Measurement of Λ EDM and search for CP violation at BESIII

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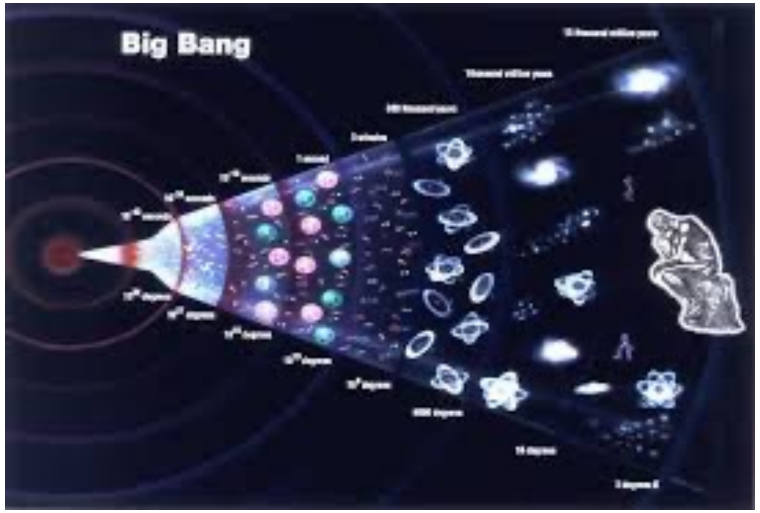
Search for CP violation

- ❑ CP violation (CPV) is a necessary condition for the Baryon Asymmetry of the Universe

- ❑ CPV only present in the weak interaction (SM), but too small for puzzle of missing antimatter

- ❑ Possibly there are new sources of CPV (new physics), need to search for CPV effects extensively



This talk: Λ Electric Dipole Moment (EDM) arXiv:2506.19180

Charm Chromoelectric Dipole Moment (CEDM) Phys.Rev.Lett.136,231903(2026)

K^0- $\overline{K^0}$ oscillation Phys.Rev.D112,052010(2025)

Beijing Electron-Positron Collider II (BEPCII)

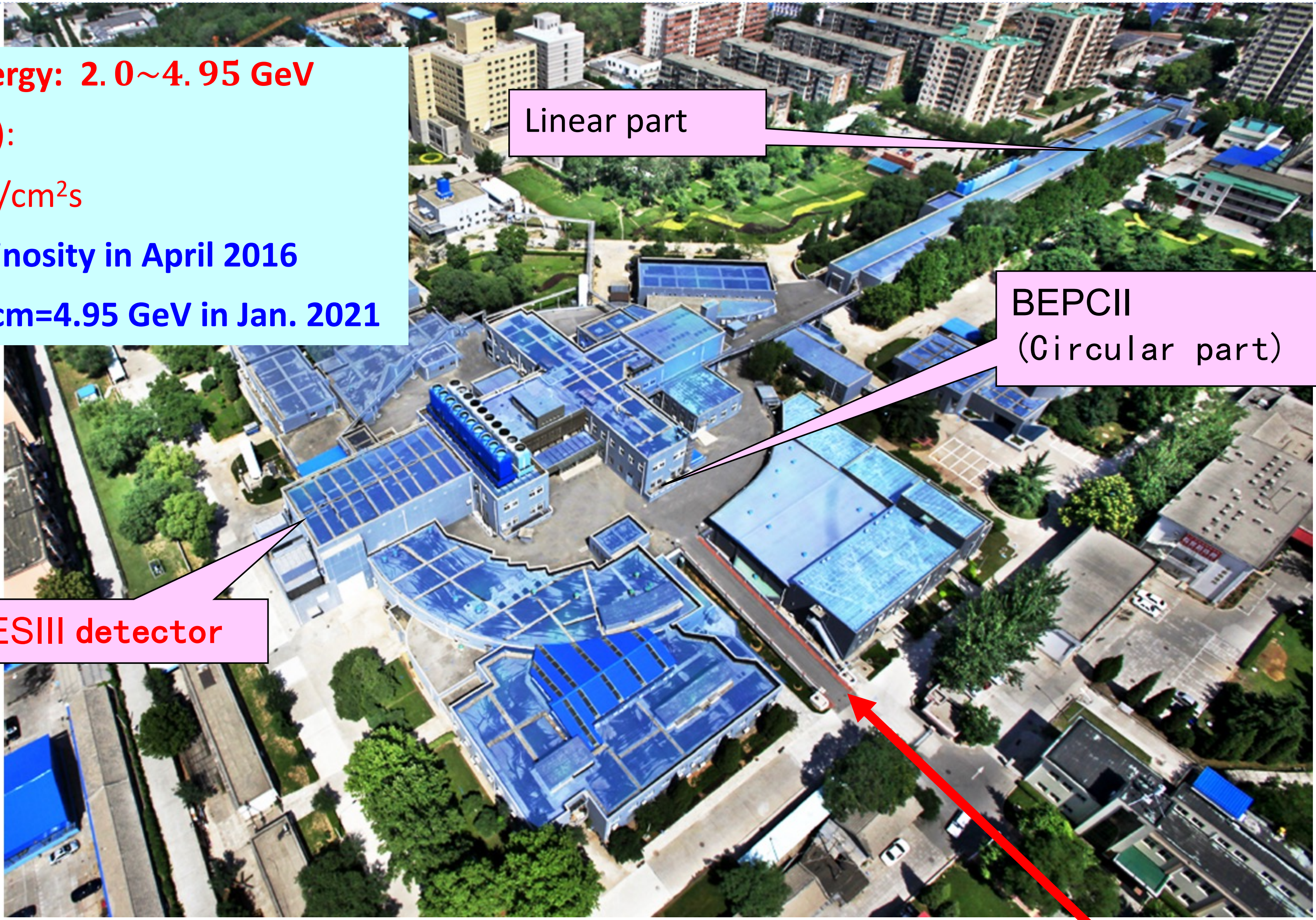
Center of mass energy: 2.0~4.95 GeV

2008- **Now** (BEPCII):

$L_{peak}=1.0\text{x}10^{33}/cm^2s$

Reached peak luminosity in April 2016

Reached highest Ecm=4.95 GeV in Jan. 2021

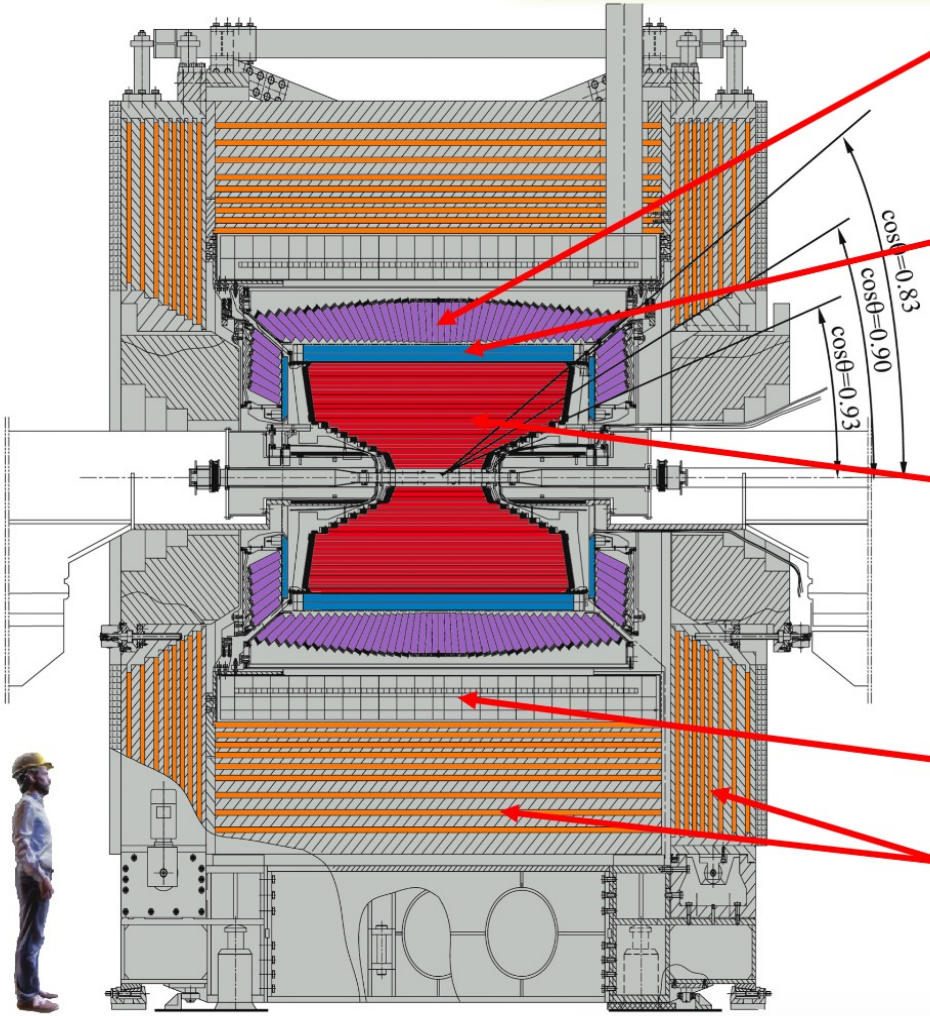


Circumference:240m

Linear part:200m

BESIII detector

The detector is designed for neutral and charged particle with excellent resolution, PID, and large coverage.



EMC: CsI crystals
$\Delta E/E$ = 2.5% @ 1 GeV - Barrel
$\Delta E/E$ = 5.0% @ 1 GeV - Endcaps

TOF:
σ_T = 80 ps Barrel
σ_T = 110 (60) ps Endcap

MDC: small cell & He gas
σ_{xy}= 130 μm
σ_p/p = 0.5% @1GeV
dE/dx = 6%

Magnet: 1T Super conducting

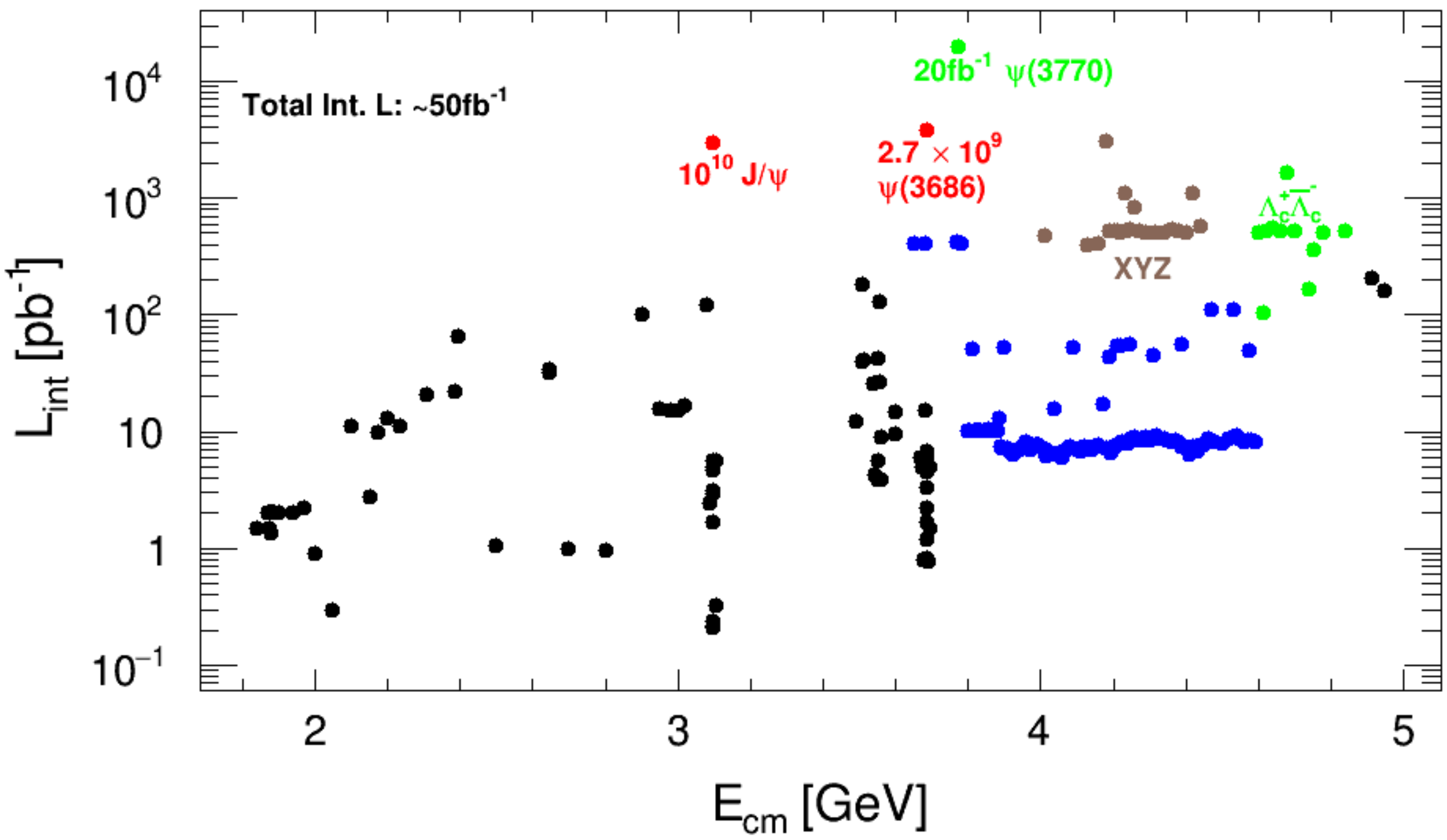
Muon ID: 9 layer RPC

Trigger: Tracks & Showers

Total weight 730 ton, ~40,000 readout channels, Data rate: 5kHz, 50Mb/s

Has been in full operation since 2008, all subdetectors are in very good status!

BESIII data samples



This talk:

$10\times10^9\ J/\psi$

$2.7\times10^9\ \psi(3686)$

Entangled hadron pair-productions near thresholds: form-factors, relative phase, polarization and CP violation.

Why (hyperon) EDM

- ❑ EDM extremely tiny in SM but can be largely enhanced by new physics

- ❑ Single measurement insufficient to disentangle various contributions

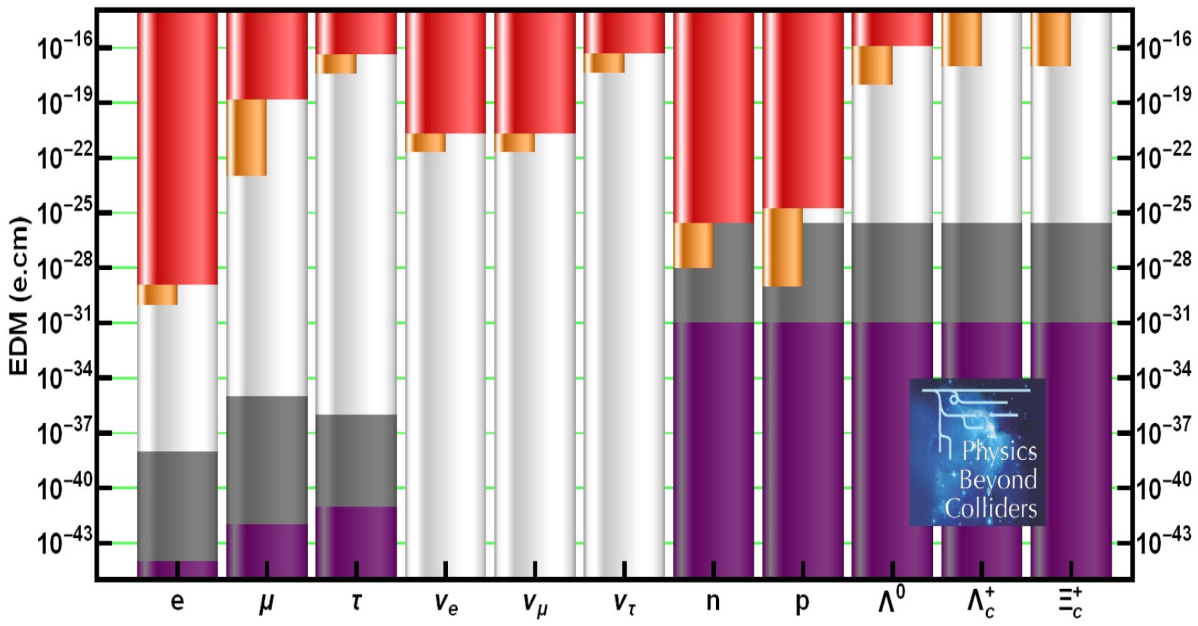
  i.e. neutron

$$d_n = -(1.5 \pm 0.7) \times 10^{-16}\,\bar{\theta}\,e\,\mathrm{cm}$$

LQCD

$$-(0.20 \pm 0.01) d_u + (0.78 \pm 0.03) d_d + (0.0027 \pm 0.0016) d_s$$

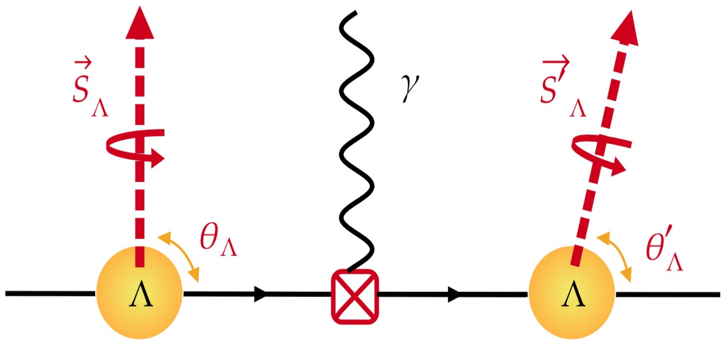
  + chromo EDM + …



- ❑ Global EDM analysis needs experimental input from various systems

Access to Λ EDM

$$\boldsymbol{\delta} = d\mu_B\, \boldsymbol{s}/2$$

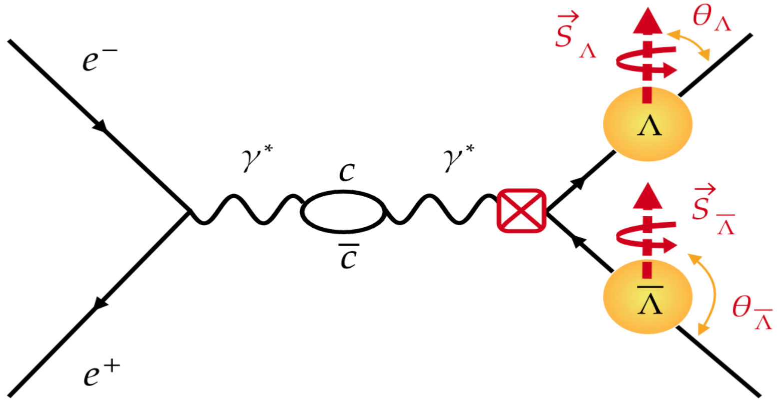


Short life-time challenge for spin procession

Only one measurement in 1980s @ Fermilab

$d_\Lambda < 1.5\times10^{-16} e$ cm

Phys. Rev. D23 (1981) 814



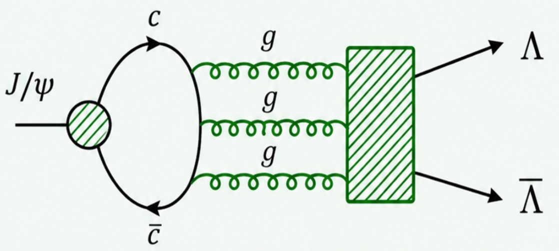
Indirect access in $J/\psi \to \Lambda\bar{\Lambda}$

$$H_T = \frac{2e}{3M^2} g_v d_\Lambda$$

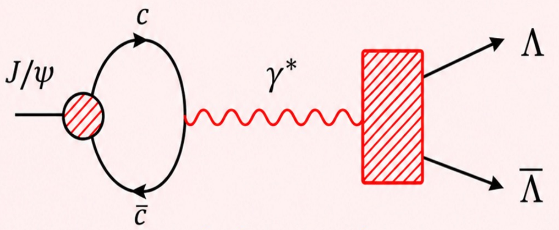
X.G.He, J.P. Ma, Phys.Rev.D47(1993)1744

X.G.He, J.P. Ma, Phys.Lett.B 839(2023)137834

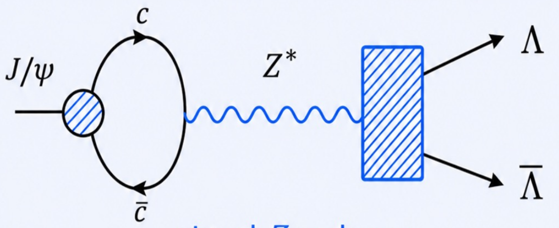
$J/\psi \to \Lambda\bar{\Lambda}$ decay



three-gluon exchange (**dominant**)



virtual photon exchange



virtual Z exchange

$J/\psi\Lambda\bar{\Lambda}$ vertex: four form factors in total

$$\mathcal{M}_{\lambda_1,\lambda_2} = \epsilon_\mu(\lambda_1 - \lambda_2)\bar{u}(\lambda_1, p_1)\left(F_V\gamma^\mu + \frac{i}{2m}\sigma^{\mu\nu}q_\nu H_\sigma + \gamma^\mu\gamma^5 F_A + \sigma^{\mu\nu}\gamma^5 q_\nu \boxed{H_T}\right)v(\lambda_2, p_2)$$

Angular distribution:

$$\frac{d\sigma}{d\Omega} \propto \sum_{[\lambda]} R(\lambda_1, \lambda_2; \lambda_1', \lambda_2')$$

$$D^{*j=1/2}_{\lambda_1,\lambda_3}(\phi_1,\theta_1)D^{j=1/2}_{\lambda_1',\lambda_3'}(\phi_1,\theta_1)\mathcal{H}^*_{\lambda_3}\mathcal{H}_{\lambda_3'}$$

$$D^{*j=1/2}_{\lambda_2,\lambda_4}(\phi_2,\theta_2)D^{j=1/2}_{\lambda_2',\lambda_4'}(\phi_2,\theta_2)\bar{\mathcal{H}}^*_{\lambda_4}\bar{\mathcal{H}}_{\lambda_4'}$$

$$R(\lambda_1, \lambda_2; \lambda_1', \lambda_2') \propto \sum_{m,m'} \rho_{m,m'} d^{j=1}_{m,\lambda_1-\lambda_2}(\theta) d^{j=1}_{m',\lambda_1'-\lambda_2'}(\theta) \times \mathcal{M}_{\lambda_1,\lambda_2}\mathcal{M}^*_{\lambda_1',\lambda_2'}\delta_{m,m'},$$

Determine H_T (all free parameters) from full angular analysis

Jinlin Fu, Hai-Bo Li, Jian-peng Wang, Fu-Sheng Yu and Jianyu Zhang
Phys. Rev. D 108, L091301 (2023)

Λ EDM measurement at BESIII

arXiv:2506.19180
submitted to Science

- 3M $J/\psi \rightarrow \Lambda\bar{\Lambda}$ decays reconstructed with purity > 99%, similar statistics as Fermilab in 1980s
- Preserve CP symmetry and a 3-order-of-magnitude improvement

$$Re(d_\Lambda) = (-3.1 \pm 3.2 \pm 0.5) \times 10^{-19}\ e\ \text{cm},$$
$$Im(d_\Lambda) = (2.9 \pm 2.6 \pm 0.6) \times 10^{-19}\ e\ \text{cm}.$$

$$-8.6 \times 10^{-19} < Re(d_\Lambda) < 3.3 \times 10^{-19}\ e\ \text{cm},$$
$$-2.5 \times 10^{-19} < Im(d_\Lambda) < 7.2 \times 10^{-19}\ e\ \text{cm},$$
$$|d_\Lambda| < 6.5 \times 10^{-19}\ e\ \text{cm}.$$

Parameter	This measurement
α_Λ	$0.7524 \pm 0.0036 \pm 0.0008$
$\alpha_{\bar{\Lambda}}$	$-0.7571 \pm 0.0036 \pm 0.0008$
$Re(G_2)$	$(9.71 \pm 0.06 \pm 0.24) \times 10^{-4}$
$Im(G_2)$	$(9.14 \pm 0.04 \pm 0.23) \times 10^{-4}$
P_L	$(-1.8 \pm 1.2 \pm 0.8) \times 10^{-3}$
$Re(F_A)$	$(-2.4 \pm 1.6 \pm 3.1) \times 10^{-6}$
$Im(F_A)$	$(-7.9 \pm 3.7 \pm 2.5) \times 10^{-6}$
$Re(H_T)$	$(-1.4 \pm 1.4 \pm 0.2) \times 10^{-6}$ GeV^{-1}
$Im(H_T)$	$(1.3 \pm 1.2 \pm 0.4) \times 10^{-6}$ GeV^{-1}
$\alpha_{J/\psi}$	$0.4748 \pm 0.0022 \pm 0.0017$
$\Delta\phi$	$0.7552 \pm 0.0042 \pm 0.0013$
A_{CP}	$(-3.1 \pm 4.6 \pm 1.1) \times 10^{-3}$
$\sin^2\theta_W^{\text{eff}}$	$-0.15 \pm 0.12 \pm 0.26$
$Re(d_\Lambda)$	$(-3.1 \pm 3.2 \pm 0.5) \times 10^{-19}$ e cm
$Im(d_\Lambda)$	$(2.9 \pm 2.6 \pm 0.6) \times 10^{-19}$ e cm

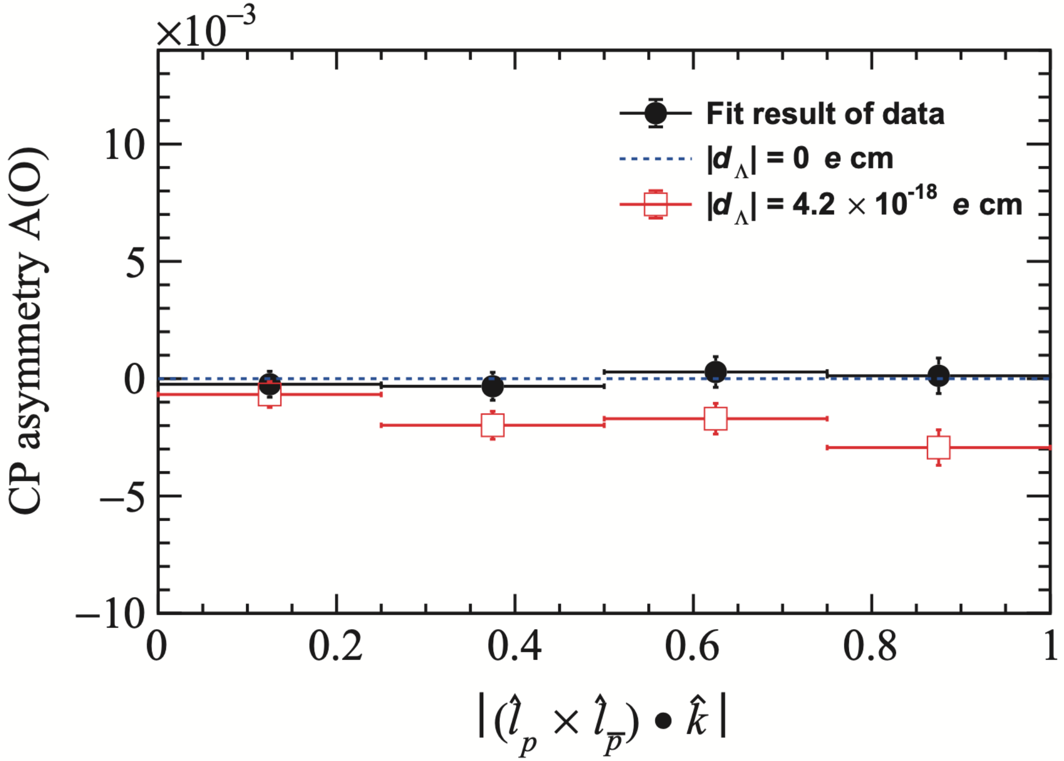
EDM visualization

arXiv:2506.19180
submitted to Science

- Non-zero EDM could affect angular distribution, asymmetry visualized in triple-product asymmetry (TPA)

$$O \equiv (\hat{l}_p \times \hat{l}_{\bar{p}}) \cdot \hat{k} \propto Re(H_T G_2^*)$$

$$A(O) = \frac{N_{\text{event}}(O > 0) - N_{\text{event}}(O < 0)}{N_{\text{event}}(O > 0) + N_{\text{event}}(O < 0)}$$



- A model with $d_\Lambda = 4.2\times10^{-18}$ e cm

  angular analysis is more sensitive than TPA

Complementary to neutron EDM (I)

arXiv:2506.19180
submitted to Science

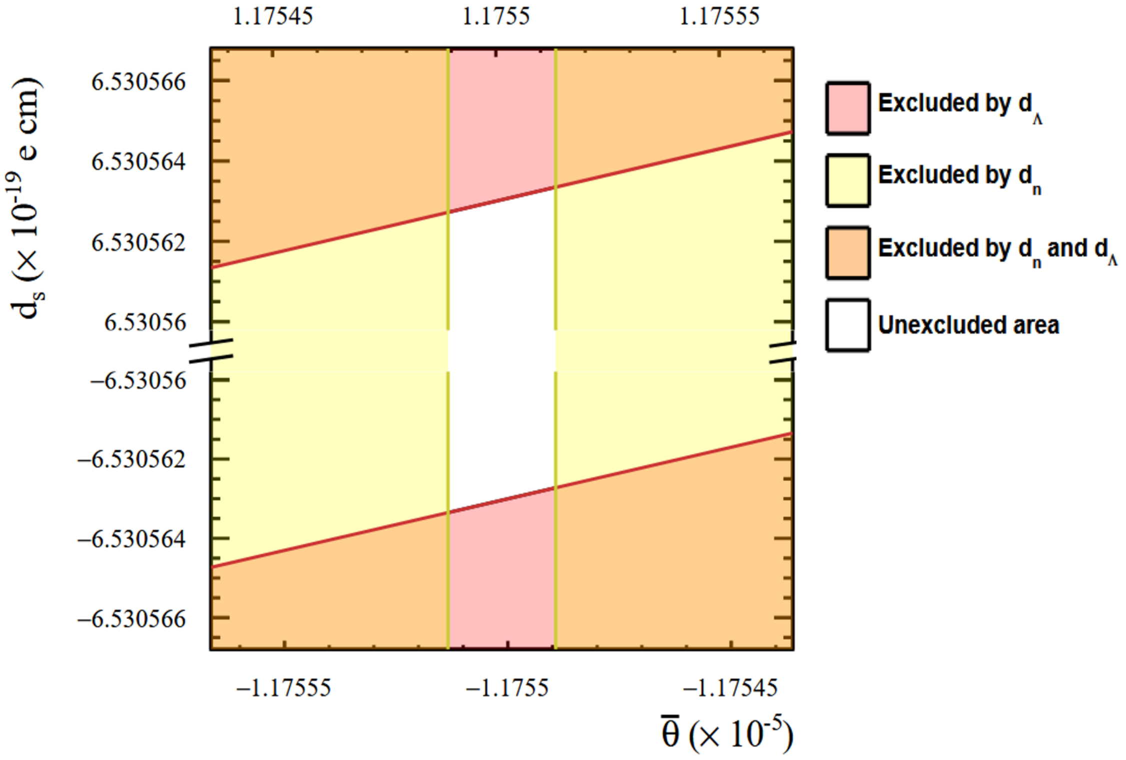
Stringent constraints on fundamental parameters $\bar{\theta}$ and d_s

Lattice QCD   PRC103,015202 (2021)   PRD98,091501(2018)

$$d_n = -(1.5 \pm 0.7) \times 10^{-16}\, \bar{\theta}\, e\ \mathrm{cm} - (0.20 \pm 0.01) d_u + (0.78 \pm 0.03) d_d + (0.0027 \pm 0.016) d_s$$

Valence quark model + QCD vaccum   JHEP12,097(2012)

$$d_\Lambda = (-2.6 \pm 0.4) \times 10^{-16}\, \bar{\theta}\, e\ \mathrm{cm} + d_s$$



Complementary to neutron EDM (II)

K-B Chen et al,
Phys.Rev.Lett. 136 (2026) 051902

Perturbative QCD Prediction of the Hyperon Electric Dipole Moment from *CP*-Violating Dipole Interactions

Kai-Bao Chen,[1] Xiao-Gang He,[2,3] Jian-Ping Ma,[4,5] and Xuan-Bo Tong[6,7]

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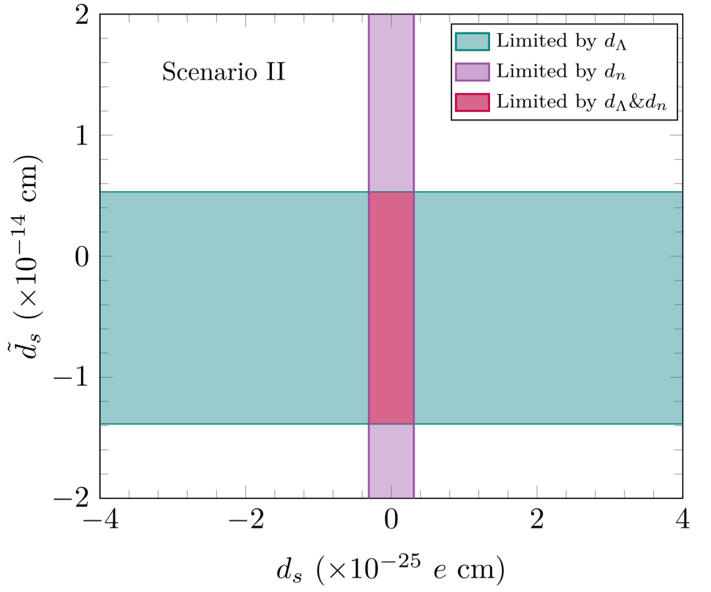
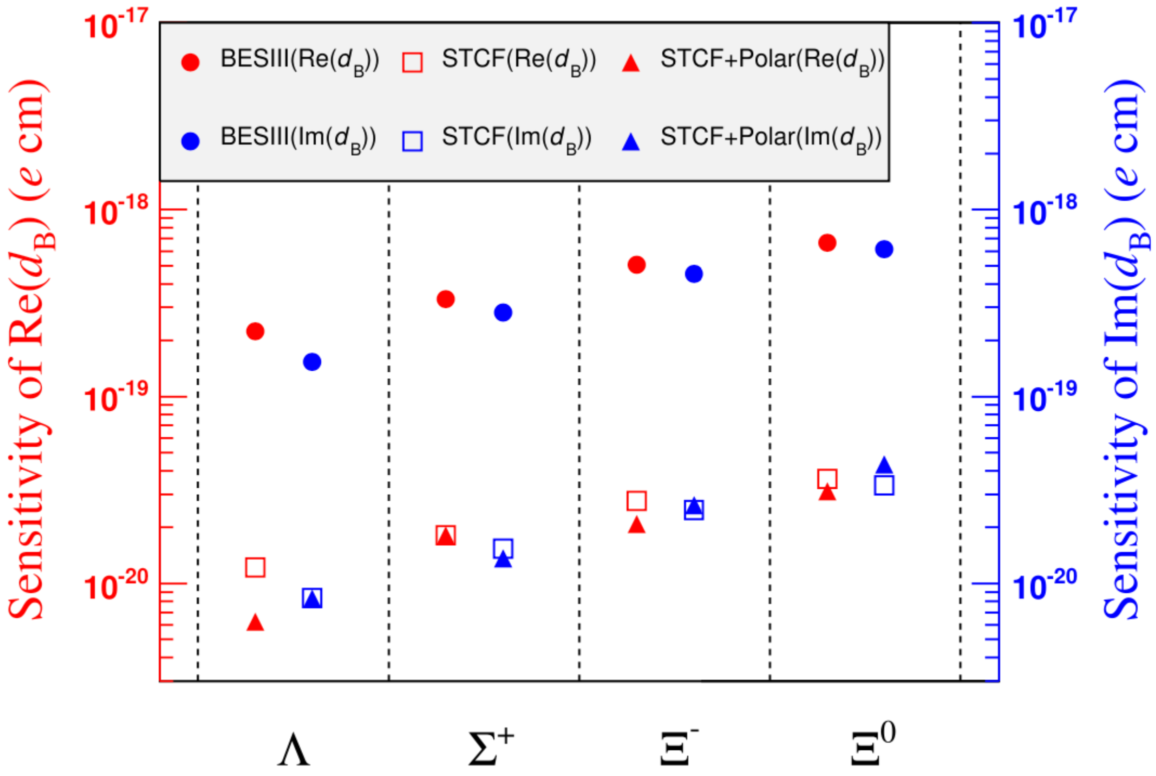
The electric dipole moment (EDM) of baryons provides a sensitive probe of *CP*-violating interactions beyond the standard model. Motivated by the recent BESIII measurement on the Λ hyperon EDM [Ablikim *et al.*, arXiv:2506.19180.], we present the first perturbative QCD analysis of the Λ EDM form factor to elucidate its origin in *CP*-violating quark dipole interactions. In particular, we derive a QCD factorization formula that relates the Λ EDM form factor to quark EDMs and chromoelectric dipole moments through convolutions with light-cone distribution amplitudes of Λ. These connections allow us to extract constraints on *CP*-violating dipole couplings from current and future hyperon EDM measurements. Our numerical analysis demonstrates that the Λ EDM exhibits unique sensitivity to the strange-quark chromoelectric dipole moment, providing complementary information to that obtained from the neutron EDM.

- PQCD relates d_Λ to quark EDM and CEDM
- d_Λ exhibits unique sentivity to strange-quark CEDM



$$|\tilde{d}_s| \lesssim 1.4 \times 10^{-14}\ \text{cm}$$

Extended to hyperon family



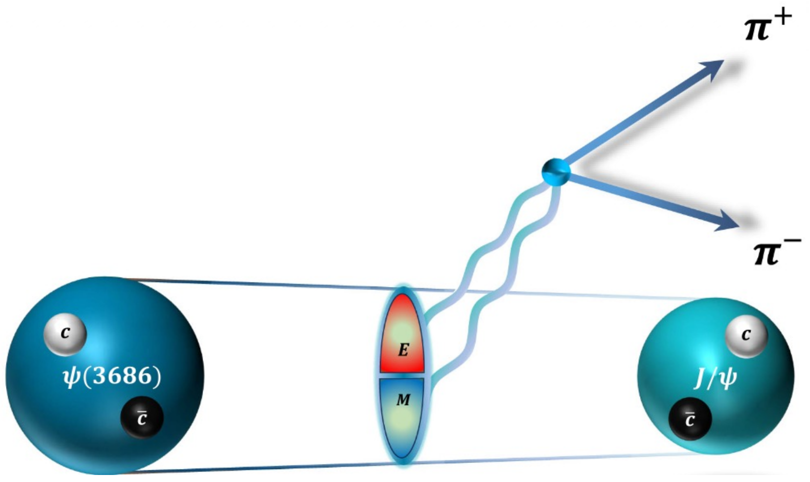
- ❑ Establish a full angular analysis to access EDM of hyperon family
- ❑ Measurements of the Σ, Ξ^-, Ξ^0 EDM at BESIII are in progress
- ❑ Sensitivity at BESIII and STCF

$$10^{-19} \sim 10^{-21}\ e\ \mathrm{cm}$$

Jinlin Fu, Hai-Bo Li, Jian-peng Wang, Fu-Sheng Yu and Jianyu Zhang
Phys. Rev. D 108, L091301 (2023)

CPV in $\psi(3686) \to J/\psi\pi^+\pi^-$

- Chromo EDM d_c' arising from anomalous couplings between charm quark and gluons, sensitive to new physics $\mathcal{L}_{\mathrm{CEDM}} = -i/2 d_c' \bar{\psi}_c \sigma^{\mu\nu}\gamma_5 \lambda_a/2 \psi_c G^a_{\mu\nu}$



- Can be extracted via TPA

T-odd observable

$$q_3 \equiv \vec{p}_{e^+} \cdot (\vec{p}_{\pi^+} - \vec{p}_{\pi^-}) \vec{p}_{e^+} \cdot \frac{\vec{p}_{\pi^+} \times \vec{p}_{\pi^-}}{|\vec{p}_{\pi^+} \times \vec{p}_{\pi^-}|}$$

CP-violating observable

$$A_{CP} = \frac{N_{\mathrm{events}}(q_3 > 0) - N_{\mathrm{events}}(q_3 < 0)}{N_{\mathrm{events}}(q_3 > 0) + N_{\mathrm{events}}(q_3 < 0)}$$

- Model dependent connection

CK model:

$$A_{CP} = (9.33 \pm 2.34) \times 10^{-3} d_c' m_c$$

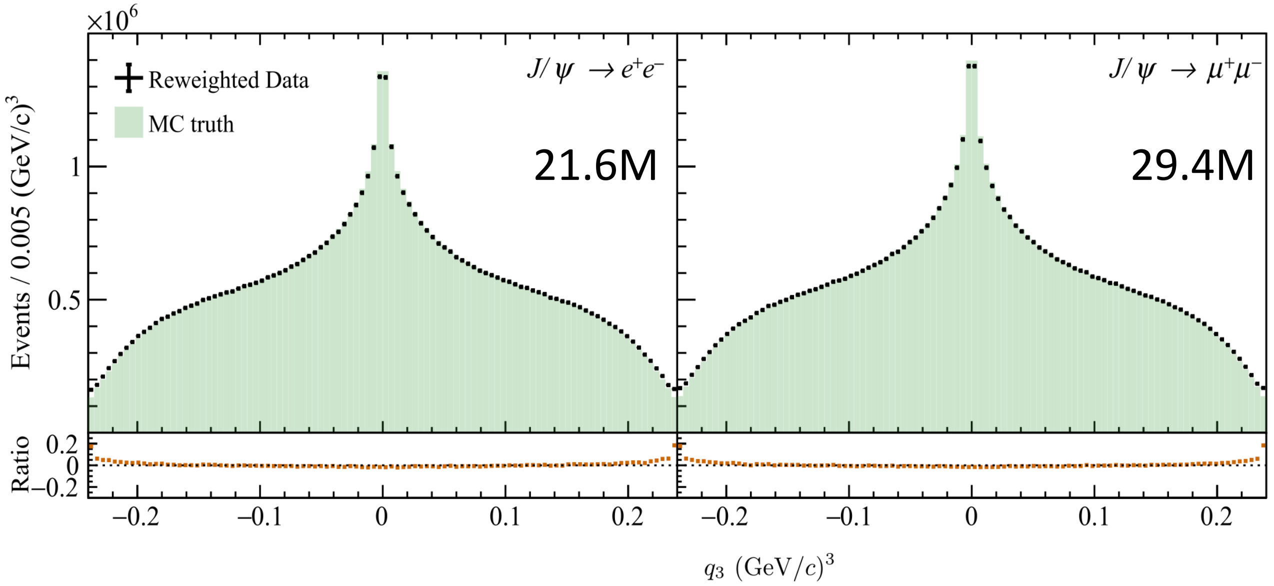
Cornell model:

$$A_{CP} = (6.93 \pm 0.97) \times 10^{-3} d_c' m_c$$

Phys.Rev.D85,114010(2012)

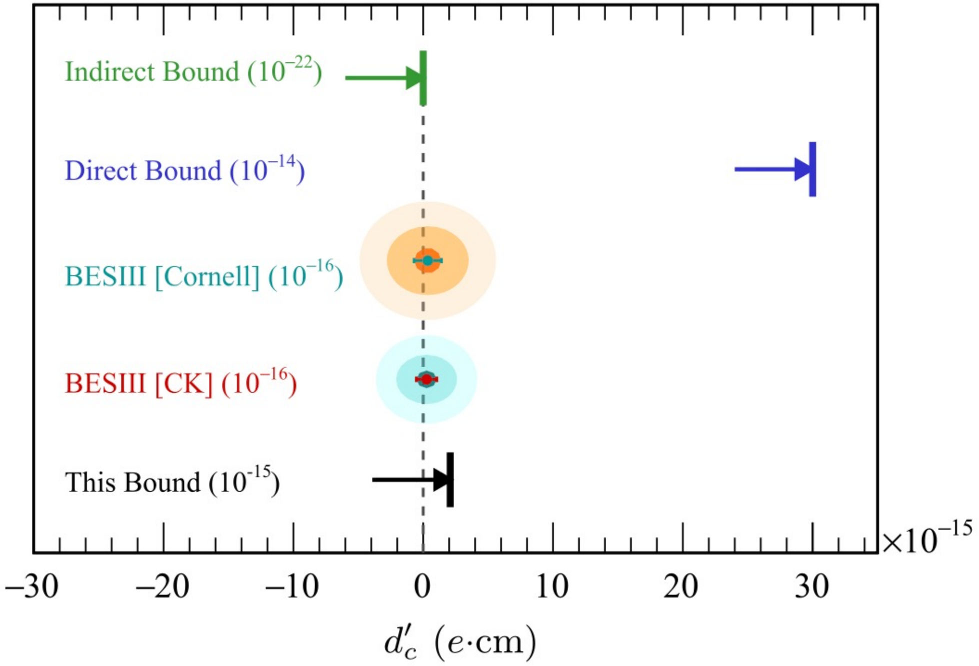
First charm CEDM result

Phys.Rev.Lett.136,231903(2026)



$$q_3 \equiv \vec{p}_{e^+} \cdot (\vec{p}_{\pi^+} - \vec{p}_{\pi^-}) \vec{p}_{e^+} \cdot \frac{\vec{p}_{\pi^+} \times \vec{p}_{\pi^-}}{|\vec{p}_{\pi^+} \times \vec{p}_{\pi^-}|}$$

Parameter	$J/\psi \to e^+e^-$	$J/\psi \to \mu^+\mu^-$
A_{CP} $(\times 10^{-4})$	$3.3 \pm 2.9 \pm 0.4$	$-1.2 \pm 2.4 \pm 0.1$
$\langle A_{CP} \rangle$ $(\times 10^{-4})$	$0.6 \pm 1.8 \pm 0.1$	
d'_c [CK] $(e\,\mathrm{cm})$	$(2.6 \pm 7.8 \pm 0.4 \pm 0.6) \times 10^{-16}$	
d'_c [Cornell] $(e\,\mathrm{cm})$	$(3.5 \pm 10.5 \pm 0.6 \pm 0.5) \times 10^{-16}$	
$\lvert d'_c \rvert$ $(e\,\mathrm{cm})$	$< 2.1 \times 10^{-15}$	



CPV in $J/\psi \to K_S^0 K_S^0$ and $\psi(3686) \to K_S^0 K_S^0$

- The final state is forbidden by Bose-Einstein statistics, but allowed via K^0- $\overline{K^0}$ oscillation

Theoretical prediction:

Phys.Rev.Lett.96,192001(2006)

$$\mathcal{B}(J/\psi \to K_S K_S) = (1.94 \pm 0.20) \times 10^{-9}$$
$$\mathcal{B}(\psi(2S) \to K_S K_S) = (0.56 \pm 0.08) \times 10^{-9}$$

$$R_{SS} \equiv \frac{\Gamma(J/\psi \to K_S K_S)}{\Gamma(J/\psi \to K_S K_L)} = (|p|^2 - |q|^2)^2 \frac{x^2 + y^2}{1 + x^2}$$
$$= (\delta_L)^2 \frac{x^2 + y^2}{1 + x^2}$$

CP-violating parameter

$$\delta_L \equiv \frac{\Gamma(K_L \to l^+ \nu \pi^-) - \Gamma(K_L \to l^- \nu \pi^+)}{\Gamma(K_L \to l^+ \nu \pi^-) + \Gamma(K_L \to l^- \nu \pi^+)}$$
$$= |p|^2 - |q|^2.$$

- Measurement at BESIII using all data set   Phys.Rev.D112,052010(2025)

$$Br(J/\psi \to K_S^0 K_S^0) < 4.7\times 10^{-9}$$

Improved by a factor of three

$$Br(\psi(3686) \to K_S^0 K_S^0) < 1.1\times 10^{-8}$$

Improved by two orders of magnitude

Summary

- With its vast J/psi and psi(3686) data samples, BESIII has performed a range of unique measurements on CPV

- Λ EDM sensitivity reaches 10^{-19} *e* cm, improving by 3 order of magnitude over the measurement from 40 years ago

- First precise measurement of charm CEDM