldsymbol{k}} \rangle = \frac{8\alpha_B \beta}{9\mathcal{N}} E_c^2 \left[\mathrm{Re}\,(F_A G_1^*) - E_c \mathrm{Im}\,(H_T G_1^* + y_m H_T G_2^*) \right],$$

$$\langle \hat{\boldsymbol{l}}_{\bar{b}} \cdot \hat{\boldsymbol{k}} \rangle = -\frac{8\bar{\alpha}_B \beta}{9\mathcal{N}} E_c^2 \left[\mathrm{Re}\,(F_A G_1^*) + E_c \mathrm{Im}\,(H_T G_1^* + y_m H_T G_2^*) \right],$$

$$\langle (\hat{\boldsymbol{l}}_b \times \hat{l}_{\bar{b}}) \cdot \hat{\boldsymbol{k}} \rangle = -\frac{16\alpha_B \bar{\alpha}_B}{27\mathcal{N}} \beta y_m E_c^3 \mathrm{Re}\,(H_T G_2^*),$$

$$\mathcal{N} = \frac{2}{3} E_c^2 \left(2\,|G_1|^2 + y_m^2\,|G_2|^2 \right)$$

P violating observable

$$\mathcal{A}(\hat{\boldsymbol{l}}_b \cdot \hat{\boldsymbol{p}} - \hat{\boldsymbol{l}}_{\bar{b}} \cdot \hat{\boldsymbol{p}}) \equiv A_{\rm PV}^{(1)} \simeq \frac{4\alpha_B}{3\mathcal{N}} E_c^2 d_J \left(4 y_m {\rm Re}\,(G_1 G_2^*) + |G_1|^2\right),$$

$$\mathcal{A}(\hat{\boldsymbol{l}}_b \cdot \hat{\boldsymbol{k}} - \hat{\boldsymbol{l}}_{\bar{b}} \cdot \hat{\boldsymbol{k}}) \equiv A_{\rm PV}^{(2)} \simeq \frac{8\alpha_B \beta}{3\mathcal{N}} E_c^2\, {\rm Re}\,(F_A G_1^*)\,,$$

CP violating observable

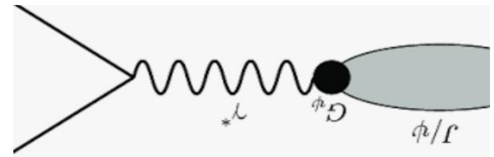
$$\mathcal{A}(\hat{\boldsymbol{l}}_b \cdot \hat{\boldsymbol{k}} + \hat{\boldsymbol{l}}_{\bar{b}} \cdot \hat{\boldsymbol{k}}) \equiv A_{\rm CPV}^{(1)} \simeq -\frac{4\alpha_B \beta}{3\mathcal{N}} E_c^3\, {\rm Im}\,(H_T G_1^* + y_m H_T G_2^*)\,,$$

$$\mathcal{A}((\hat{\boldsymbol{l}}_b \times \hat{\boldsymbol{l}}_{\bar{b}}) \cdot \hat{\boldsymbol{k}}) \equiv A_{\rm CPV}^{(2)} \simeq -\frac{8\alpha_B \bar{\alpha}}{9\mathcal{N}} \beta y_m E_c^3 {\rm Re}\,(H_T G_2^*)\,,$$

F_A in the SM

On-shell $e^+e^- \to J/\psi$ by a photon ($s = m^2_{J/\psi}$)and J/ψ decays into $\Lambda\bar{\Lambda}$

$$i\left(\frac{e^2 Q_e Q_q}{s}\bar{e}\gamma^\mu e < J/\Psi|\bar{c}\gamma_\mu c|0>\right)$$



$$\times i\left(-\frac{g^2 g_V^c g_A^q}{4\cos^2\theta_W(s-m_Z^2)} < 0|\bar{c}\gamma^\nu c|J/\Psi>< \bar{\Lambda}\Lambda\bar{q}\gamma_\nu\gamma_5 q|0>\right)$$

$$g_V^e = (1-4\sin^2\theta_W)/2,\ g_A^u = -g_A^d = -g_A^s = 1/2$$

$< 0|\bar{q}\gamma^\mu\gamma_5 q|\Lambda >= D w_q \bar{\Lambda}\gamma^\mu\gamma_5\Lambda.$ Here $D \approx 0.80$, $w_u = w_d = 1/6$ and $w_s = 4/6$

$$< 0|\bar{c}\gamma_\mu c|J/\Psi >= \epsilon_\mu^J g_V,\ g_V = 1.25 GeV^2$$

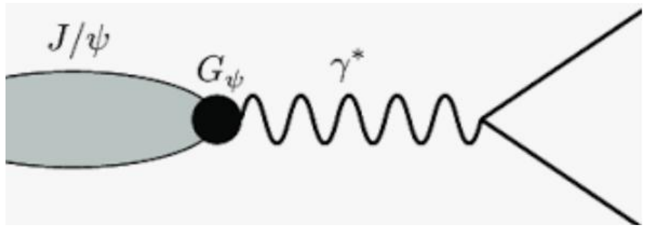
$$F_A^R = \frac{g_V^2}{s - m^2_{J/\Psi} + i m_{J/\Psi}\Gamma_{J/\Psi}/2}\frac{g^2(1-8\sin^2\theta_W/3)}{24\cos^2\theta_W(s-m_Z^2)}D$$

Dipole moment contribution to H_T

H_T is flavor conserving CP violating. It is extremely small in the SM.

Beyond SM, it may be large. Consider now Λ edm contribution.

$$L_{edm} = -i\frac{d_\Lambda}{2}\Lambda\sigma_{\mu\nu}\gamma_5\Lambda F^{\mu\nu}$$



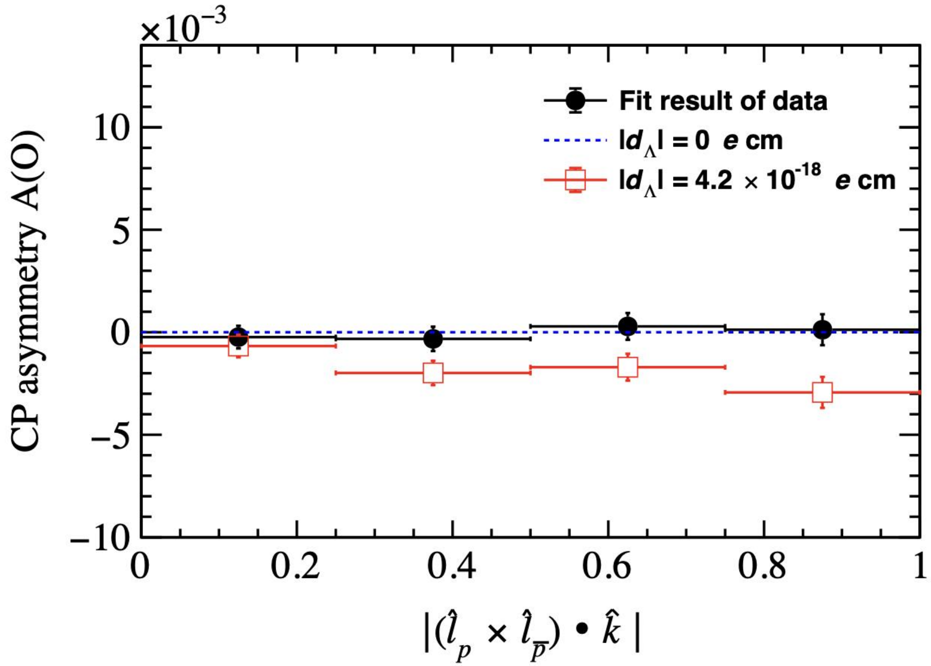
Exchange a photon H_T -> $\frac{ed_\Lambda}{s}\bar{e}\gamma^\mu e\Lambda\sigma_{\mu\nu}\gamma_5\Lambda q^\nu$

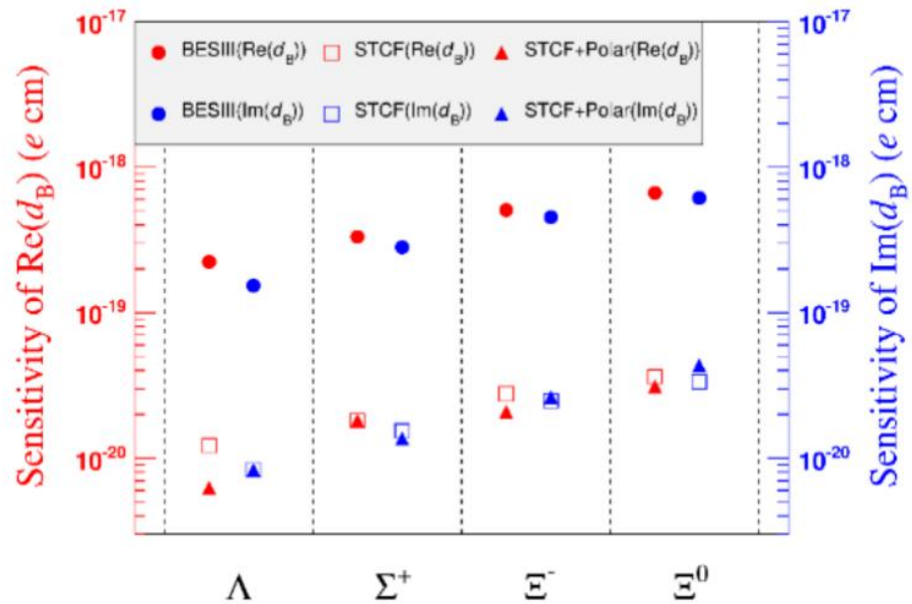
BESIII and STCF sensitivities to Hyperon EDMs

arXiv: 2506.19180

$$Re(d_\Lambda) = (-3.1 \pm 3.2 \pm 0.5) \times 10^{-19}\ e\ \text{cm},$$

$$Im(d_\Lambda) = (2.9 \pm 2.6 \pm 0.6) \times 10^{-19}\ e\ \text{cm}.$$





Xuelei Sun et al, arXiv: 2411.19469; HB Li's group

Naive link: Known data and sensitivity to EDM

Parameters	$\Sigma^+\bar{\Sigma}^-$ [72]	$\Sigma^-\bar{\Sigma}^+$	$\Sigma^0\bar{\Sigma}^0$ [73]	$\Lambda\bar{\Lambda}$ [42]	$p\bar{p}$ [74]	$\Xi^0\bar{\Xi}^0$ [75, 76]	$\Xi^-\bar{\Xi}^+$ [40]
$\sqrt{s}$ (GeV)	2.9000	—	$m_{J/\psi}$	$m_{J/\psi}$	3.0800	$m_{J/\psi}$	$m_{J/\psi}$
$\alpha^B_{J/\psi}$	0.35 ± 0.23	—	-0.449 ± 0.022	0.4748 ± 0.0038	—	0.514 ± 0.016	0.586 ± 0.016
α_B	-0.982 ± 0.14	-0.068 ± 0.008	0.22 ± 0.31	0.7519 ± 0.0043	0.62 ± 0.11	-0.3750 ± 0.0038	-0.376 ± 0.008
$\bar{\alpha}_B$	-0.99 ± 0.04	—	—	0.7559 ± 0.0078	—	-0.3790 ± 0.0040	-0.371 ± 0.007
$\Delta\Phi$ (rad.)	1.3614 ± 0.4149	—	—	0.7521 ± 0.0066	—	1.168 ± 0.026	1.213 ± 0.049
$\|G_E/G_M\| \equiv$ R	0.85 ± 0.22	—	1.04 ± 0.37	0.96 ± 0.14	0.80 ± 0.15	1	1
$\|G_M\|$ $(\times 10^{-2})$	(derived)	—	0.71 ± 0.09	(derived)	3.47 ± 0.18	0.81 ± 0.21	1.14 ± 0.10

Best known hyperon EDM bound comes from Λ < 1.6 x 10^{-16} ecm

P/CP violation	$A^{(1)}_{\rm PV}$ $(\times 10^{-4})$	$A^{(2)}_{\rm PV}$ $(\times 10^{-4})$	$\sqrt{\epsilon \cdot t} \cdot d^{(1)}_B$ $(\times 10^{-18}\, e\,{\rm cm})$ BESIII	$\sqrt{\epsilon \cdot t} \cdot d^{(1)}_B$ STCF	$\sqrt{\epsilon \cdot t} \cdot d^{(2)}_B$ $(\times 10^{-18}\, e\,{\rm cm})$ BESIII	$\sqrt{\epsilon \cdot t} \cdot d^{(2)}_B$ STCF	$\sqrt{\epsilon \cdot t} \cdot \delta$ $(\times 10^{-4})$ BESIII	$\sqrt{\epsilon \cdot t} \cdot \delta$ STCF
Λ $(\epsilon = 0.4)$	4.42	5.45	4.64	0.25	8.64	0.47	2.30	0.13
Σ^+ $(\epsilon = 0.2)$	−3.02	7.80	2.58	0.14	18.4	1.00	3.06	0.17
Ξ^0 $(\epsilon = 0.2)$	−1.55	−3.23	8.85	0.47	82.6	4.41	2.92	0.16
Ξ^- $(\epsilon = 0.2)$	−1.45	−2.55	8.93	0.48	95.9	5.20	3.21	0.17

TABLE IV: P violating asymmetries and baryon EDMs from current measurements summarized in table III. For the latter, $d^{(1)}_B$ ($d^{(2)}_B$) corresponds to the upper bounds at 95% CL resulted from $A^{(1)}_{\rm CPV}$ ($A^{(2)}_{\rm CPV}$), assuming statistics dominates the uncertainties at BESIII/STCFs. The last two columns show the statistical uncertainties δ with 10 billion events from a 12-year running time for BESIII and $t = 1$ for one-year data collection at STCF [50], assuming the systematical errors are well under control and a detector efficiency of ϵ indicated in the first column [81].

Perturbative QCD calculation for linking for EDM with non-zero q²

KB Chen, XG He, JP Ma, XB Tong, PRL, arXiv: 2509.22087

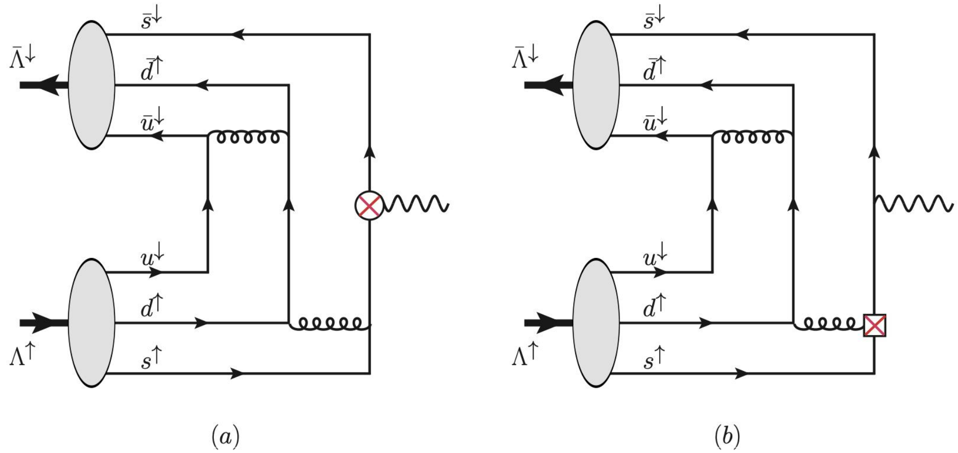


Figure 1: (a). A typical diagram for the contribution from the EDM d_s. The photon vertex with a cross-circle is the EDM vertex. (b). A typical diagram for the contribution from the CEDM $\tilde{d}_s$. The gluon vertex with a crossed square represents the CEDM vertex.

$$d_\Lambda = 5.29 \times 10^{-4} d_s + 4.61 \times 10^{-5} (d_u + d_d) + 6.21 \times 10^{-5} e\tilde{d}_s + 1.98 \times 10^{-5} e\tilde{d}_d - 2.14 \times 10^{-5} e\tilde{d}_u \ .$$

When q² not zero, experimental constraints are much stronger by a few order of magnitudes!

3. Tauon edm measurement at $e^+e^- \to \tau^+ \tau^-$

XG He, CW Liu, LP Ma and ZY Zou arXiv: 2501.06687

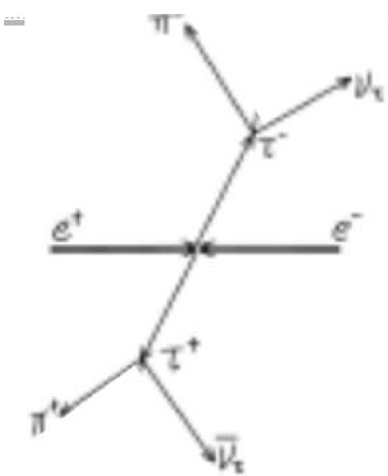
Use similar method replacing J/psi -> hyperon pairs by psi(2S) -> $\tau^+ \tau^-$, or just $e^+e^- \to \gamma^* \to \tau^+ \tau^-$

current bounds from BELLE II

$$\mathrm{Re}(d_\tau) = (6.2 \pm 6.3) \times 10^{-18}\ e\,\mathrm{cm},$$
$$\mathrm{Im}(d_\tau) = (4.0 \pm 3.2) \times 10^{-18}\ e\,\mathrm{cm},$$

But because tauon decays always has a neutrino in the final state, harder to reconstruct moments, for eaxmple using $\tau(k) \to \pi(l) + \nu$.

Still if spacial resoltution in better than 38.6 μm (the flying lenth of tauon from psi(2S) decay, there are substantial event to recustract tauon momentu,



STCF can reach a better resoltuion than current best bounds.

Bell II can also use Upsilon(4S) to do similar things

do

τ(k) –> π(l) + ν, ρ(l) + ν

For the the imaginary part, we have $\vec{k}_\tau \cdot l_\pi^{lab} = E_\tau E_\pi^{lab} - \frac{1}{2}(m_\tau^2 + m_\pi^2)$

$$\mathrm{Im}(d_\tau) = \frac{-e(3s + 6m_\tau^2)}{4s\sqrt{s - 4m_\tau^2}} \left(\frac{\langle \hat{l}_{h^-} \cdot \hat{k} \rangle}{\alpha_h} + \frac{\langle \hat{l}_{h'^+} \cdot \hat{k} \rangle}{\overline{\alpha}_{h'}} \right) . \quad (6)$$

There are two different methods to extract the real part of the EDM from the distributions:

$$\mathrm{Re}(d_\tau)^a = e\frac{9}{4} \frac{s + 2m_\tau^2}{\alpha_h \alpha_{h'} m_\tau \sqrt{s^2 - 4sm_\tau^2}} \langle (\hat{l}_- \times \hat{l}_+) \cdot \hat{k} \rangle \,, \quad (7)$$

and

$$\mathrm{Re}(d_\tau)^b = -e\frac{45}{4} \frac{(s + 2m_\tau^2)\langle (\hat{p} \cdot \hat{k})(\hat{l}_- \times \hat{l}_+) \cdot \hat{p} \rangle}{\alpha_h \alpha_{h'} m_\tau (\sqrt{s} - 2m_\tau)\sqrt{s - 4m_\tau^2}} . \quad (8)$$

$$\hat{l}_{\mp} \cdot \hat{k} = \pm \frac{1}{\sqrt{E_{\mp}^2 - m_h^2}} \left(\frac{4E_{\mp} m_\tau^2/\sqrt{s} - m_\tau^2 - m_h^2}{2m_\tau \sqrt{1 - 4m_\tau^2/s}} \right)$$

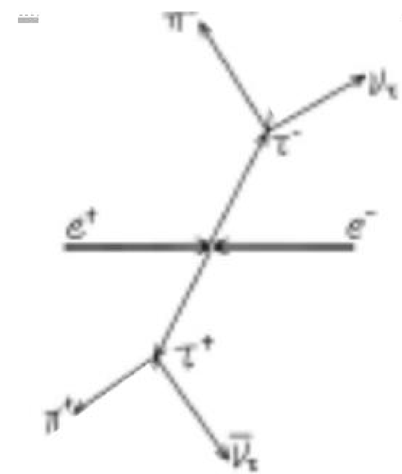
$$\hat{k} \;=\; u\hat{l}_+ + v\hat{l}_- + \mathrm{sgn}\left((\hat{l}_- \times \hat{l}_+) \cdot \hat{k} \right) w\hat{l}_- \times \hat{l}_+$$

We note that it suffices for measurements to determine $\mathrm{sgn}((\hat{l}_- \times \hat{l}_+) \cdot \hat{k})$ for reconstructing $\hat{k}$. The proportion of $\hat{k}$ being measured is then given by

$$P_\tau = 1 - \left(\frac{1}{l_0} \int_0^D \exp\left(-\frac{l}{l_0} \right) dl \right)^2 , \qquad (13)$$

where $l_0 = v\gamma/\Gamma$ with Γ the total decay width of τ^-, $\gamma = \sqrt{s}/(2m_\tau)$, and $v = \sqrt{\gamma^2 - 1}/\gamma$. l_0 is the τ mean pass length. The integral represents the probability of τ^- decaying before its flight distance reaches D in the lab frame, and the square is because it suffices to probe the momenta of either τ^- or τ^+.

Im(dτ) easy to measure.
Re(dτ) needs to reconstruct the momentum direction k.



$$\delta_{\rm Im} = \frac{3s+6m_\tau^2}{4s\sqrt{s-4m_\tau^2}}\sqrt{\frac{4}{3\sum_h^{\pi,\rho}\left(\alpha_h^2 N_{\rm Im}^h + \overline{\alpha}_h^2\overline{N}_{\rm Im}^h\right)}}\,.$$

The event number is given by

$$\begin{aligned} N_{\rm Im}^h &= \epsilon L\sigma\mathcal{B}(\tau^-\to h^-\nu_\tau)\,, \\ \overline{N}_{\rm Im}^h &= \epsilon L\sigma\mathcal{B}(\tau^+\to h^+\nu_{\overline{\tau}})\,, \end{aligned}$$

The standard deviations of $\mathrm{Re}(d_\tau)^{a,b}$ in order are

$$\delta_{\rm Re}(D)^a = \frac{3e}{4}\frac{s+2m_\tau^2}{m_\tau\sqrt{s^2-4sm_\tau^2}}\sqrt{\frac{2}{N_{\rm Re}^{\rm eff}}}\,,$$

and

$$\delta_{\rm Re}(D)^b = \frac{3e}{4}\frac{\sqrt{s^2+3sm_\tau^2+2m_\tau^4}}{m_\tau(\sqrt{s}-2m_\tau)\sqrt{s-4m_\tau^2}}\sqrt{\frac{20}{N_{\rm Re}^{\rm eff}}}\,,$$

where the effective number of events is given by

$$N_{\rm Re}^{\rm eff} = P_\tau\epsilon L\left(\alpha_\pi^2\mathcal{B}(\tau^-\to\pi^-\nu_\tau)+\alpha_\rho^2\mathcal{B}(\tau^-\to\rho^-\nu_\tau)\right)^2$$

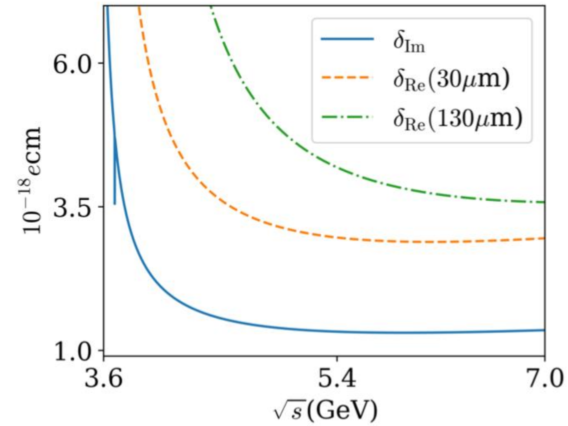


Fig. 1. The expected precision of d_τ with $L\epsilon = 0.63\,\mathrm{ab}^{-1}$.

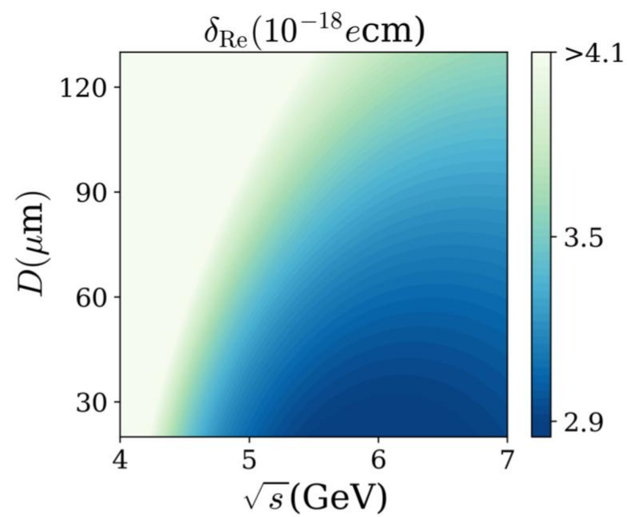


Fig. 2. The precision of $\mathrm{Re}(d_\tau)$ may be achieved with $L\epsilon = 0.63\,\mathrm{ab}^{-1}$. The color indicates the values of $\delta_{\rm Re}$, as shown in the color bar on the right.

Table I. The precision of d_τ that may be achieved with $L\epsilon = 0.63\,\text{ab}^{-1}$ is given in units of $10^{-18} e\,\text{cm}$. The absolute value is defined as $\delta^2_{|d_\tau|}(D) = \delta_{\text{Re}}(D)^2 + \delta_{\text{Im}}(D)^2$, where D is in units of μm. The case $D = 0$ corresponds to situations where the τ-lepton momentum can be reconstructed with 100% accuracy which is shown only as a reference number.

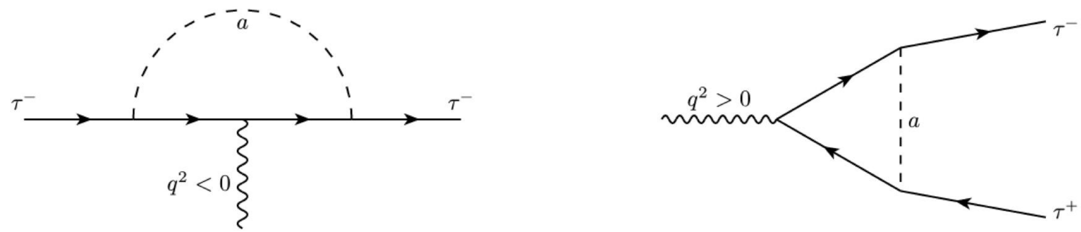
$\sqrt{s}$	$m_{\psi(2S)}$	4.2 GeV	4.9 GeV	5.6 GeV	6.3 GeV	7 GeV
δ_{Im}	3.5	1.8	1.4	1.3	1.3	1.4
$\delta_{\text{Re}}(180)$	234	14.7	6.6	4.9	4.3	4.1
$\delta_{\text{Re}}(130)$	82	9.4	5.0	4.0	3.7	3.6
$\delta_{\text{Re}}(80)$	29	6.2	3.9	3.3	3.2	3.2
$\delta_{\text{Re}}(30)$	11	4.4	3.2	2.9	2.9	3.0
$\delta_{\text{Re}}(0)$	7.7	4.0	3.0	2.8	2.8	2.9
$\delta_{\|d_\tau\|}(80)$	30	6.5	4.1	3.6	3.5	3.5

Theoretical model study for tau EDM

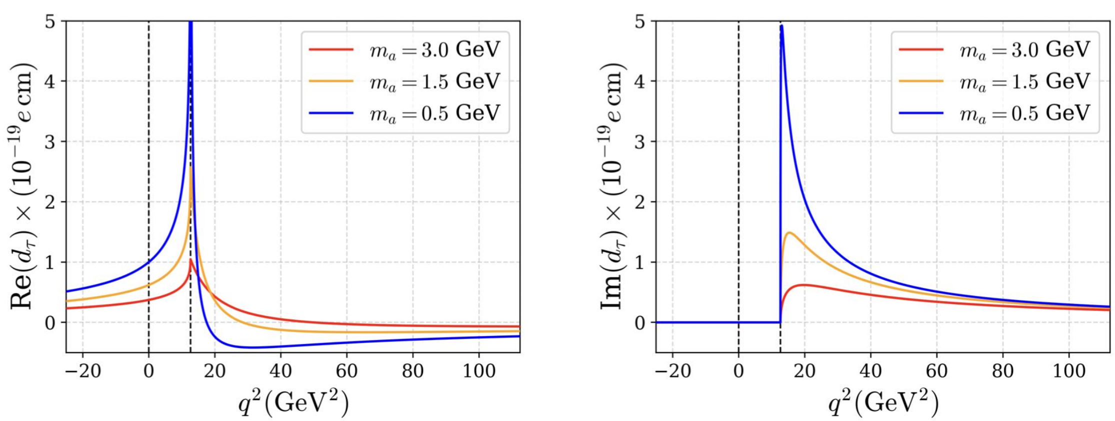
ZL Huang, XY Du, XG He, CW Liu, ZY Zou, arXiv:2510.23348

A light ALP example:

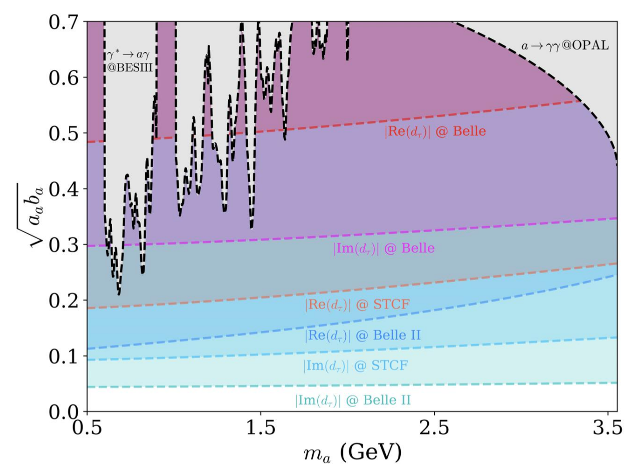
$$\mathcal{L} = \frac{1}{2}(\partial_\mu a)(\partial^\mu a) - \frac{1}{2}m_a^2 a^2 + \bar{\tau}(i\partial\!\!\!/ - m_\tau)\tau + a\,\bar{\tau}(a_a + ib_a\gamma_5)\tau,$$



(a) spacelike (b) timelike



(a) $\mathrm{Re}(d_\tau(q^2))$ (b) $\mathrm{Im}(d_\tau(q^2))$



A 2HDM realization

$$\Phi_1 = \begin{pmatrix} G^+ \\ \frac{1}{\sqrt{2}}\left(v+h+iG^0\right) \end{pmatrix}, \quad \Phi_2 = \begin{pmatrix} H^+ \\ \frac{1}{\sqrt{2}}\left(-H+iA\right) \end{pmatrix}.$$

$$V(\Phi_1,\Phi_2) = m_{11}^2\Phi_1^\dagger\Phi_1 + m_{22}^2\Phi_2^\dagger\Phi_2 - (m_{12}^2\Phi_1^\dagger\Phi_2 + \text{h.c.}) + \frac{1}{2}\lambda_1\left(\Phi_1^\dagger\Phi_1\right)^2 + \frac{1}{2}\lambda_2\left(\Phi_2^\dagger\Phi_2\right)^2 + \lambda_3\left(\Phi_1^\dagger\Phi_1\right)\left(\Phi_2^\dagger\Phi_2\right) + \lambda_4\left(\Phi_1^\dagger\Phi_2\right)\left(\Phi_2^\dagger\Phi_1\right) + \left(\frac{1}{2}\lambda_5\left(\Phi_1^\dagger\Phi_2\right)^2 + \left(\lambda_6\Phi_1^\dagger\Phi_1 + \lambda_7\Phi_2^\dagger\Phi_2\right)\left(\Phi_1^\dagger\Phi_2\right) + \text{c.c.}\right).$$

In the basis, all λi real

$$M_{h,H}^2 = \begin{pmatrix} \lambda_1 v^2 & \lambda_6 v^2 \\ \lambda_6 v^2 & m_{22}^2 + \frac{1}{2}(\lambda_3+\lambda_4+\lambda_5)v^2 \end{pmatrix}.$$

Alignment limit: λ_6=0

H heavy, A arbitray mass

$$m_{H^\pm}^2 = m_{22}^2 + \frac{1}{2}\lambda_3 v^2 \qquad m_H^2 - m_A^2 = \lambda_5 v^2,$$

$$m_A^2 = m_{22}^2 + \frac{1}{2}(\lambda_3+\lambda_4-\lambda_5)v^2,$$

Allow CPV

Yukawa coupling:

$$-\mathcal{L}_Y = \bar{L}_L Y_1' \Phi_1 l_R + \bar{L}_L Y_2' \Phi_2 l_R + \text{h.c.}$$

$$= \bar{l}\hat{M}_l l + \bar{l}\left(-\frac{\text{Re}(Y_2)}{\sqrt{2}} - i\frac{\text{Im}(Y_2)}{\sqrt{2}}\gamma_5\right) lH + \bar{l}\left(-\frac{\text{Im}(Y_2)}{\sqrt{2}} + i\frac{\text{Re}(Y_2)}{\sqrt{2}}\gamma_5\right) lA + (\bar{\nu}_L Y_2 l_R H^+ + \text{h.c.}),$$

A -> a

$$a_a = -\text{Im}(Y_2^{\tau\tau})/\sqrt{2},$$
$$b_a = \text{Re}(Y_2^{\tau\tau})/\sqrt{2}.$$

A renormalizable realization of large tauon EDM!

4. Conclusions

BESIII can improve Λ edm by about 2 orders of magnitude from J/ψ decays into Λ-pair.

STCF will be able to improve another two orders of magnitude. Can do measurement of EDM for other hyperons too!

Similarly the tauon EDM can also be measured better than current bound.

Linking quark EDM at $q^2 = 0$ to hyperon q^2 not zero can be made!

Large tauon EDM close to current experimental bounds possible!