Measuring the edm of a fast decaying particle

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XG He and JP Ma, PLB 839(2023)137834

Y Du, XG He, JP Ma, XY Liu, PRD 110 (2024) 076019

XG He, CW Liu, JP Ma and ZY Zou JHEP04(2025)001[arXiv: 2501.06687]

见微学术沙龙, 中国科学技术大学

6, June, 2025

形成“研究部+大平台”的聚焦根本性科学问题的科研体系

天文与天体物理研究部

- 暗物质与暗能量观测
- 实验室天体物理
- 多信使天文学

实验室天体物理实验平台

JUST光谱望远镜

粒子与核物理研究部

- 暗物质探测
- 中微子特性
- 多信使天文学

暗物质与中微子实验平台

PandaX二期

Trident中微子望远镜

凝聚态物理研究部

- 马约拉纳零能模拓扑量子器件

拓扑材料研究实验平台

上海大本营平台

前进观测基地

“思源一号”：大规模科学计算平台

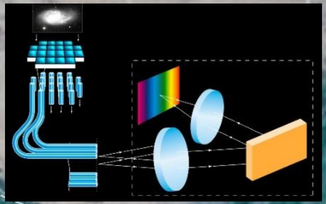
工程技术部

李所科研版图

围绕根本性科学问题，建设专用科学装置群实现极限探测能力

青海冷湖前进观测基地
JUST光谱望远镜

4.4米口径双焦点❖
国际最优视宁度条件，海拔4300米❖
探索黑暗宇宙，寻找宜居行星❖



2800km

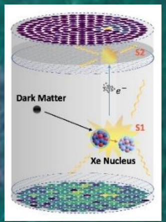
上海张江
大本营研究平台

- 实验室天体物理研究平台
- 拓扑材料研究平台
- 大规模科学计算平台

2000km

四川锦屏前进观测基地
PANDAX暗物质与中微子探测装置

数十吨级PandaX液氙探测器❖
2400米岩石覆盖下的国际最深的地下实验室❖
以极低的本底探测暗物质和中微子信号❖



2000km

海南南海前进观测基地
TRIDENT中微子望远镜（海铃计划）

❖3500米深海下4km×4km×0.5km的切伦科夫光探测阵列
❖以全灵敏度巡天捕捉高能天体中微子
❖探索极端天体环境下宇宙射线的起源及基本物理规律

国际化的研究队伍

高度国际化

科研人员（含博士后）109人，来自6大洲17个国家和地区

长聘体系100%拥有长期海外工作/学习经历

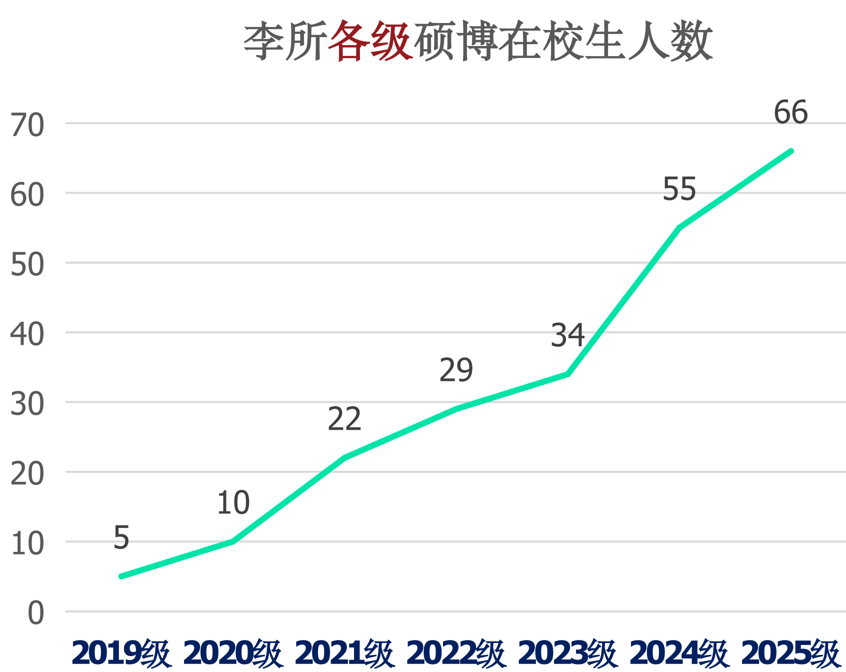
1位 诺奖获得者　4位 中科院院士　1位 中科院外籍院士

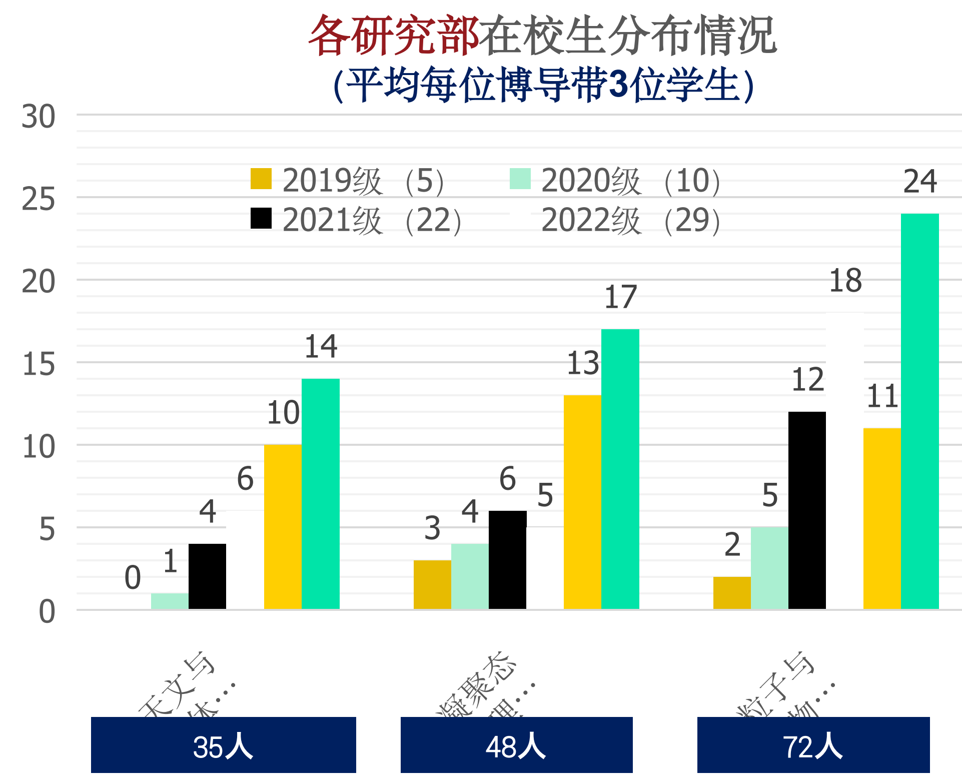
类别	2024	稳定期
李政道讲席教授	9	15
特聘学者	5	10
长聘学者	5	15
青年学者	30	60

类别	2024	稳定期
研究系列	11	20
工程技术系列	7	20
博士后	48	100
研究生	155	500

在校研究生情况

李所在读硕博研究生共计155人，其中外籍研究生10人，占比6.5%。





高质量建设物理学国家高层次人才培养中心

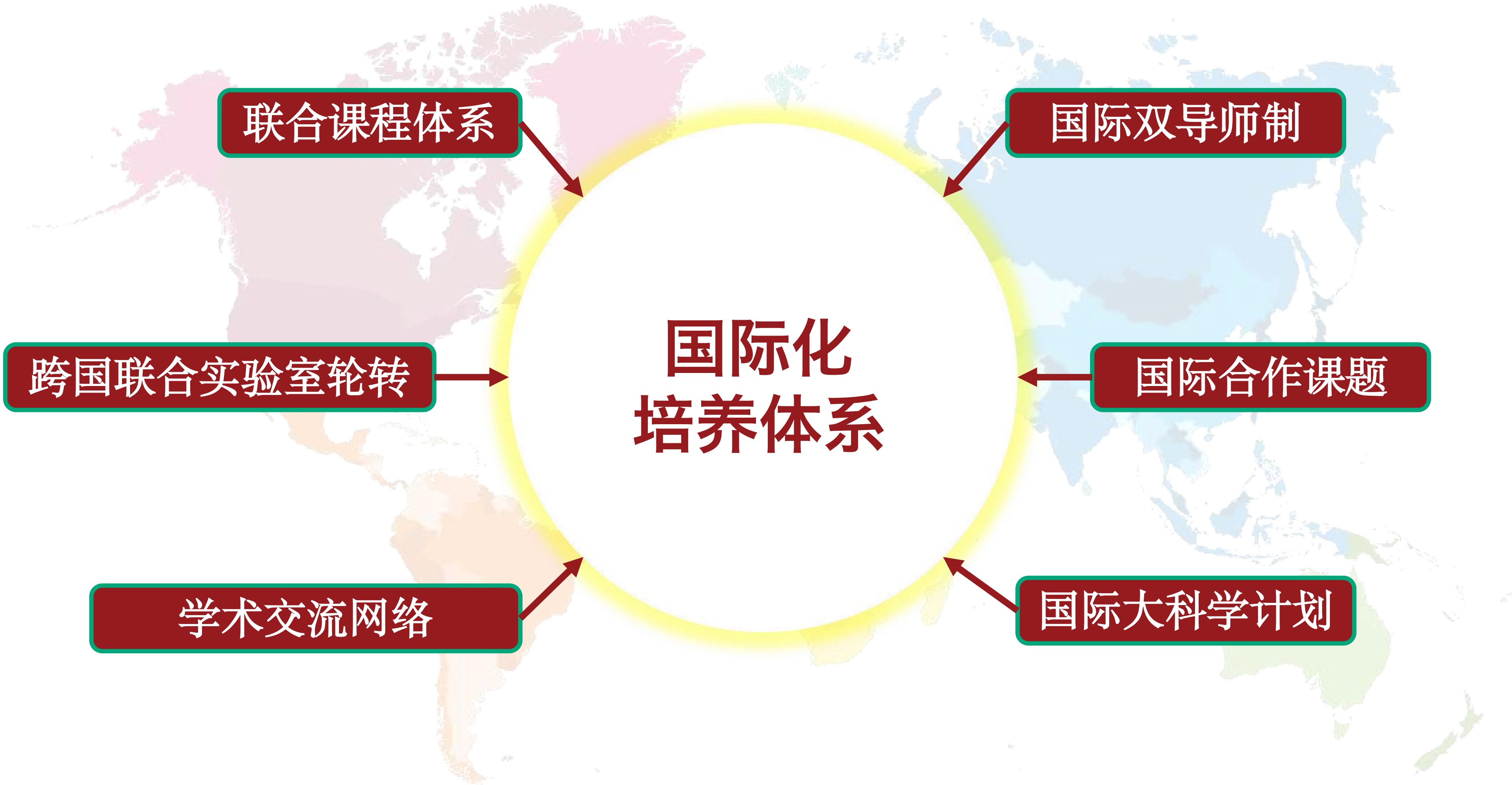
联合物理与天文学院，自然科学研究院、张江高等研究院，全覆盖物理学与天文学方向

对标国际 创新培养

- 李政道博士生荣誉体系培养方案和实施细则
- 李政道博士生奖学金项目
- 已选拔104名“李政道博士生”
- 建设6门荣誉课程，全英文覆盖专业基础课
- 建设基础科学国际合作联盟
- 博士生国际联合培养
- 设立国际交流基金项目
- 设立本科生预培养基金项目

全国14个，物理方向3个

依托基础研究机构联盟，打造博士生的国际化培养体系



发展愿景

- 在根本科学问题的研究上取得重大突破，揭示自然界最深刻的规律；
- 产生一批尖端技术，推动相关高精度/高端科研设备研制的自主化；
- 造就一批世界级科学家，形成上海学派，助力上海打造全球人才高地；
- 利用科学目标驱动和好奇心启动培养不同类型研究生，发挥致远学院、物理学院、李所的各自优势培养基础研究后备力量；
- 产出一批诺奖级成果，打造世界一流基础研究机构。


李政道研究所欢迎您！
TDLI

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 $e^+e^- \to \tau^+ \tau^-$

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, $\vec{S} \to -\vec{S}$

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

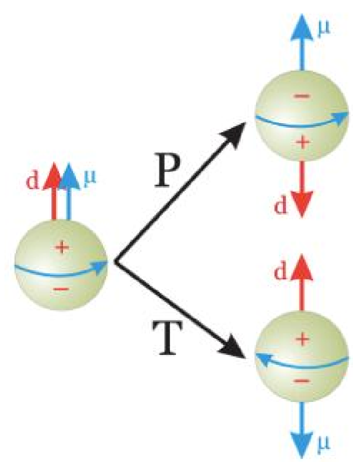
H_{edm} violates both P and T, CPT is conserved, CP is also violated!

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

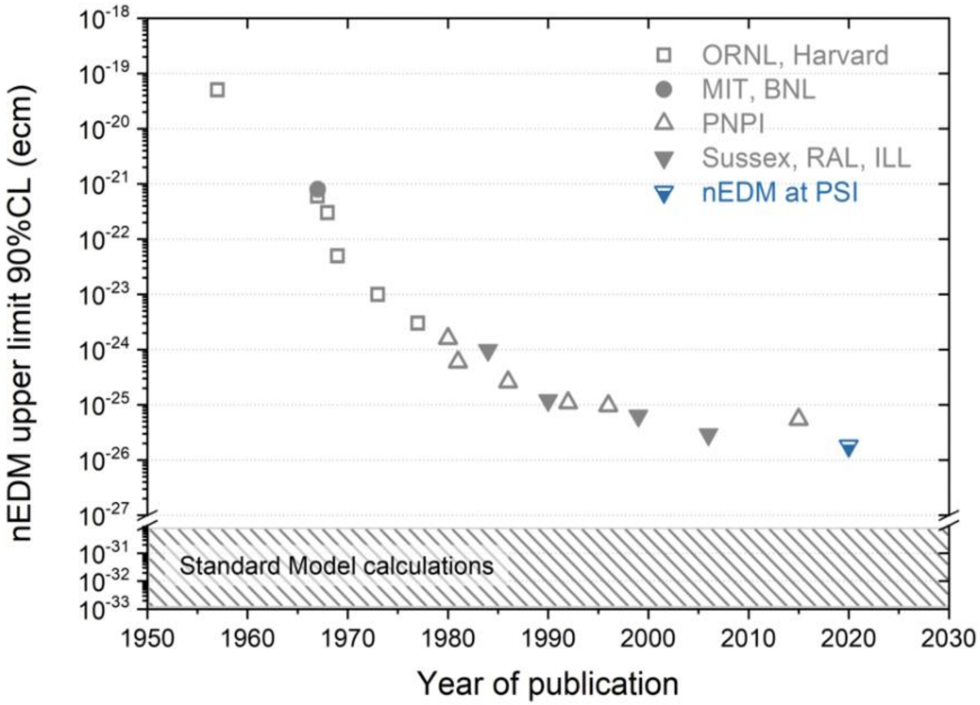
In non-relativestic limit H_{edm} reduce to $d\frac{\vec{\sigma}}{2}\cdot\vec{E} = d\vec{S}\cdot\vec{E}$.

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!



History of Neutron EDM measurement



The first measreuiment started by Smith, Purcell, and Ramsey in 1951 (and published in 1957) obtaining a limit of $|dn| < 5\times 10-20$ 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.

$$h\nu = 2\mu_n B \pm 2 d_n E \qquad d_n = \frac{h\,\Delta\nu}{4E}$$

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 $\mathrm{Re}(d_\tau)$ -2.2 to 0.45×10^{-17} ecm, $\mathrm{Im}(d_\tau)$ -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
$d_p^{\rm qEDM}$	$\frac{1}{3}(4d_u - d_d)$	—	$d_p^{\rm qCDM}$	$-\frac{1}{3}\left(4Q_d f_d - Q_u f_u\right)$	—
$d_n^{\rm qEDM}$	$\frac{1}{3}(4d_d - d_u)$	—	$d_p^{\rm qCDM}$	$-\frac{1}{3}\left(4Q_u f_u - Q_d f_d\right)$	—
$d_{\Sigma^+}^{\rm qEDM}$	$\frac{1}{3}(4d_u - d_s)$	$-\frac{1}{3}d_s$	$d_p^{\rm qCDM}$	$-\frac{1}{3}\left(4Q_u f_u - Q_s f_s\right)$	$-\frac{1}{9}ef_s$
$d_{\Sigma^0}^{\rm qEDM}$	$\frac{1}{3}(2d_u + 2d_d - d_s)$	$-\frac{1}{3}d_s$	$d_p^{\rm qCDM}$	$-\frac{1}{3}\left(2Q_u f_u + 2Q_d f_d - Q_s f_s\right)$	$-\frac{1}{9}ef_s$
$d_{\Sigma^-}^{\rm qEDM}$	$\frac{1}{3}(4d_d - d_s)$	$-\frac{1}{3}d_s$	$d_p^{\rm qCDM}$	$-\frac{1}{3}\left(4Q_d f_d - Q_s f_s\right)$	$-\frac{1}{9}ef_s$
$d_{\Xi^0}^{\rm qEDM}$	$\frac{1}{3}(4d_s - d_u)$	$\frac{4}{3}d_s$	$d_p^{\rm qCDM}$	$-\frac{1}{3}\left(4Q_s f_s - Q_u f_u\right)$	$\frac{4}{9}ef_s$
$d_{\Xi^-}^{\rm qEDM}$	$\frac{1}{3}(4d_s - d_d)$	$\frac{4}{3}d_s$	$d_p^{\rm qCDM}$	$-\frac{1}{3}\left(4Q_s f_s - Q_d f_d\right)$	$\frac{4}{9}ef_s$
$d_{\Lambda^0}^{\rm qEDM}$	d_s	d_s	$d_p^{\rm qCDM}$	$-Q_s f_s$	$\frac{1}{3}ef_s$

EDM of neutron and electron in KM model

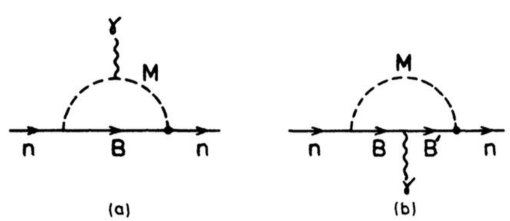
Quark EDM D_q and neutron EDM D_n, $D_n = (4D_d - D_u)/3$

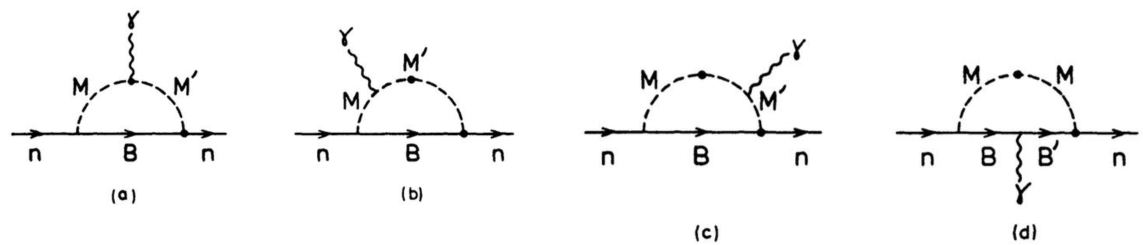
In KM model, quark EDM only generated at two electroweak and one strong loop level (3 loop effects)l, very small ~ 10^{-33} e.cm. (Shabalin, 1978, 1980)

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, arXiv: 2405.09625 (PRD accepted)

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

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

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

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

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

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

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

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

$$\begin{aligned}
c_8(\omega) &= 2E_c^2\left|\hat{\boldsymbol{p}}\times\hat{\boldsymbol{k}}\right|\left\{2d_J y_m\mathrm{Im}\left(G_1G_2^*\right) - \beta\omega\mathrm{Im}\left[F_A\left(G_1 - y_m G_2\right)^*\right]\right\},\\
b_{1n}(\omega) &= b_{2n}(\omega) = 2\left|\hat{\boldsymbol{p}}\times\hat{\boldsymbol{k}}\right| E_c^2\omega y_m\mathrm{Im}\left(G_1G_2^*\right),\\
b_{1p}(\omega) &= 2E_c^2\left\{2y_m d_J\mathrm{Re}\left(G_1G_2^*\right) + \beta\omega\left[y_m\mathrm{Re}\left(F_AG_2^*\right) + 2E_c\mathrm{Im}\left(H_TG_1^*\right)\right]\right\},\\
b_{2p}(\omega) &= 2E_c^2\left\{2y_m d_J\mathrm{Re}\left(G_1G_2^*\right) + \beta\omega\left[y_m\mathrm{Re}\left(F_AG_2^*\right) - 2E_c\mathrm{Im}\left(H_TG_1^*\right)\right]\right\},\\
b_{1k}(\omega) &= 2E_c^2\left\{2d_J\omega\left(|G_1|^2 - y_m\mathrm{Re}\left(G_1G_2^*\right)\right) + \beta\,\mathrm{Re}\left[F_A\left((1+\omega^2)G_1 - \omega^2 y_m G_2\right)^*\right]\right.\\
&\quad\left. -2E_c\beta\,\mathrm{Im}\left[H_T\left(\omega^2G_1 + (1-\omega^2)y_mG_2\right)^*\right]\right\},\\
b_{2k}(\omega) &= 2E_c^2\left\{2d_J\omega\left(|G_1|^2 - y_m\mathrm{Re}\left(G_1G_2^*\right)\right) + \beta\,\mathrm{Re}\left[F_A\left((1+\omega^2)G_1 - \omega^2 y_m G_2\right)^*\right]\right.\\
&\quad\left. +2E_c\beta\,\mathrm{Im}\left[H_T\left(\omega^2G_1 + (1-\omega^2)y_mG_2\right)^*\right]\right\},
\end{aligned}$$

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 $\bar{\Lambda}$

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

$$
\begin{aligned}
\langle \hat{\boldsymbol{l}}_b \cdot \hat{p} \rangle &= \frac{4\alpha_B}{9\mathcal{N}} E_c^2 d_J \left(4y_m \mathrm{Re}\left(G_1 G_2^*\right) + |G_1|^2 \right), \\
\langle \hat{\boldsymbol{l}}_{\bar{b}} \cdot \hat{\boldsymbol{p}} \rangle &= -\frac{4\bar{\alpha}_B}{9\mathcal{N}} E_c^2 d_J \left(4y_m \mathrm{Re}\left(G_1 G_2^*\right) + |G_1|^2 \right), \\
\langle \hat{\boldsymbol{l}}_b \cdot \hat{\boldsymbol{k}} \rangle &= \frac{8\alpha_B \beta}{9\mathcal{N}} E_c^2 \left[\mathrm{Re}\left(F_A G_1^*\right) - E_c \mathrm{Im}\left(H_T G_1^* + y_m H_T G_2^*\right)\right], \\
\langle \hat{\boldsymbol{l}}_{\bar{b}} \cdot \hat{\boldsymbol{k}} \rangle &= -\frac{8\bar{\alpha}_B \beta}{9\mathcal{N}} E_c^2 \left[\mathrm{Re}\left(F_A G_1^*\right) + E_c \mathrm{Im}\left(H_T G_1^* + y_m H_T G_2^*\right)\right], \\
\langle (\hat{\boldsymbol{l}}_b \times \hat{l}_{\bar{b}}) \cdot \hat{\boldsymbol{k}} \rangle &= -\frac{16\alpha_B \bar{\alpha}_B}{27\mathcal{N}} \beta y_m E_c^3 \mathrm{Re}\left(H_T G_2^*\right),
\end{aligned}
$$

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

P violating observable

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

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

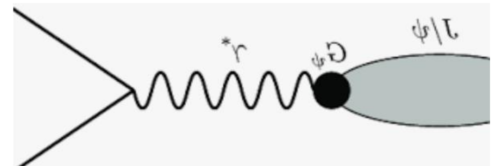
CP violating observable

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

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

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 $w_s = 4/6$

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

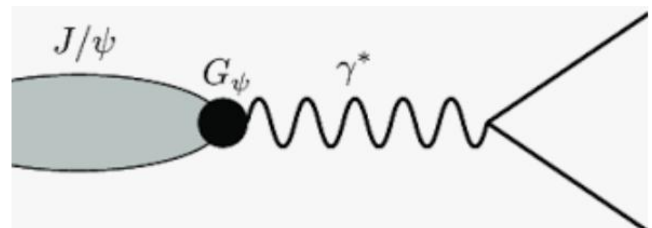
$$F_A^R = \frac{g_V^2}{s - m^2_{J/\Psi} + i m_{J/\Psi}\Gamma_{J/\Psi}/2}\frac{g^2(1-8\sin^2\theta_W/3)}{24\cos^2\theta_W(s-m_Z^2)}D$$

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.

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



Excahnge a photon

$$\frac{ed_\Lambda}{s}\bar{e}\gamma^\mu e\Lambda\sigma_{\mu\nu}\gamma_5\Lambda q^\nu$$

We have

$$H_T^N = \frac{ed_\Lambda}{s}\frac{s}{e^2Q_c} = \frac{3}{2e}d_\Lambda$$

J/ψ to Octet baryon pairs B anti–B

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

$$H_T = \mid \frac{e \cdot Q_c \cdot g_V \cdot d_B}{m^2_{J/\psi}}.$$

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

Known data and sensitivity to EDM

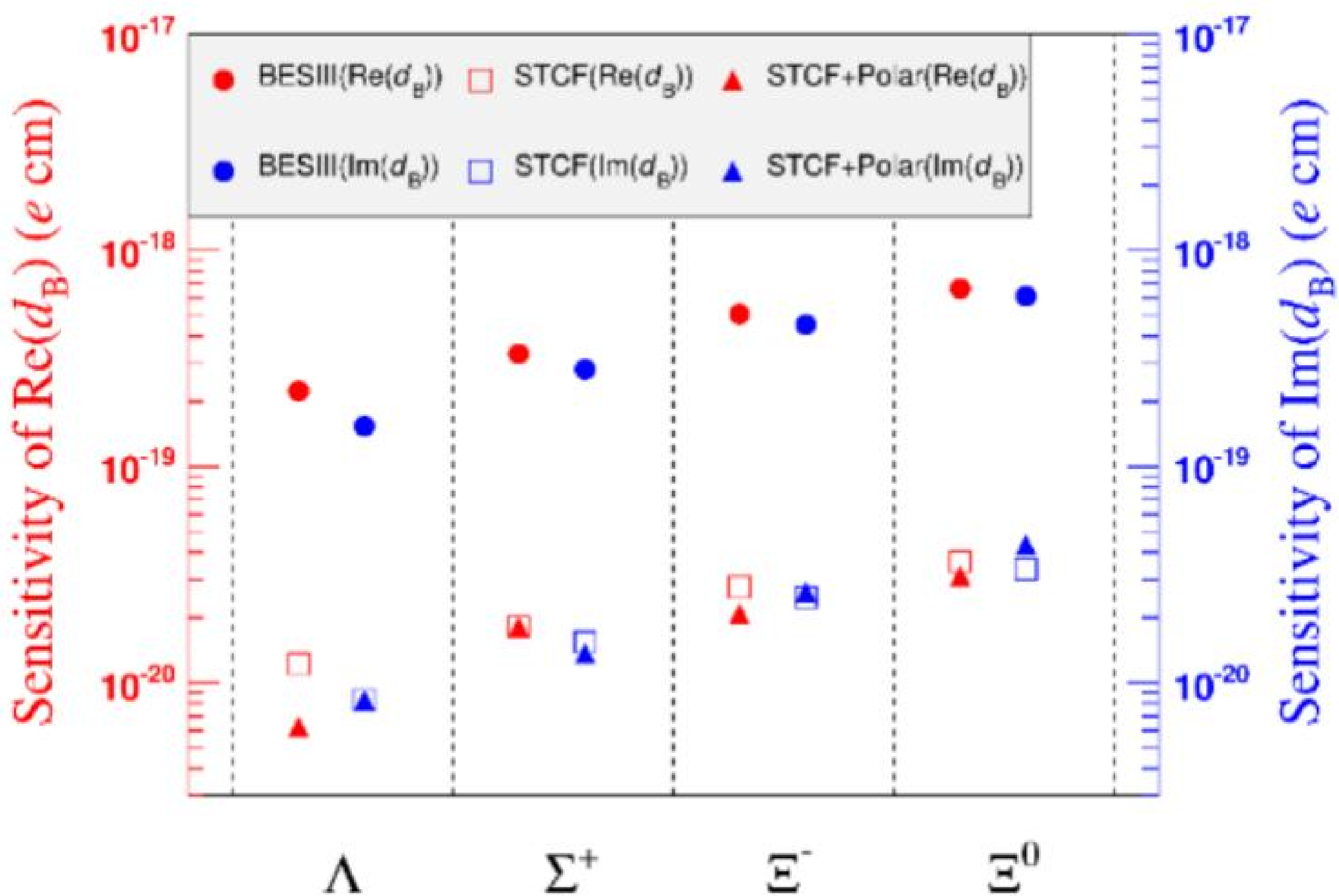
Parameters	$\Sigma^+\bar{\Sigma}^-$ [72]	$\Sigma^-\bar{\Sigma}^+$	$\Sigma^0\bar{\Sigma}^0$ [73]	$\Lambda\bar{\Lambda}$ [42]	$p\bar{p}$ [74]	$\Xi^0\bar{\Xi}^0$ [75, 76]	$\Xi^-\bar{\Xi}^+$ [40]
$\sqrt{s}$ (GeV)	2.9000	—	$m_{J/\psi}$	$m_{J/\psi}$	3.0800	$m_{J/\psi}$	$m_{J/\psi}$
$\alpha^B_{J/\psi}$	0.35 ± 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
$\lvert G_E/G_M\rvert \equiv$ R	0.85 ± 0.22	—	1.04 ± 0.37	0.96 ± 0.14	0.80 ± 0.15	1	1
$\lvert G_M\rvert$ ($\times 10^{-2}$)	(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 $\Lambda < 1.6 \times 10^{-16}$ ecm

P/CP violation	$A^{(1)}_{\text{PV}}$ ($\times 10^{-4}$)	$A^{(2)}_{\text{PV}}$ ($\times 10^{-4}$)	$\sqrt{\epsilon \cdot t} \cdot d^{(1)}_B$ ($\times 10^{-18}$ e cm)		$\sqrt{\epsilon \cdot t} \cdot d^{(2)}_B$ ($\times 10^{-18}$ e cm)		$\sqrt{\epsilon \cdot t} \cdot \delta$ ($\times 10^{-4}$)	
			BESIII	STCF	BESIII	STCF	BESIII	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 $A^{(1)}_{\text{CPV}}$ ($A^{(2)}_{\text{CPV}}$), 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].

STCF sensitivities to Hyeron EDMs



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

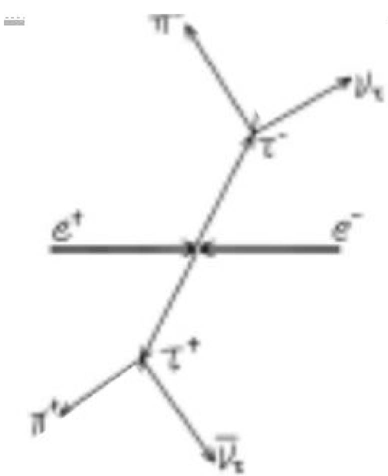
XG He, CW Liu, LP Ma and ZY Zou arXiv: 2501.06687

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

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

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

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

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

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

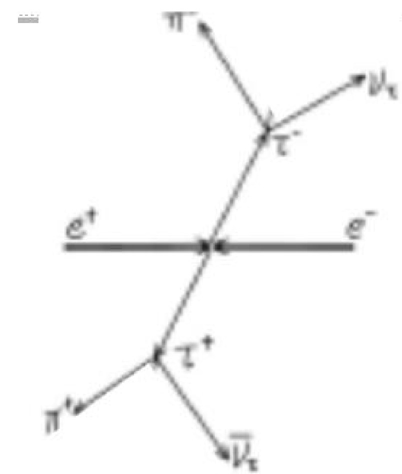
$$\hat{k} \; = \; u\hat{l}_+ + v\hat{l}_- + \mathrm{sgn}\left((\hat{l}_- \times \hat{l}_+) \cdot \hat{k} \right) w\hat{l}_- \times \hat{l}_+$$

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

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

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

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

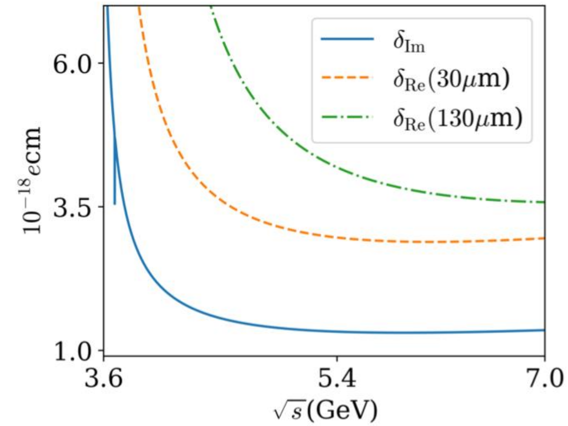


Fig. 1. The expected precision of d_τ with $L\epsilon = 0.63\,\mathrm{ab}^{-1}$.

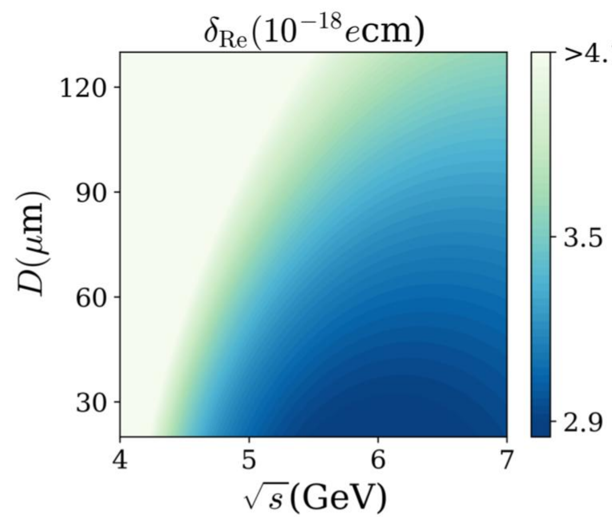


Fig. 2. The precision of $\mathrm{Re}(d_\tau)$ may be achieved with $L\epsilon = 0.63\,\mathrm{ab}^{-1}$. The color indicates the values of $\delta_{\rm Re}$, as shown in the color bar on the right.

Table I. The precision of d_τ that may be achieved with $L\epsilon = 0.63\,\mathrm{ab}^{-1}$ is given in units of $10^{-18} e\,\mathrm{cm}$. The absolute value is defined as $\delta^2_{|d_\tau|}(D) = \delta_{\mathrm{Re}}(D)^2 + \delta_{\mathrm{Im}}(D)^2$, 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
$\delta_{\mathrm{Re}}(180)$	234	14.7	6.6	4.9	4.3	4.1
$\delta_{\mathrm{Re}}(130)$	82	9.4	5.0	4.0	3.7	3.6
$\delta_{\mathrm{Re}}(80)$	29	6.2	3.9	3.3	3.2	3.2
$\delta_{\mathrm{Re}}(30)$	11	4.4	3.2	2.9	2.9	3.0
$\delta_{\mathrm{Re}}(0)$	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

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.