Perturbative QCD prediction of the Hyperon EDM from CP-Violating dipole interactions

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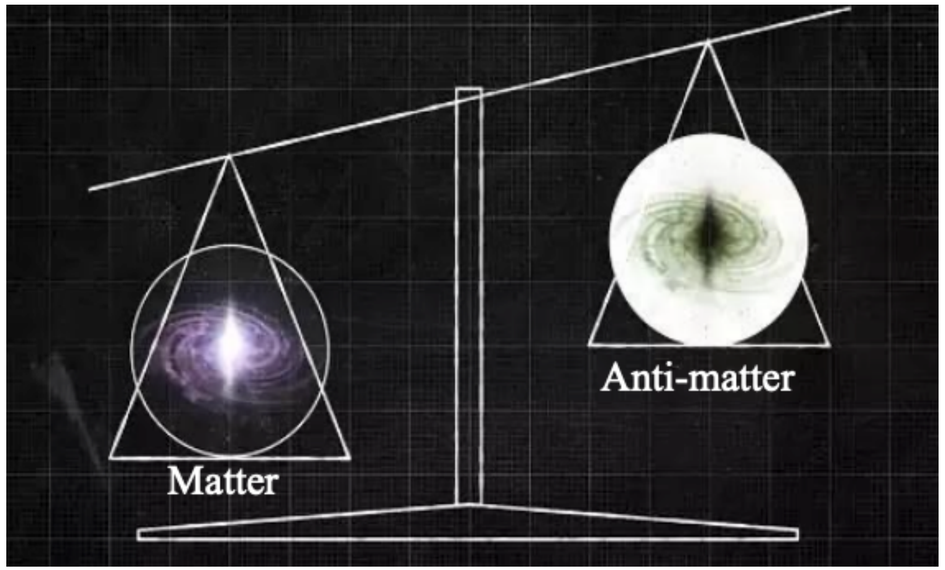
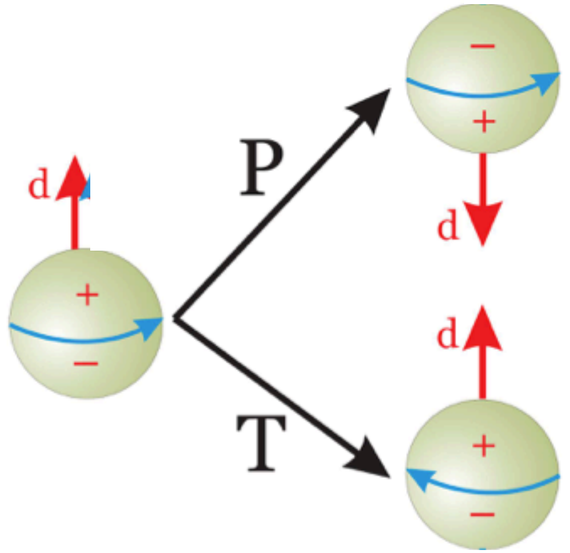
Based on **K.B. Chen, X.G. He, J.P. Ma, X.B. Tong**

PRL 136, 051902 (2026), arXiv: 2509.22087

5th May, DIS 2026 Bologna

Motivation: why look for a EDM?





- Explaining the baryon asymmetry of the Universe requires new CP violation

$$\left(n_B - n_{\bar{B}}\right)/n_\gamma \sim 10^{-10}\ (\text{observed})$$
$$\sim 10^{-20}\ (\text{SM})$$

- Electric dipole moments (EDMs) of leptons and baryons are clean probes for **BSM CP violations (CPV):**

$$\mathcal{L}_{\text{CPV}} \sim d_q \bar{q}\sigma^{\mu\nu}\gamma_5 q F_{\mu\nu} + \tilde{d}_q \bar{q}\sigma^{\mu\nu}\gamma_5 T^a q G^a_{\mu\nu} + \cdots$$

quark dipole interactions

Why do we need hyperon EDM?

- **Neutron EDM** constraints are already very strong:

$$|d_n| < 1.8 \times 10^{-26} e \cdot \text{ cm}$$

[C. Abel et al., PRL 124, 081803 (2020)]

[R. Alarcon et al., arXiv:2203.08103]

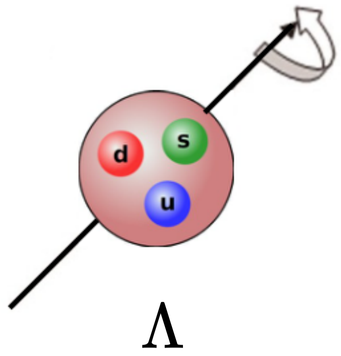
quark EDM

$$d_n = -(0.20 \pm 0.01) d_u + (0.78 \pm 0.03) d_d + (0.0027 \pm 0.016) d_s$$
$$- (0.55 \pm 0.28) e\, \tilde{d}_u - (1.1 \pm 0.55) e\, \tilde{d}_d + (50 \pm 40)\text{MeV} \cdot \text{e}\tilde{d}_G + \cdots$$

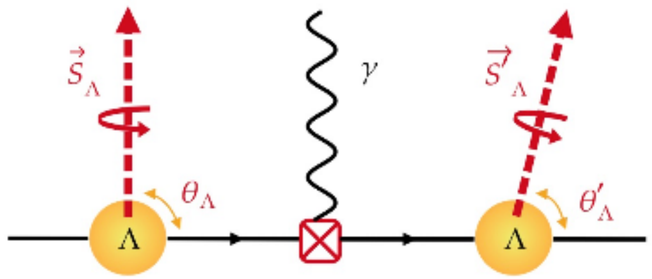
chomo-EDM

⇨ But one system alone cannot disentangle all CPV operators

- **Hyperon EDMs** provide complementary constraint, especially on the strange quark sector



Λ



Spin-precession

Short-lifetime, hard to improve the precision:

$$|d_\Lambda| < 1.5 \times 10^{-16} e\,\text{cm}.$$

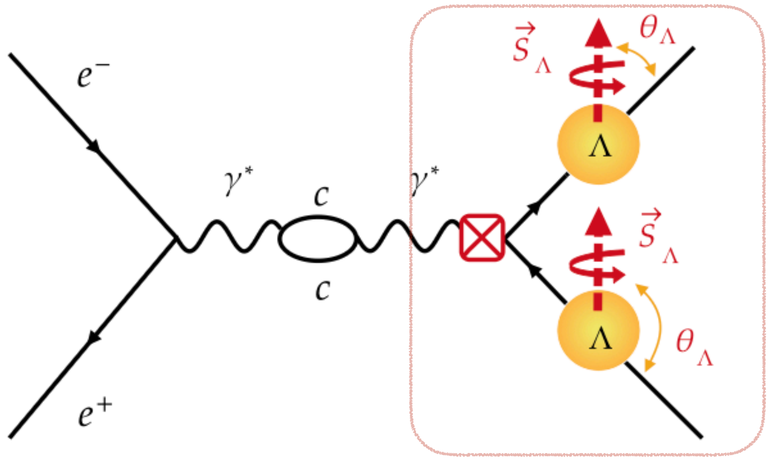
Obtained at Fermilab more than 40 years ago.

[L. Pondrom et al., Phys. Rev. D 23, 814 (1981)]

New avenue: spin-correlations of $\Lambda\bar{\Lambda}$

- **BESIII measurement:**

$$e^+e^- \to J/\psi \to \Lambda\bar{\Lambda}$$



[G. He, J. P. Ma, and B. McKellar, PRD 47, R1744 (1993)]

✓ Huge samples near J/ψ resonance

✓ Λ-polarization through $\Lambda \to \pi^- p$

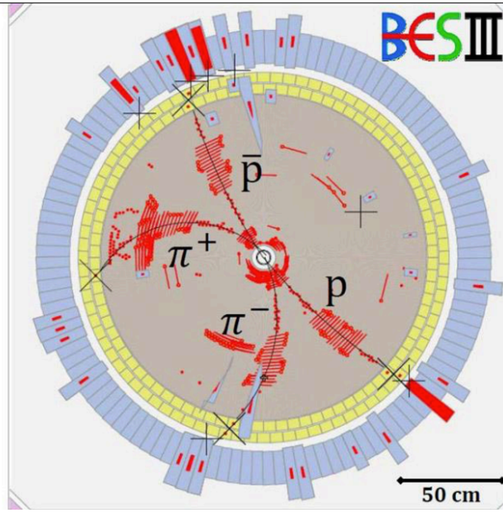
✓ Λ EDM form factor

$Q = M_{J/\psi}$

$$|d_\Lambda| < 6.5 \times 10^{-19} e\,\mathrm{cm}\ \ (95\%\ \mathrm{C.L.})$$

[BESIII Collaboration, arXiv:2506.19180, accepted by Nature]

~ three-order-of-magnitude improvement!



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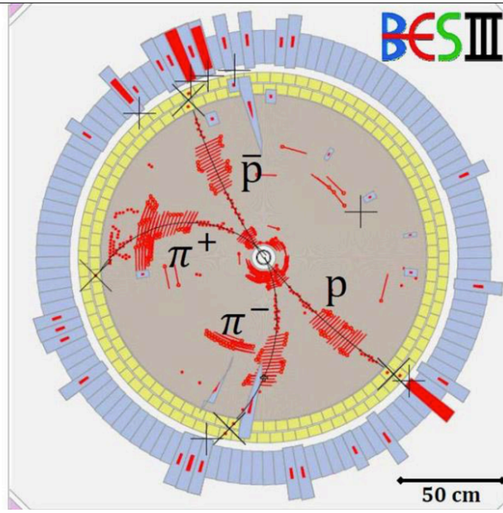

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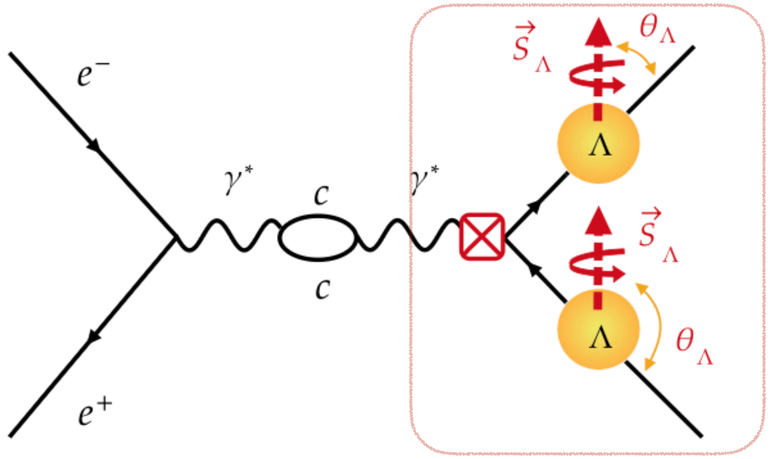

[G. He, J. P. Ma, and B. McKellar, PRD 47, R1744 (1993)]

✓ Huge samples near J/ψ resonance

✓Λ-polarization through $\Lambda \to \pi^- p$

✓Not static, but a EDM form factor

$Q = M_{J/\psi}$

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~ three-order-of-magnitude improvement!

★ **A key theoretical question:** [Chen-He-Ma-Tong PRL 136, 051902 (2026)]

How is the Λ-EDM form factor related to the CPV interactions at quark-gluon level?

$$\langle 0|J^\mu|\Lambda\bar{\Lambda}\rangle = d_\Lambda(Q)\bar{V}(\bar{P},\bar{\lambda})\gamma_5\sigma^{\mu\nu}q_\nu U(P,\lambda) \quad \Longleftrightarrow \quad \mathcal{L}_{\mathrm{CPV}} = -\frac{i}{2}\sum_q d_q\bar{q}\sigma^{\mu\nu}\gamma_5 q F_{\mu\nu} - \frac{i}{2}\sum_q \tilde{d}_q\bar{q}\sigma^{\mu\nu}\gamma_5 T^a q G^a_{\mu\nu} + \cdots$$

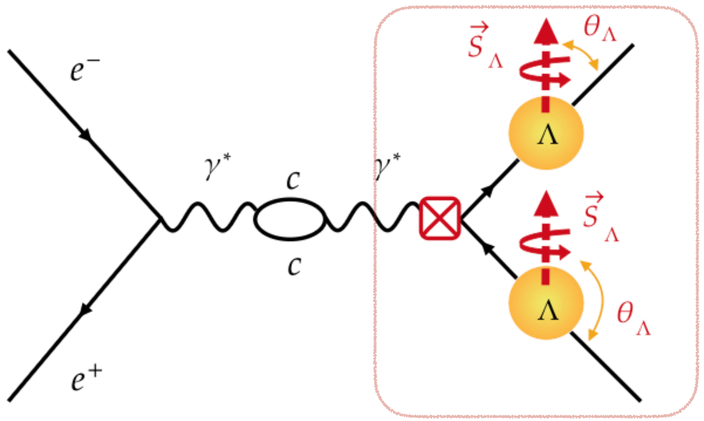
Perturbative analysis [Chen-He-Ma-Tong PRL 136, 051902 (2026)]

- Our approach: perturbative analysis of the Λ-EDM form factor within QCD factorization

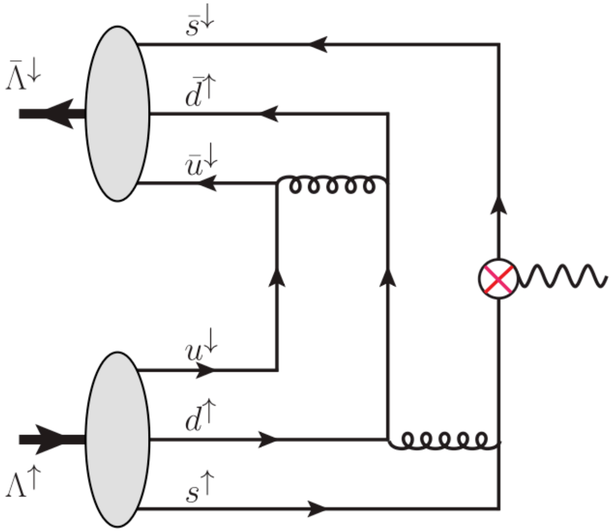
$$\langle 0|J^\mu|\Lambda\bar{\Lambda}\rangle = d_\Lambda(Q)\bar{V}(\bar{P},\bar{\lambda})\gamma_5\sigma^{\mu v}q_\nu U(P,\lambda)$$

$$Q \gg \Lambda_{\rm QCD}$$

$$\mathcal{L}_{\rm CPV} = -\frac{i}{2}\sum_q d_q\bar{q}\sigma^{\mu\nu}\gamma_5 qF_{\mu\nu} - \frac{i}{2}\sum_q \tilde{d}_q\bar{q}\sigma^{\mu\nu}\gamma_5 T^a qG^a_{\mu\nu} + \cdots$$



$$Q = M_{J/\psi}$$



Collinear factorization formula:

$$d_\Lambda(Q) \propto H(d_{q_i}, \tilde{d}_{q_i}, x_i, Q) \otimes F_\Lambda(x_i)$$

➡ Interpretation of the BESIII results

Hard interactions(CPV)

Hyperon structure (non-perturbative)

Quark dipole interactions and Λ-EDM form factor

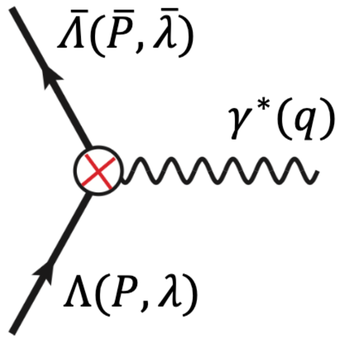
- CP-violating effective Lagrangian:

$$\mathcal{L}_{\rm CPV} = -\frac{i}{2}\sum_q \left(d_q \bar{q}\sigma^{\mu\nu}\gamma_5 q F_{\mu\nu} + \tilde{d}_q \bar{q}\sigma^{\mu\nu}\gamma_5 T^a q G^a_{\mu\nu} \right) + \cdots$$

Quark EDM

Quark CEDM (chromo-electric dipole moment)

- Λ EDM form factor:



$$\langle 0|J^\mu|\Lambda(P,\lambda)\bar{\Lambda}(\bar{P},\bar{\lambda})\rangle = d_\Lambda(Q)\bar{V}(\bar{P},\bar{\lambda})\gamma_5\sigma^{\mu v}q_v U(P,\lambda) + \cdots$$

$Q^2 = (P+\bar{P})^2$: the photon virtuality

The BESIII measurement corresponds to $d_\Lambda\left(Q = M_{J/\psi}\right)$

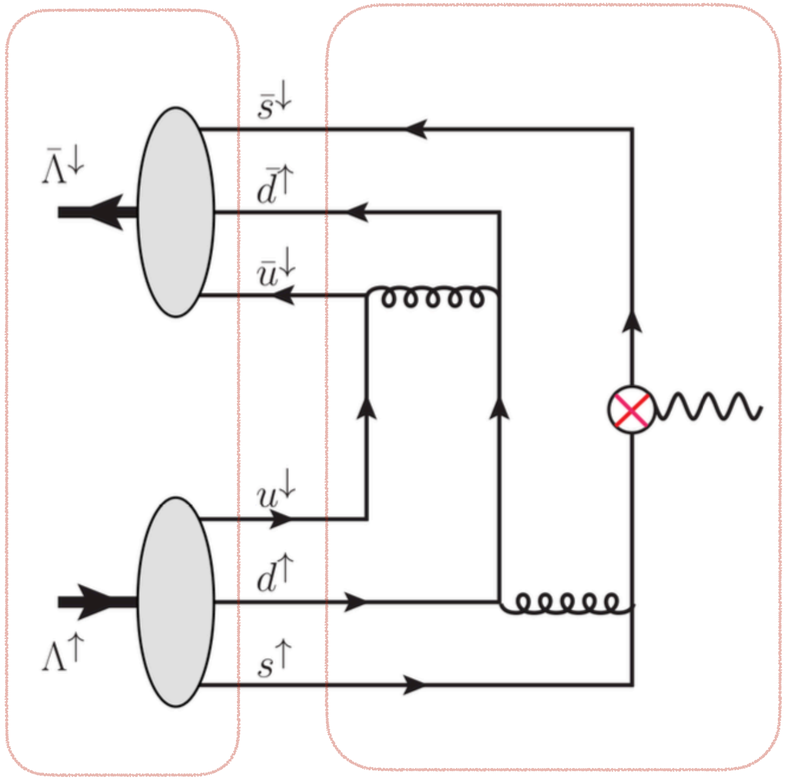
➡ Derive the leading-power contributions of $d_\Lambda(Q)$ in large-Q^2limit

The Framework

Collinear factorization for hard exclusive processes:

[Lepage-Brodsky 1980
Efremov-Radyushkin 1980]

Hadronic form factors ~ Light-cone distribution amplitudes (LCDAs) ⊗ Hard coefficients



- What is special for the EDM calculations?

$$\langle 0|J^{\mu}|\Lambda(P,\lambda)\bar{\Lambda}(\bar{P},\bar{\lambda})\rangle = d_{\Lambda}(Q)\bar{V}(\bar{P},\bar{\lambda})\gamma_5\sigma^{\mu v}q_v U(P,\lambda)$$

Helicity flip

- In QCD, quark helicity is conserved, so hadron helicity flip require orbital angular momentum, which is higher-twist effects ,

  e.g., the Pauli EM form factor $F_2 \sim 1/Q^6$

- For EDM, the quark dipole interactions provides the helicity flip

$$\mathcal{L}_{\rm CPV} = -\frac{i}{2}\sum\left(d_q\bar{q}\sigma^{\mu\nu}\gamma_5 q F_{\mu\nu} + \tilde{d}_q\bar{q}\sigma^{\mu\nu}\gamma_5 T^a q G^a_{\mu\nu}\right) + \cdots$$

➡ d_Λ has the leading-twist/power contributions $\sim 1/Q^4$

Leading-twist Λ LCDAs

$$4\epsilon^{abc}\int\frac{d\lambda_1 d\lambda_2 d\lambda_3}{(2\pi)^3}e^{iP^+(\lambda_1 x_1+\lambda_2 x_2+\lambda_3 x_3)}\langle 0|u_\alpha^a(\lambda_3 n)d_\beta^b(\lambda_2 n)s_\gamma^c(\lambda_1 n)|\Lambda(P)\rangle$$

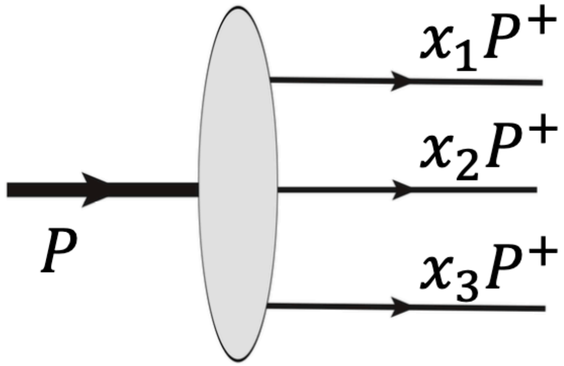
$$=\mathcal{V}_\Lambda([x])(\gamma\cdot\hat{P}C)_{\alpha\beta}(\gamma_5 U)_\gamma+\mathcal{A}_\Lambda([x])(\gamma\cdot\hat{P}\gamma_5 C)_{\alpha\beta}U_\gamma+\mathcal{T}_\Lambda([x])(\hat{P}^\nu i\sigma_{\mu\nu}C)_{\alpha\beta}(\gamma^\mu\gamma_5 U)_\gamma+\cdots$$

Λ LCDAs

V. M. Braun et al., Nucl. Phys. B553, 355 (1999)

$\hat{P}^\mu=(P^+,0,0,0)$

$[x]=x_1,x_2,x_3$



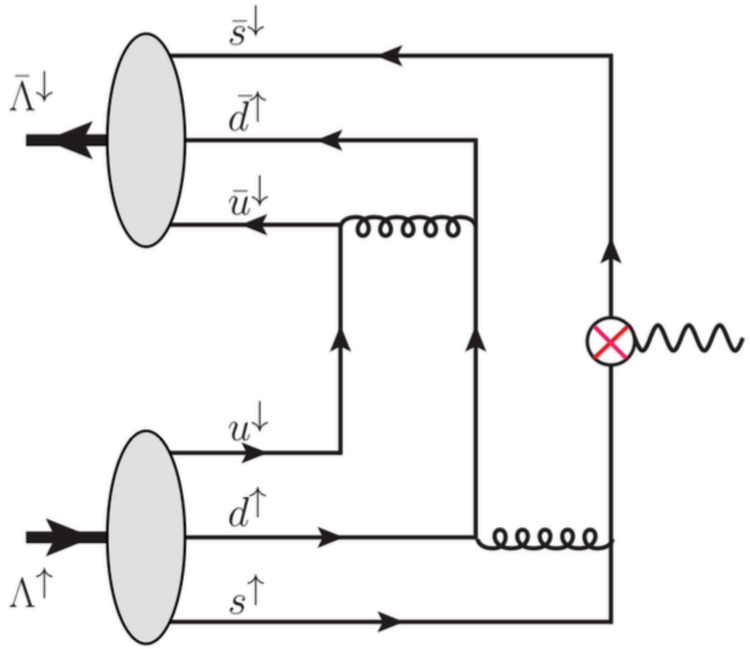
Fock-state expansion:

$$|\Lambda^\uparrow\rangle=\int\frac{[d^3x]}{4\sqrt{6}}\{[\mathcal{V}_\Lambda([x])-\mathcal{A}_\Lambda([x])]|u^\uparrow d^\downarrow s^\uparrow\rangle+[\mathcal{V}_\Lambda([x])+\mathcal{A}_\Lambda([x])]|u^\downarrow d^\uparrow s^\uparrow\rangle-2\mathcal{T}_\Lambda([x])|u^\uparrow d^\uparrow s^\downarrow\rangle\}$$

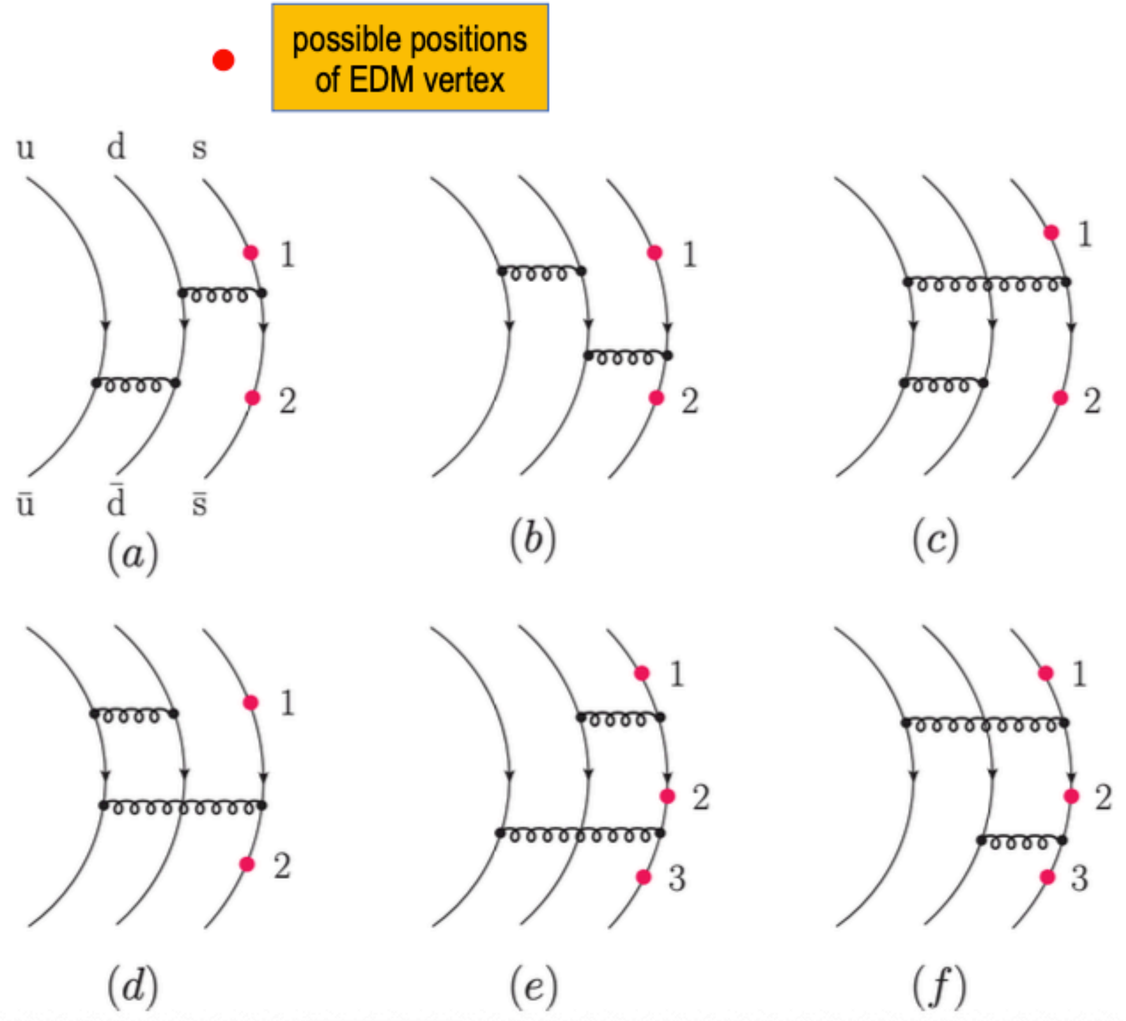
V. L. Chernyak et al., Z. Phys. C 42, 569 (1989)

Perturbative calculation

- Quark EDM contributions



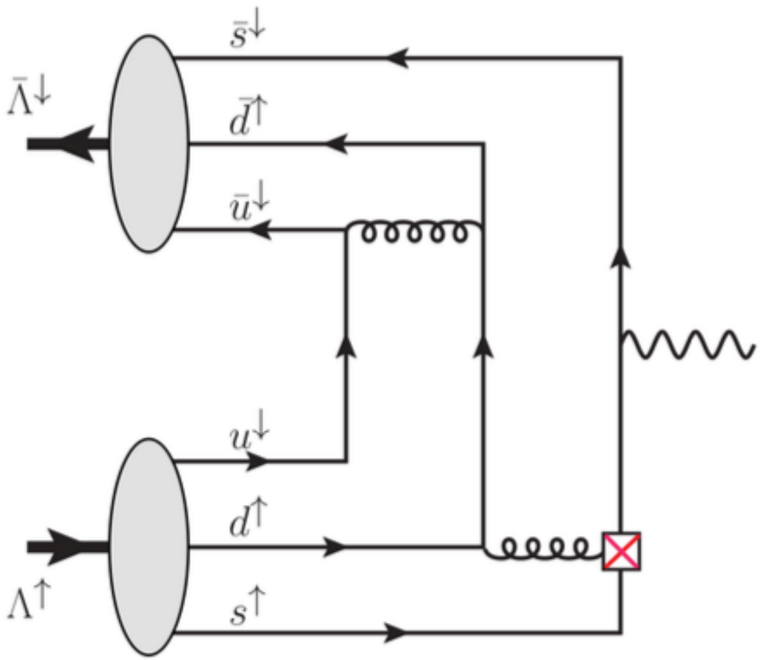
A typical diagram for the s quark EDM contribution



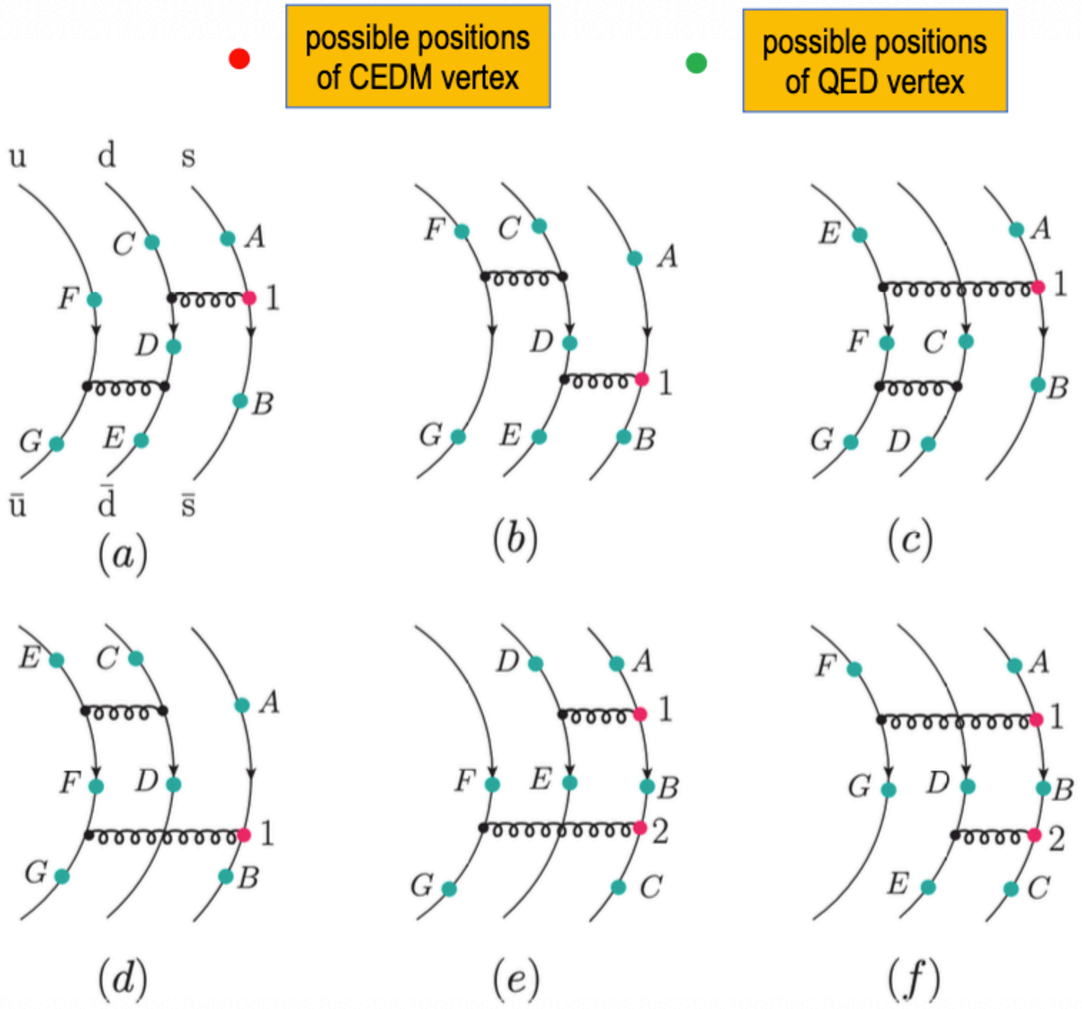
14 diagrams for each quark EDM contribution

Perturbative calculation

- Quark Chromo-EDM contributions



A typical diagram for the s quark CEDM contribution



56 diagrams for each quark CEDM contribution

Analytical results

- Factorization formulas:

$$d_\Lambda(Q)\Big|_{\text{EDMs}} = C_B \frac{(4\pi\alpha_s)^2}{Q^4}\int [d^3x][d^3y]\{d_s[(\mathcal{V}_\Lambda([x])\mathcal{V}_{\bar\Lambda}([y]) - \mathcal{A}_\Lambda([x])\mathcal{A}_{\bar\Lambda}([y]))\mathcal{H}_s([x],[y]) + (\mathcal{V}_\Lambda([x])\mathcal{A}_{\bar\Lambda}([y]) - \mathcal{A}_\Lambda([x])\mathcal{V}_{\bar\Lambda}([y]))\mathcal{C}_s([x],[y])] + (d_d + d_u)(\mathcal{V}_\Lambda([x]) + \mathcal{A}_\Lambda([x]))\mathcal{T}_{\bar\Lambda}([y])\mathcal{H}_q([x],[y])\}$$

$$C_B = 2/27$$

$$[d^3x] = dx_1dx_2dx_3$$

$$d_\Lambda(Q)\Big|_{\text{CEDMs}} = eg_sC_B\frac{4\pi\alpha_s}{Q^4}\int [d^3x][d^3y]\{\tilde d_s\tilde{\mathcal{H}}_s([x],[y])[\mathcal{V}_\Lambda([x])\mathcal{V}_{\bar\Lambda}([y]) - \mathcal{A}_\Lambda([x])\mathcal{A}_{\bar\Lambda}([y])] + [\tilde d_d\tilde{\mathcal{H}}_d([x],[y]) + \tilde d_u\tilde{\mathcal{H}}_u([x],[y])][\mathcal{V}_\Lambda([x]) + \mathcal{A}_\Lambda([x])]\mathcal{T}_{\bar\Lambda}([y])\}$$

➡ Connecting Λ EDM form factor to quark EDMs and CEDMs

Hard coefficients:

$$\mathcal{H}_s([x],[y]) = \frac{-2}{\bar x_1^2\bar y_1^2x_3y_3} - \frac{1}{2x_2x_3y_2y_3}\left(\frac{1}{\bar x_3\bar y_2} - \frac{1}{\bar x_1\bar y_2} - \frac{1}{\bar x_2\bar y_1}\right)$$

$$\mathcal{C}_s([x],[y]) = \frac{-1}{2x_2x_3y_2y_3}\left(\frac{1}{\bar x_3\bar y_2} - \frac{1}{\bar x_1\bar y_2} + \frac{1}{\bar x_2\bar y_1}\right)$$

$$\mathcal{H}_q([x],[y]) = \frac{-1}{x_1x_3y_1y_3}\left(\frac{1}{\bar x_2\bar y_3} - \frac{1}{\bar x_1\bar y_3} + \frac{1}{\bar x_1\bar y_2}\right) + \frac{2}{\bar x_2^2\bar y_2^2}\left(\frac{1}{x_3y_3} + \frac{1}{x_1y_1}\right)$$

$$\tilde{\mathcal{H}}_s([x],[y]) = Q_s\left[\frac{1}{\bar x_1\bar y_1}\left(\frac{1}{x_3y_3} + \frac{1}{x_2y_2}\right) + \frac{2}{x_2x_3y_2y_3}\right] + Q_d\left[\frac{1}{x_1y_1}\left(\frac{1}{x_3y_3} + \frac{1}{\bar x_2\bar y_2}\right) + \frac{2}{x_3y_3\bar x_2\bar y_2}\right] + Q_u\left[\frac{1}{x_1y_1}\left(\frac{1}{\bar x_3\bar y_3} + \frac{1}{x_2y_2}\right) + \frac{2}{x_2y_2\bar x_3\bar y_3}\right]$$

$$\tilde{\mathcal{H}}_d([x],[y]) = -Q_s\left[\frac{2}{x_2y_2}\left(\frac{1}{x_3y_3} + \frac{1}{\bar x_1\bar y_1}\right) + \frac{4}{x_3y_3\bar x_1\bar y_1}\right] - Q_d\left[\frac{2}{\bar x_2\bar y_2}\left(\frac{1}{x_3y_3} + \frac{1}{x_1y_1}\right) + \frac{4}{x_1x_3y_1y_3}\right] - Q_u\left[\frac{2}{x_2y_2}\left(\frac{1}{\bar x_3\bar y_3} + \frac{1}{x_1y_1}\right) + \frac{4}{x_1y_1\bar x_3\bar y_3}\right]$$

$$\tilde{\mathcal{H}}_u = \tilde{\mathcal{H}}_d(Q_u \leftrightarrow Q_d)$$

Numerical estimation

- Input of Λ LCDAs

  - Asymptotic form (the first term of conformal partial wave expansion of LCDA): *V. M. Braun et al., Nucl. Phys. B807, 89 (2009)*

    $\mu = Q \to \infty$

$$\mathcal{A}_\Lambda([x]) = f_\Lambda f_{\rm as}([x]) = 120 f_\Lambda x_1 x_2 x_3, \quad \mathcal{V}_\Lambda([x]) = \mathcal{T}_\Lambda([x]) = 0, \quad f_\Lambda \approx 6\times10^{-3}\text{GeV}^2$$

⟹ Only s quark contribute:

$$d_\Lambda = 1.72 \times 10^{-4} d_s + 2.06 \times 10^{-5} e\tilde{d}_s$$

But not valid for $Q = M_{J/\psi}$

  - Including the next-term in the expansion:

$$\mathcal{T}_\Lambda([x],\mu) = 7\sqrt{3/2}\, f_{\rm as}([x])(x_3 - x_2)\pi_{10}(\mu)$$

$$\mathcal{V}_\Lambda([x],\mu) = -\frac{7}{2}\sqrt{3/2}\, f_{\rm as}([x])(x_3 - x_2)[\varphi_{10}(\mu) - 3\varphi_{11}(\mu)]$$

$$\mathcal{A}_\Lambda([x],\mu) = \frac{1}{2}\sqrt{3/2}\, f_{\rm as}([x])[-2\varphi_{00}(\mu) + 7(x_3 + x_2 - 2x_1)(\varphi_{10}(\mu) + \varphi_{11}(\mu))]$$

G. S. Bali

⇩

Determined from Lattice: *G. S. Bali et al., (RQCD Collaboration) JHEP 08 (2019) 065*
G. S. Bali et al., (RQCD Collaboration) PRD 111, 094517 (2025)

Numerical estimation

- Estimation for Λ EDM
  - Asymptotic form: $\mu = Q \to \infty$

$$d_\Lambda = 1.72 \times 10^{-4} d_s + 2.06 \times 10^{-5} e\tilde{d}_s$$

✦ Including the next-term for BESIII: [Chen-He-Ma-Tong PRL 136, 051902 (2026)]

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

- Compared with the neutron static EDM d_n: *R. Alarcon et al., arXiv:2203.08103*

$$d_n = -(0.20 \pm 0.01) d_u + (0.78 \pm 0.03) d_d + (0.0027 \pm 0.0016) d_s - (0.55 \pm 0.28) e\tilde{d}_u - (1.1 \pm 0.55) e\tilde{d}_d$$

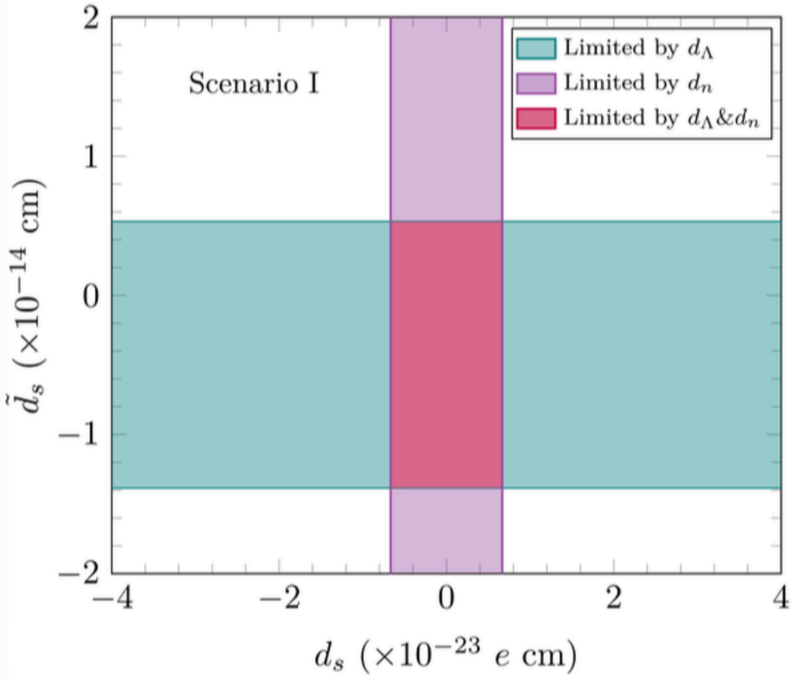
✓ No $\tilde{d}_s$ (strange quark CEDM) contributions from the neuron EDM (cancellation with strong CP phase by PQ symmetry)

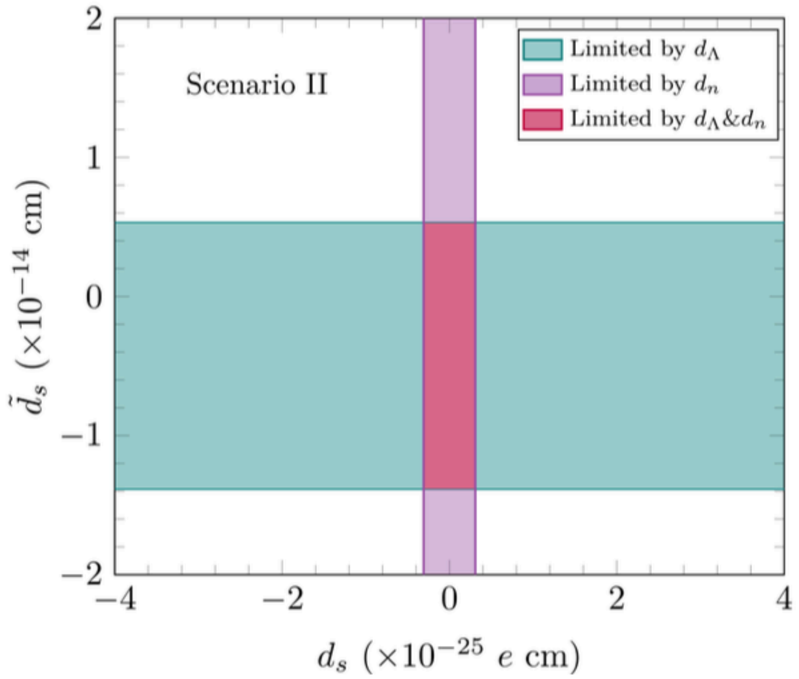
✓ d_Λ provide unique constrains on $\tilde{d}_s$

Combined constraint from ΛEDM and nEDM

$-8.6\times10^{-19} < \mathrm{Re}(d_\Lambda) < 3.3\times10^{-19} e$ cm,

$|d_n| < 1.8\times10^{-26}\ e$ cm





Scenario I: $d_s \gg d_u, d_d$

Scenario II: $d_s = d_u = d_d$

$\tilde{d}_u$ and $\tilde{d}_d$ are neglected

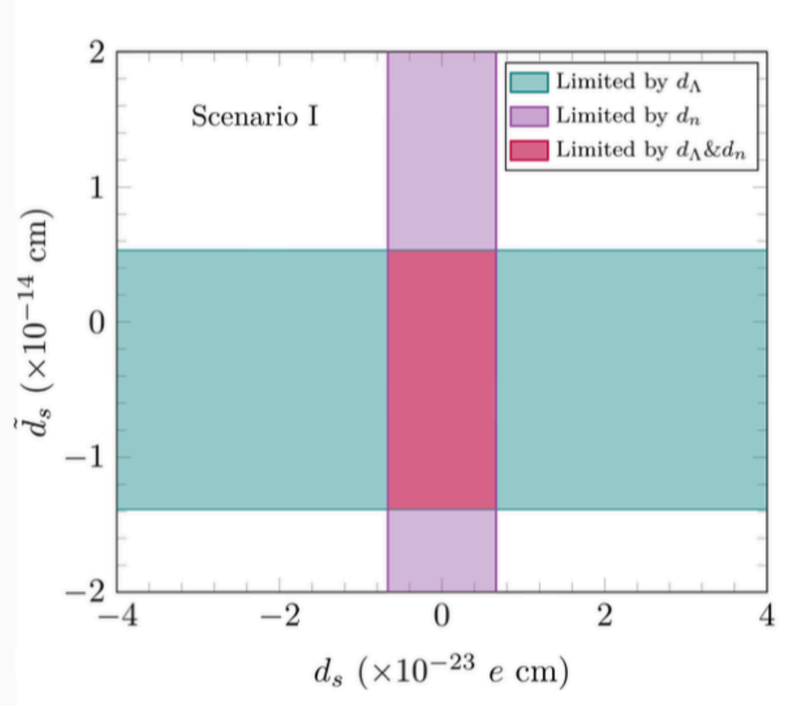
Implications

- ✓ Λ EDM bound: sensitive to both d_s and $\tilde{d}_s$, strong correlated
- ✓ nEDM gives a strong bound only on d_s
- ✓ Combined: reducing $\tilde{d}_s$ to a finite region
- ✓ Unique power in probing strange quark CEDM

$$|\tilde{d}_s| < 1.4\times10^{-14}\mathrm{cm}$$

Summary

- Inspired by the BESIII measurement on Λ EDM, we perform a perturbative analysis for the Λ EDM form factor at large-Q
- Derived the collinear factorization formulas linking Λ EDM form factor to quark EDM and quark CEDMs through convolution with Λ LCDAs
- Our numerical results show that the Λ EDM is uniquely sensitive to the strange quark CEDM that not is accessible by nEDM
- Further measurements on other hyperons would provide more robust constraints



$$|\tilde{d}_s| < 1.4\times10^{-14}\text{cm}$$