Hyperon Physics at BESIII

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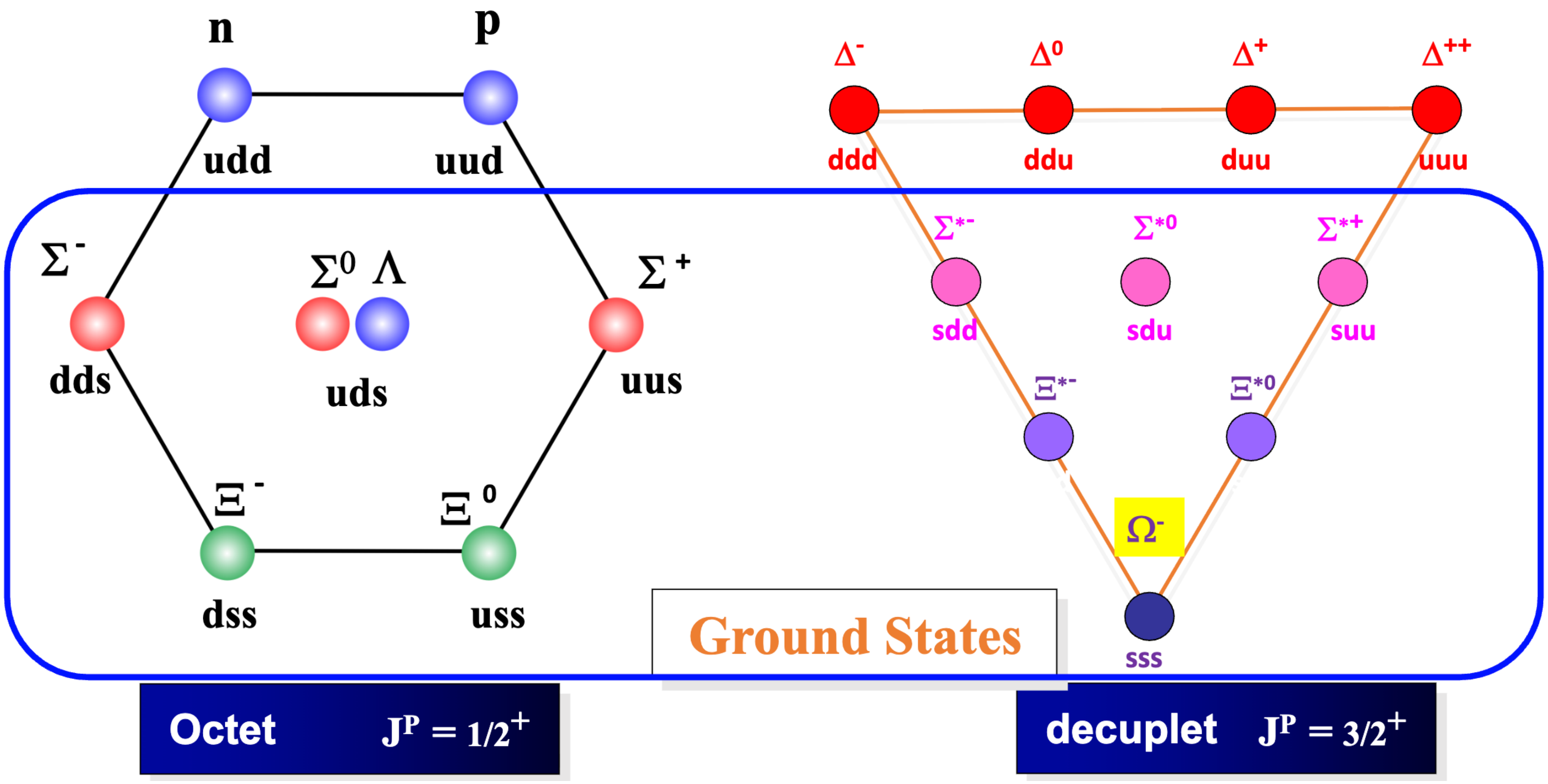
National Centre For Nuclear Research

(On behalf of BESIII Collaboration)

MESON 2026

Why hyperons?

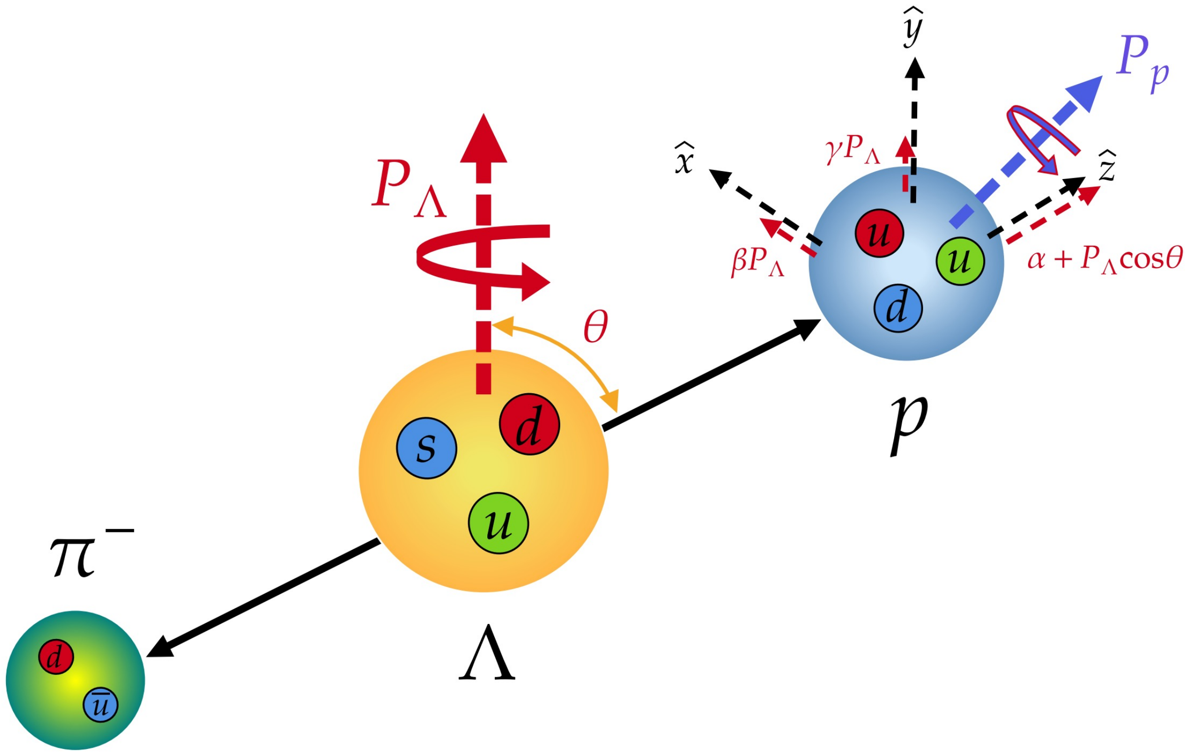
Hyperon: a unique role in particle physics



Advantage of hyperons

- Polarization experimentally accessible by the weak, parity violating decay:

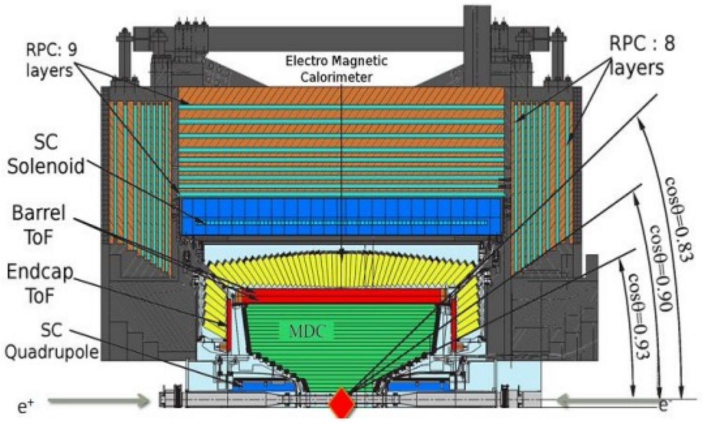
$$I(\cos\theta_p) = N(1+\alpha_\Lambda P_\Lambda \cos\theta_p)$$



BESIII: a hyperon factory

Electromagnetic Calorimeter
CsI(Tl): L=28 cm
Barrel σ_E=2.5%
Endcap σ_E=5.0%

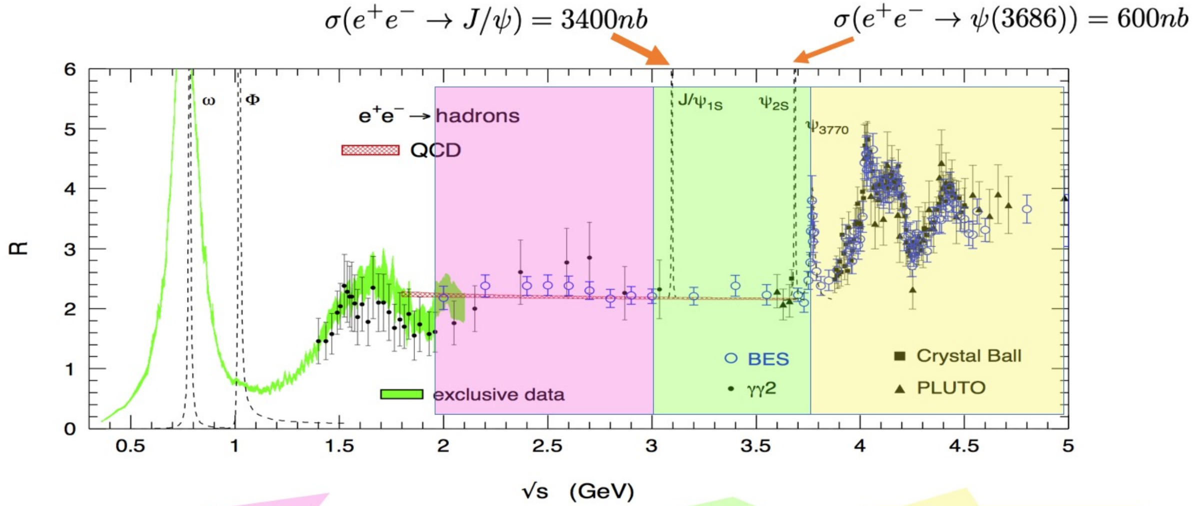
Muon Counter
RPC
Barrel: 9 layers
Endcap: 8 layers
$\sigma_{spatial}$=1.48 cm



Main Drift Chamber
Small cell, 43 layer
σ_{xy}=130 μm
dE/dx~6%
σ_p/p= 0.5% at 1 GeV

Time Of Flight
Plastic scintillator
σ_T(barrel)=80 ps
σ_T(endcap)=110 ps
(update to 65 ps with MRPC)

With 10 billion J/ψ and 2.7 billion $\psi(3686)$ collected at BESIII, $\sim 10^7$ entangled hyperon pairs can be produced, which enables precise studies of the hyperon physics.



- Hadron form factors
- R values and QCD
- Hadronization
- Fragmentation functions
- Nucleon structure

- Light hadron spectroscopy
- Hyperon physics
- Physics with τ lepton

- XYZ particles
- Charm mesons
- Charm baryons

More $\psi(3686)$ data will be taken after the upgrade of BEPCII and BESIII inner tracker.

BESIII: a hyperon factory

10 billion J/ψ events collected:
- **Large Br. in J/ψ decay**
- **Quantum entangled pair productions**
- **High efficiency, background free**

Front. Phys. 12(5), 121301 (2017)
Phys. Rev. D 100, 114005 (2019)

Decay mode	$\mathcal{B}$(units 10^{-4})	Detection efficiency	No. events expected at BESIII
$J/\psi \to \Lambda\bar{\Lambda}$	$19.43 \pm 0.03 \pm 0.33$	40%	3200×10^3
$\psi(2S) \to \Lambda\bar{\Lambda}$	$3.97 \pm 0.02 \pm 0.12$	40%	650×10^3
$J/\psi \to \Xi^0\bar{\Xi}^0$	11.65 ± 0.04	14%	670×10^3
$\psi(2S) \to \Xi^0\bar{\Xi}^0$	2.73 ± 0.03	14%	160×10^3
$J/\psi \to \Xi^-\bar{\Xi}^+$	10.40 ± 0.06	19%	810×10^3
$\psi(2S) \to \Xi^-\bar{\Xi}^+$	2.78 ± 0.05	19%	210×10^3

Hyperon Physics

Hyperon EDM

Hyperon-Nucleon Interactions

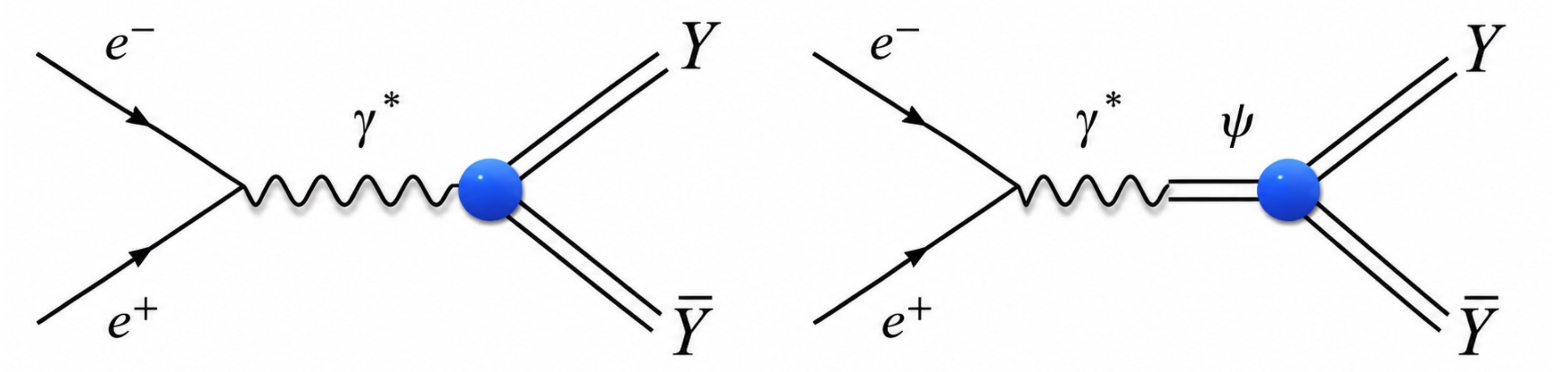
Other Physics

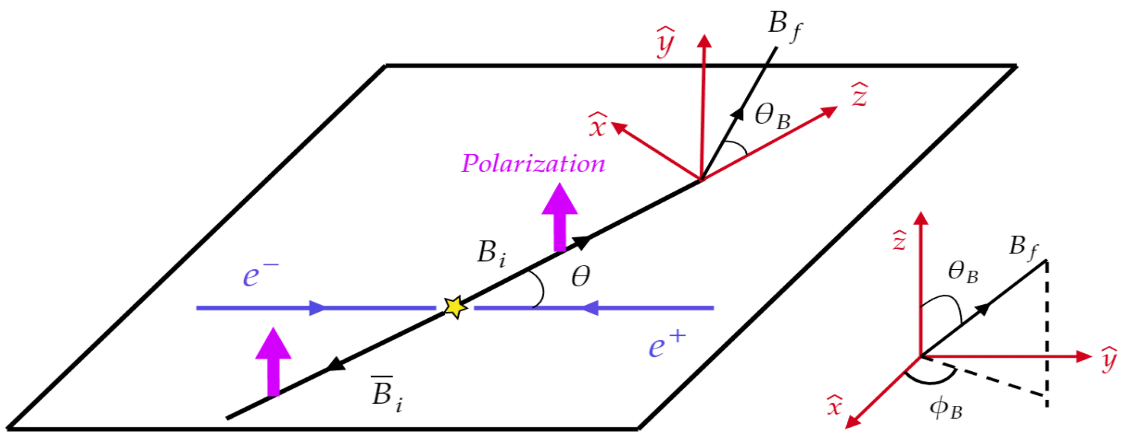
CP Violation in hyperon decay
- **Decay parameter**
- **Decay branching fraction**

Rare decays
- **Radiative decay**
- **Semi-leptonic decay**

Hyperon production
- **Time-like EM FF**
- **Cross Section**

Hyperons production at BESIII



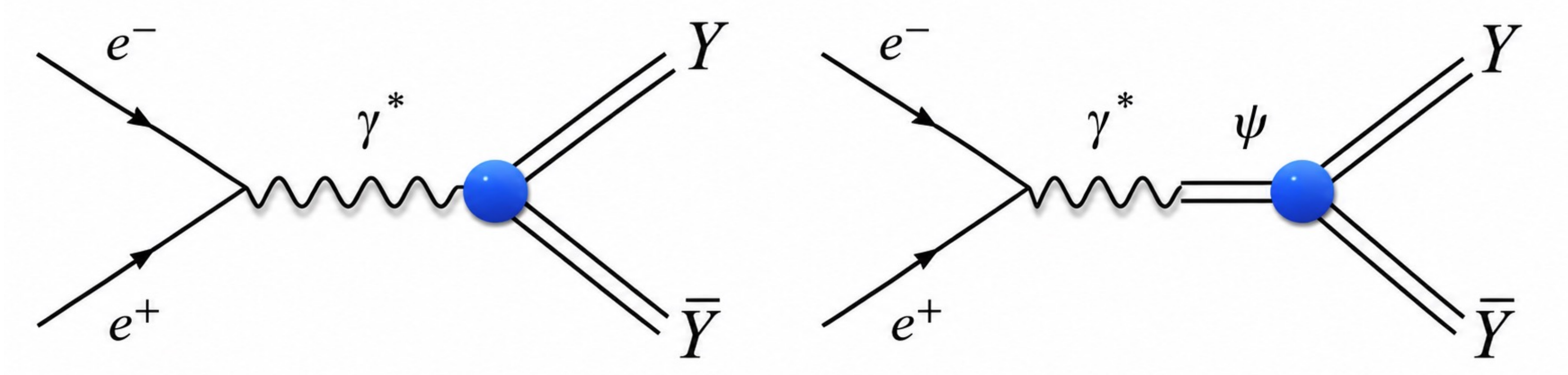


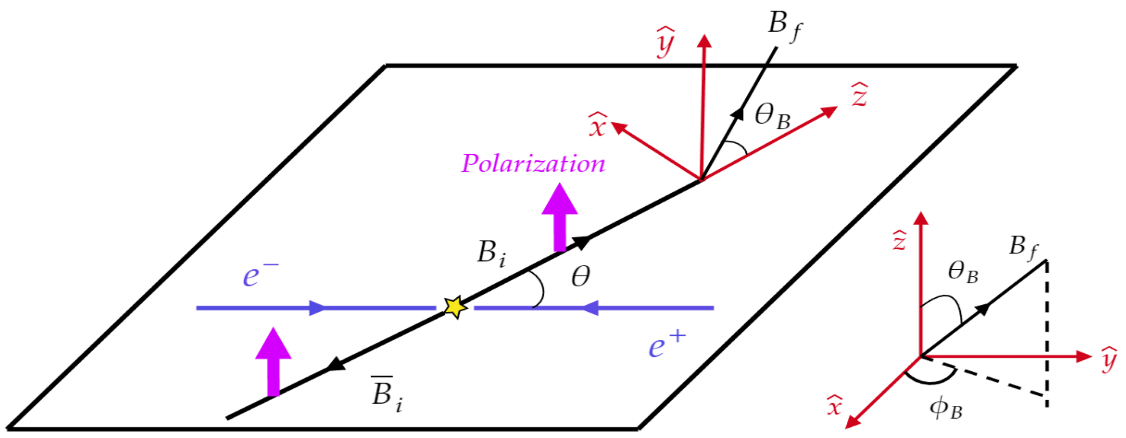
- **The form factors G_E,G_M construct the production parameters:**

$$\alpha_\psi = \frac{s|G_M|^2 - 4M_\Xi^2|G_E|^2}{s|G_M|^2 - 4M_\Xi^2|G_E|^2},$$

$$\Delta\Phi = \arg\left(\frac{G_E}{G_M}\right),$$

Hyperons production at BESIII



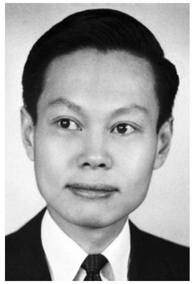


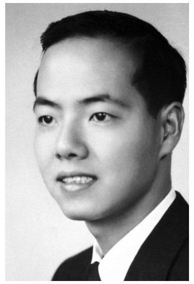
- The non-zero $\Delta\Phi$ represents the transverse polarization.

$$P_y(\cos\theta) = \frac{\sqrt{1-\alpha_\psi^2}\,\sin(\Delta\Phi)\cos\theta\sin\theta}{1+\alpha_\psi\cos^2\theta}$$

CPV in hyperon sector

CP observables in hyperon decays





General Partial Wave Analysis of the Decay of a Hyperon of Spin $\frac{1}{2}$

T. D. LEE* AND C. N. YANG
Institute for Advanced Study, Princeton, New Jersey

(Received October 22, 1957)

Phys. Rev. 108, 1645 (1957)

The amplitude of spin ½ baryon B_i decay to a spin ½ baryon B_f and π:

$$\boldsymbol{\mathcal{A}} \sim S\sigma_0 + P\boldsymbol{\sigma}\cdot\hat{\boldsymbol{n}}$$

The decay parameters are defined as:

$$\alpha_Y = \frac{2\,\mathrm{Re}\left(S^* P\right)}{|S|^2+|P|^2}, \quad \beta_Y = \frac{2\,\mathrm{Im}\left(S^* P\right)}{|S|^2+|P|^2}, \quad \gamma_Y = \frac{|S|^2-|P|^2}{|S|^2+|P|^2}$$

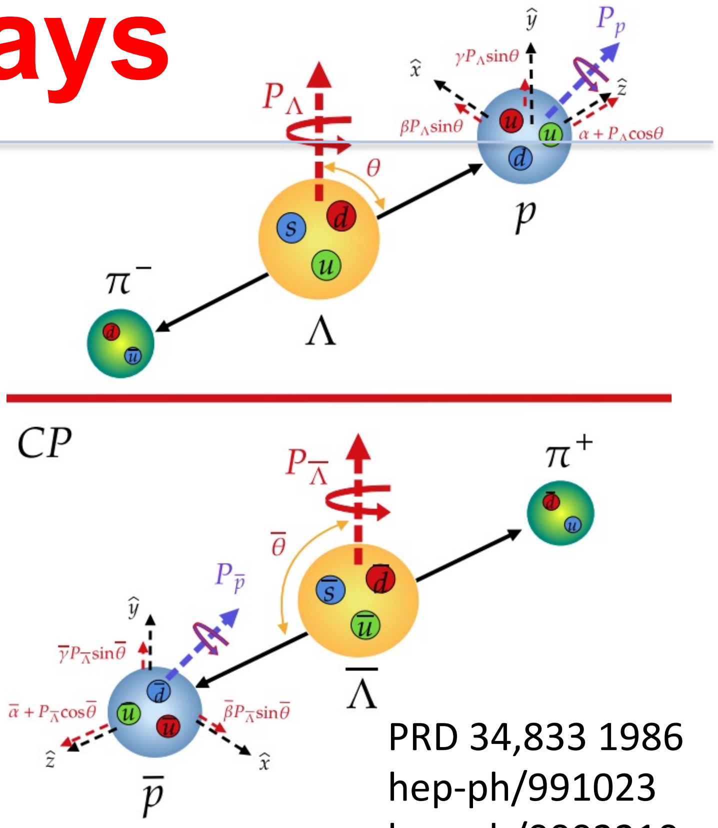
Two complex amplitudes: **ϕ weak phase, δ strong phase**

$$S = \Sigma^i S_i e^{i(\phi_i^S+\delta_i^S)}, \qquad P = \Sigma^i P_i e^{i(\phi_i^P+\delta_i^P)}$$

Under CP transformation:

$$\bar{S} = -\Sigma^i S_i e^{i(-\phi_i^S+\delta_i^S)}, \qquad \bar{P} = \Sigma^i P_i e^{i(-\phi_i^P+\delta_i^P)}$$

If CP conserved: $S \xrightarrow{CP} -S$, $P \xrightarrow{CP} P$ ⇒ $\alpha \xrightarrow{CP} \bar{\alpha} = -\alpha$, $\beta \xrightarrow{CP} \bar{\beta} = -\beta$



PRD 34,833 1986
hep-ph/991023
hep-ph/0002210

CPV observables

$$\Delta = \frac{\Gamma-\bar{\Gamma}}{\Gamma+\bar{\Gamma}}$$

$$A = \frac{\Gamma\alpha + \bar{\Gamma}\bar{\alpha}}{\Gamma\alpha - \bar{\Gamma}\bar{\alpha}} \approx \frac{\alpha+\bar{\alpha}}{\alpha-\bar{\alpha}} + \Delta$$

$$B = \frac{\Gamma\beta + \bar{\Gamma}\bar{\beta}}{\Gamma\beta - \bar{\Gamma}\bar{\beta}} \approx \frac{\beta+\bar{\beta}}{\beta-\bar{\beta}} + \Delta$$

$e^+e^- \to J/\psi \to \Xi^-\bar{\Xi}^+, \Xi^- \to \Lambda(\to p\pi^-)\pi^- + c.c.$

- **The 9 kinematical variables – 9 dimension PHSP**

$$\xi = (\theta_{\Xi}, \theta_{\Lambda}, \phi_{\Lambda}, \theta_{\bar{\Lambda}}, \phi_{\bar{\Lambda}}, \theta_p, \phi_p, \theta_{\bar{p}}, \phi_{\bar{p}})$$

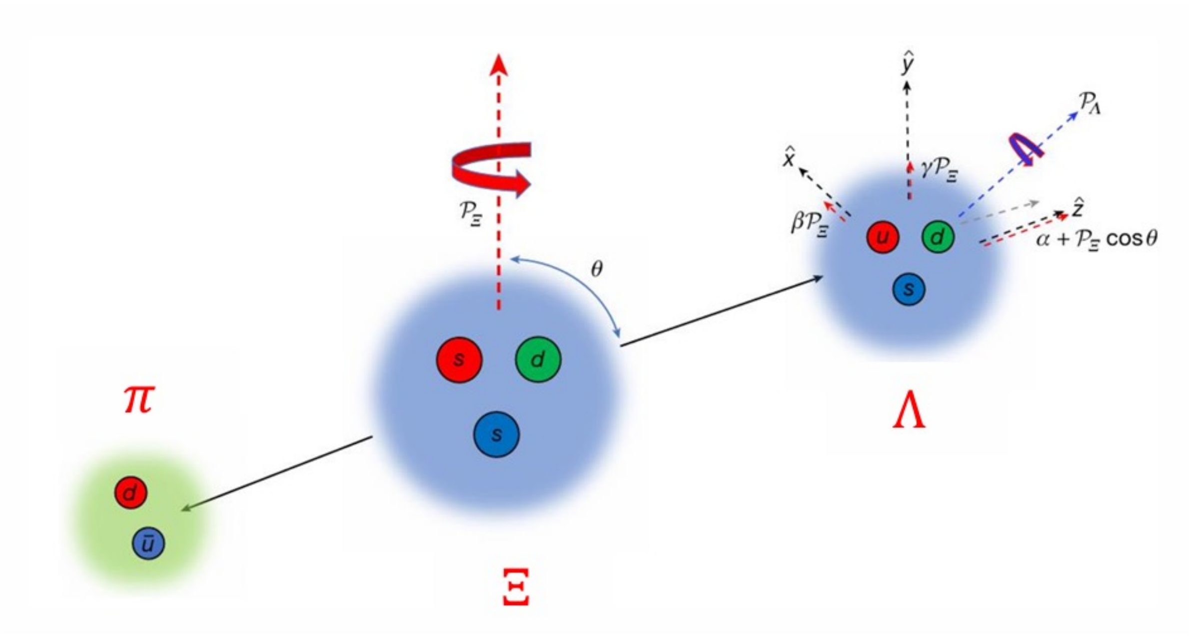
- **The 8 free parameters**

$$\boldsymbol{\omega} = (\alpha_{\psi}, \Delta\Phi, \alpha_{\Xi}, \phi_{\Xi}, \alpha_{\bar{\Xi}}, \phi_{\bar{\Xi}}, \alpha_{\Lambda}, \alpha_{\bar{\Lambda}})$$

Hyperon Production | Hyperon decays

$$W(\xi;\boldsymbol{\omega}) = \sum_{\mu,\bar{\nu}} C_{\mu\bar{\nu}} \sum_{\mu'\bar{\nu}'} a^{\Xi}_{\mu,\mu'} a^{\bar{\Xi}}_{\bar{\nu},\bar{\nu}'} a^{\Lambda}_{\mu',0} a^{\bar{\Lambda}}_{\bar{\nu}',0}$$

Phys. Rev. D 99, 056008 (2019)



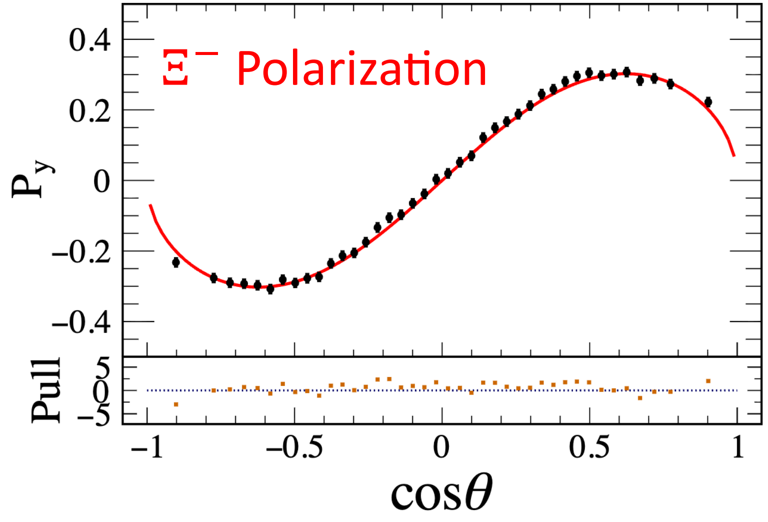
Search for CPV in entangled $\Xi^- - \bar{\Xi}^+$ pairs

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

Parameter	This Letter
α_ψ	$0.5851 \pm 0.0044 \pm 0.0034$
$\Delta\Phi$ (rad)	$1.2205 \pm 0.0159 \pm 0.0056$
α_Ξ	$-0.3813 \pm 0.0026 \pm 0.0005$
$\bar{\alpha}_\Xi$	$0.3873 \pm 0.0026 \pm 0.0006$
ϕ_Ξ (rad)	$-0.0008 \pm 0.0072 \pm 0.0010$
$\bar{\phi}_\Xi$ (rad)	$0.0020 \pm 0.0072 \pm 0.0006$
α_Λ	$0.7434 \pm 0.0039 \pm 0.0015$
$\bar{\alpha}_\Lambda$	$-0.7478 \pm 0.0038 \pm 0.0015$
$(\xi_P - \xi_S) \times 10^{-2}$ (rad)	$-0.2 \pm 1.2 \pm 0.1$
$(\delta_P - \delta_S) \times 10^{-2}$ (rad)	$0.3 \pm 1.2 \pm 0.2$
$A_{CP}^{\Xi} \times 10^{-3}$	$-7.8 \pm 4.8 \pm 0.8$
$\Delta\phi_{CP}^{\Xi} \times 10^{-3}$ (rad)	$0.6 \pm 5.1 \pm 0.2$
$A_{CP}^{\Lambda} \times 10^{-3}$	$-2.9 \pm 4.3 \pm 0.7$
$\langle\alpha_\Xi\rangle$	$-0.3843 \pm 0.0018 \pm 0.0005$
$\langle\phi_\Xi\rangle$ (rad)	$-0.0014 \pm 0.0050 \pm 0.0008$
$\langle\alpha_\Lambda\rangle$	$0.7456 \pm 0.0022 \pm 0.0014$

Phys. Rev. Lett. 136, 201802 (2026)

580K $\Xi^- - \bar{\Xi}^+$ pairs with > 99% purity



The precision of the asymmetry parameter: 10^{-3}

Measurement of the weak (CPV) phase difference in Ξ^- decays, most precise results in weakly baryon decays

$(\xi_P - \xi_S)_{SM} = (-2.1 \pm 1.7) \cdot 10^{-4}$ rad [PRD105(2022)116022]

Three CP tests

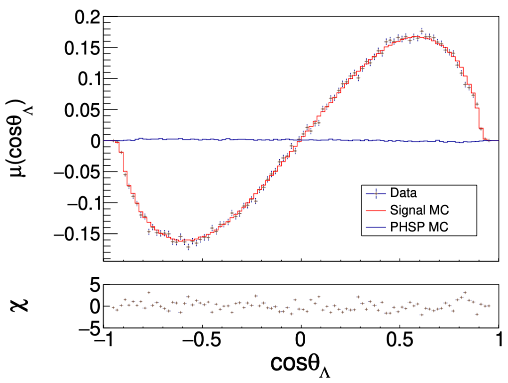
The precision of $\langle\alpha_\Lambda\rangle$ obtained from 580K Ξ^- is comparable to that obtained from the measurement of 3.2 million Λ decays!

Hyperon polarization

$$\mu(\cos\theta_\Lambda) \approx \frac{1+\alpha_{J/\psi}\cos^2\theta_\Lambda}{3+\alpha_{J/\psi}} P_y(\theta_\Lambda)$$

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

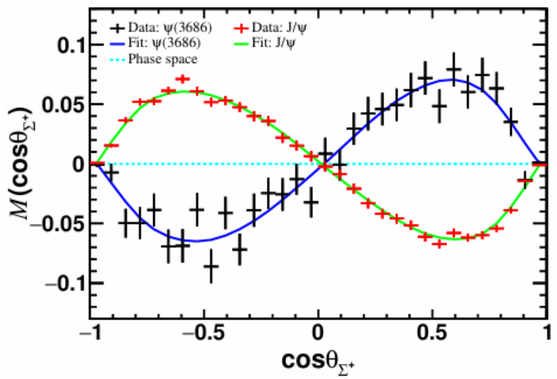
PRL129, 131801(2022)



$\Delta\Phi = (0.7521 \pm 0.0042 \pm 0.0066)$ rad

$\psi \to \Sigma^+\bar{\Sigma}^-$

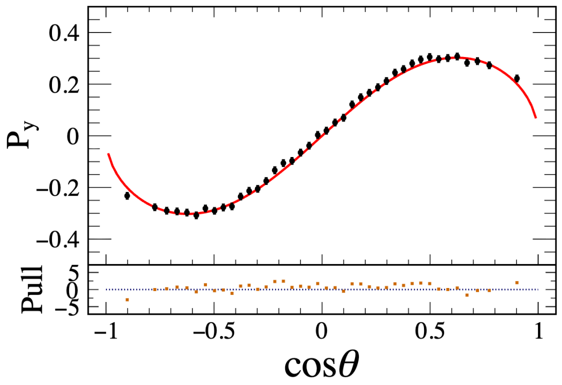
PRL135, 141804 (2025)



$\Delta\Phi(J/\psi) = (-0.2744 \pm 0.0033 \pm 0.0010)$rad
$\Delta\Phi(\psi(2S)) = (0.427 \pm 0.022 \pm 0.003)$rad

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

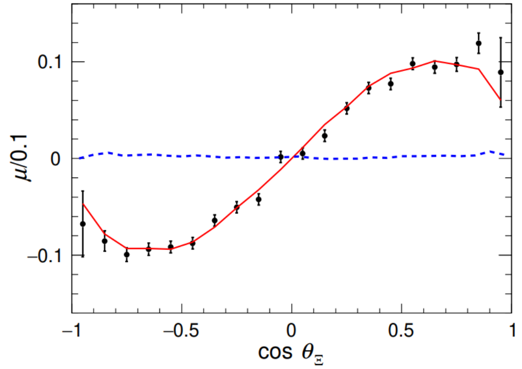
Phys. Rev. Lett. 136, 201802 (2026)



$\Delta\Phi = (1.2205 \pm 0.0159 \pm 0.0056)$ rad

$J/\psi \to \Xi^0\bar{\Xi}^0$

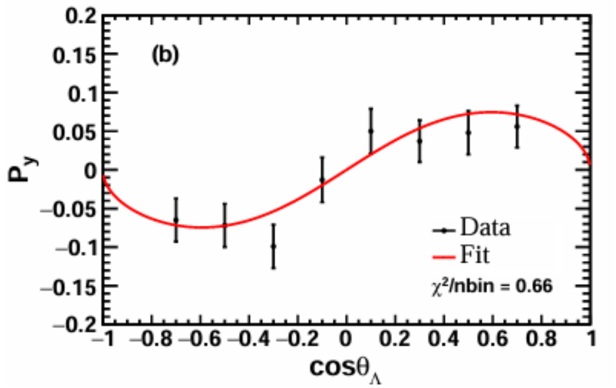
Phys. Rev. D 108, L031106 (2023)



$\Delta\Phi = (1.168 \pm 0.019 \pm 0.018)$ rad

$\psi(3686) \to \Lambda\bar{\Lambda}$

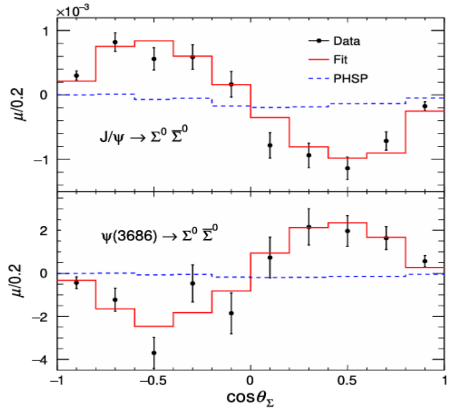
arXiv:2509.15276



$\Delta\Phi = (0.366 \pm 0.064 \pm 0.013)$ rad

$\psi \to \Sigma^0\bar{\Sigma}^0$

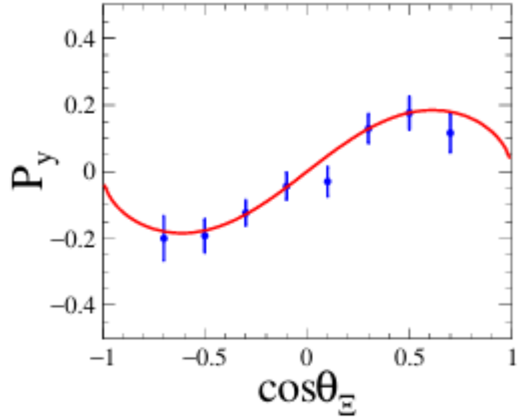
Phys. Rev. Lett. 133 (2024) 10, 101902



$\Delta\Phi(J/\psi) = (-0.0828 \pm 0.0068 \pm 0.0033)$rad
$\Delta\Phi(\psi(2S)) = (0.512 \pm 0.085 \pm 0.034)$rad

$\psi(2S) \to \Xi^-\bar{\Xi}^+$

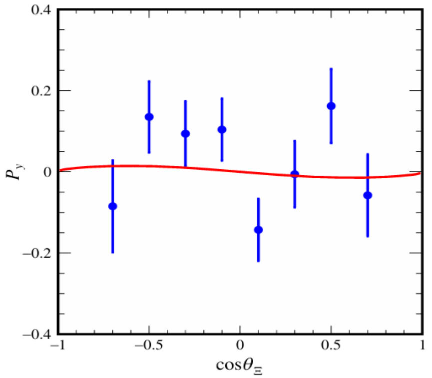
Phys. Rev. D 106, L091101 (2022)



$\Delta\Phi = (0.667 \pm 0.111 \pm 0.058)$ rad

$\psi(3686) \to \Xi^0\bar{\Xi}^0$

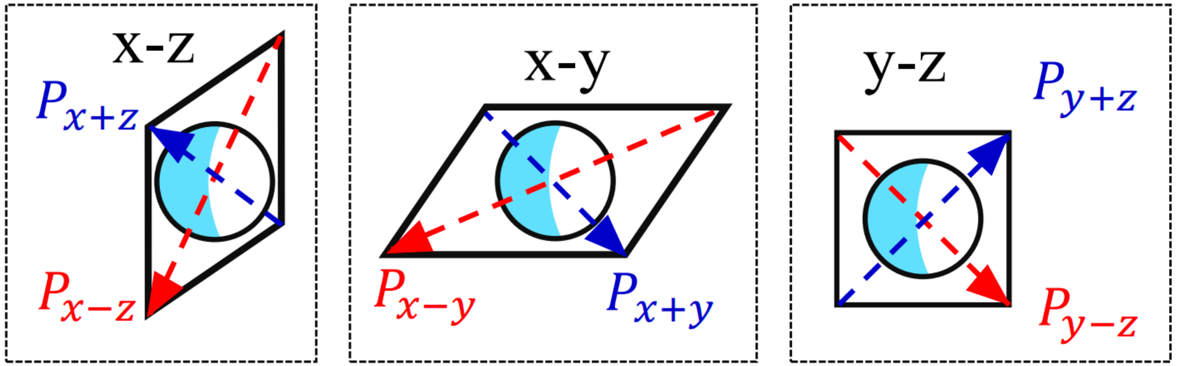
Phys. Rev. D 108, L011101 (2023)



$\Delta\Phi = (-0.050 \pm 0.150 \pm 0.020)$ rad

First complete measurement of $\Xi(1530)^0$ structure

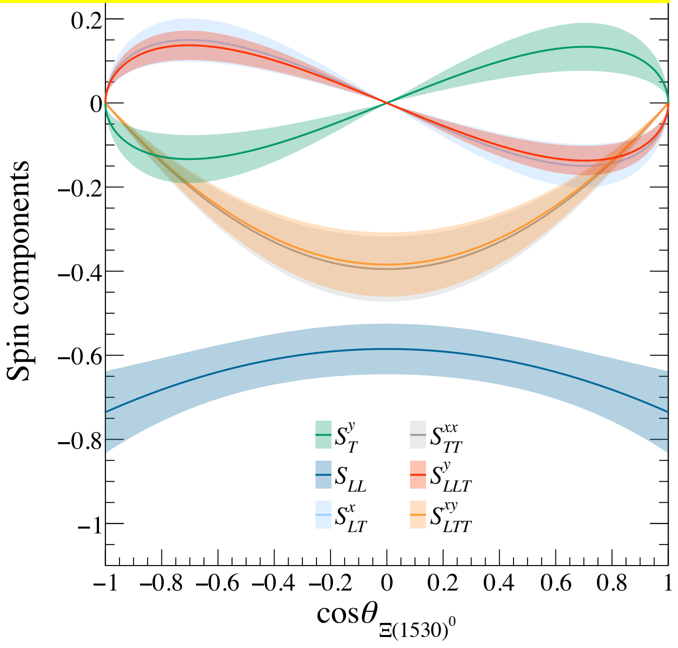
- Spin-3/2 particles exhibit not only vector polarization but also tensor polarization.

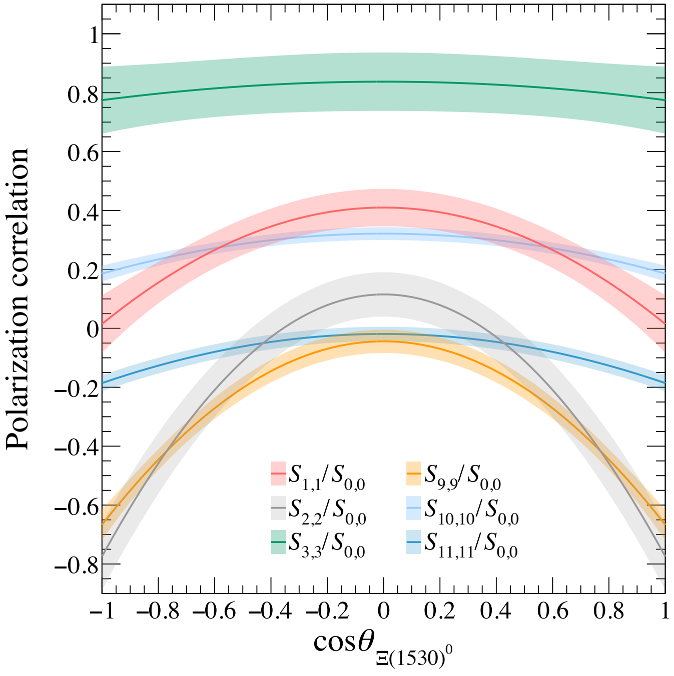


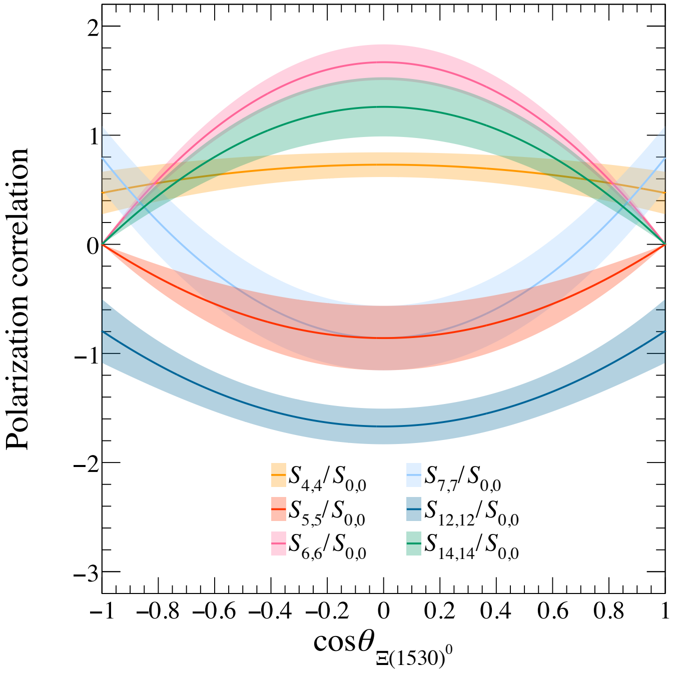
- Four independent form factors: electric charge (G_E), magnetic dipole (G_M), electric quadrupole (G_Q), and magnetic octupole (G_O) moments.
- A more detailed picture of the internal structure of baryons.

α_ψ	$0.02 \pm 0.06 \pm 0.06$	$\lvert G_E \rvert$	$0.0035 \pm 0.0006 \pm 0.0004$
α_1	$-0.42 \pm 0.08 \pm 0.05$	$\lvert G_M \rvert$	$0.0056 \pm 0.0006 \pm 0.0003$
α_2	$0.75 \pm 0.06 \pm 0.06$	$\lvert G_Q \rvert$	$0.0129 \pm 0.0007 \pm 0.0005$
ϕ_1 (rad)	$-1.81 \pm 0.13 \pm 0.07$	$\lvert G_O \rvert$	$0.0039 \pm 0.0002 \pm 0.0001$
ϕ_3 (rad)	$2.37 \pm 0.08 \pm 0.05$		
ϕ_4 (rad)	$1.02 \pm 0.15 \pm 0.08$		

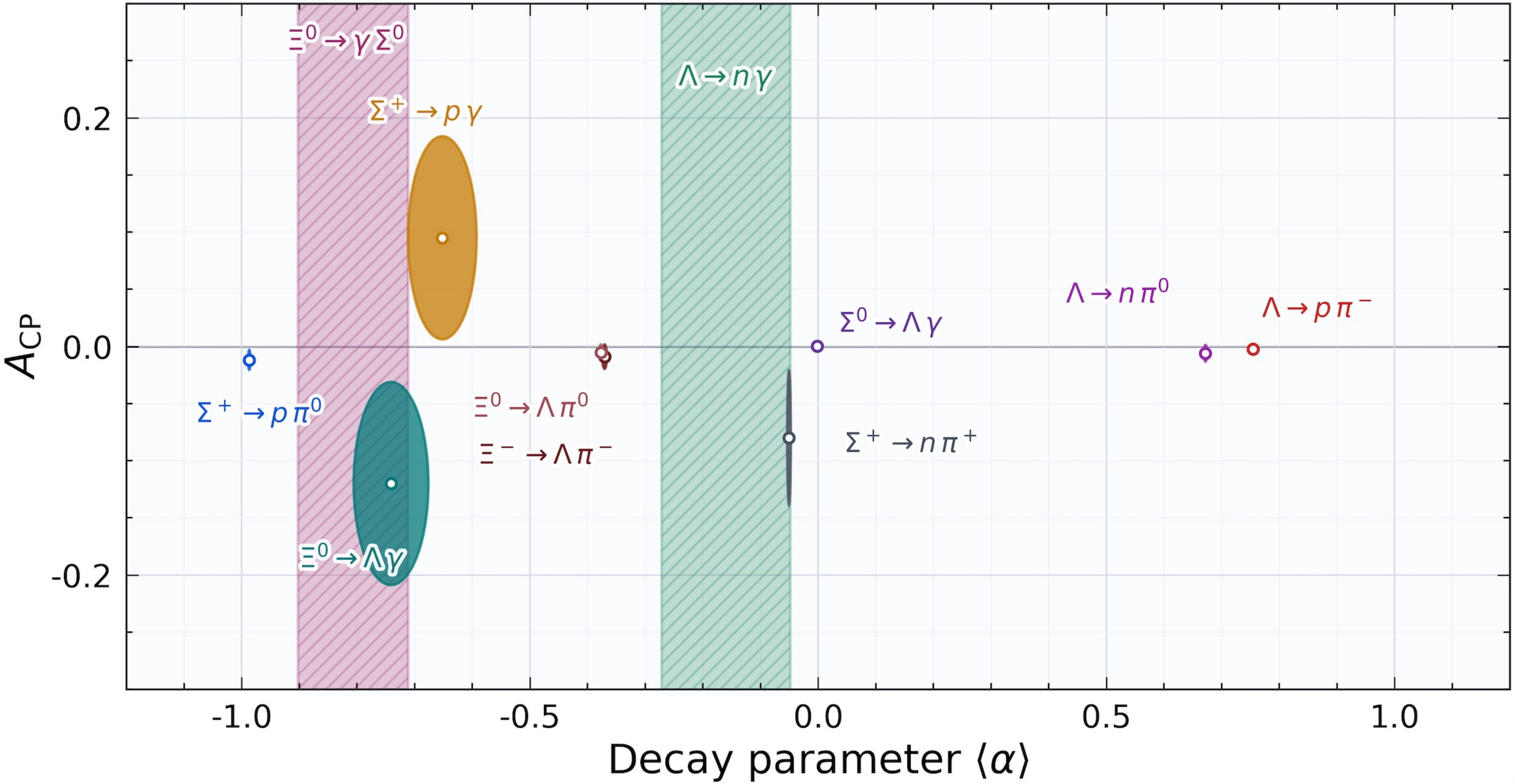
arXiv: 2601.12293 (accepted by PRL)





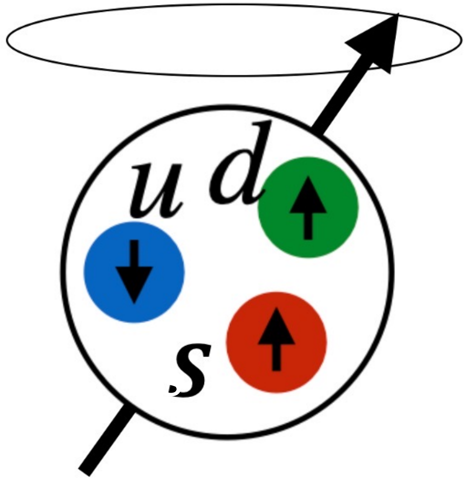


Summary of BESIII achievement on hyperon decay



Electric Dipole Moment

- Definition in the ensemble of particles: Λ, Σ, Ξ



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

MDM: $\boldsymbol{\mu} = g\mu_B\, \boldsymbol{s}/2$

Spin polarization vector:

$\boldsymbol{s} = \mathrm{Tr}[\rho\boldsymbol{\sigma}] = \frac{2}{\hbar} < \hat{\boldsymbol{S}} >$

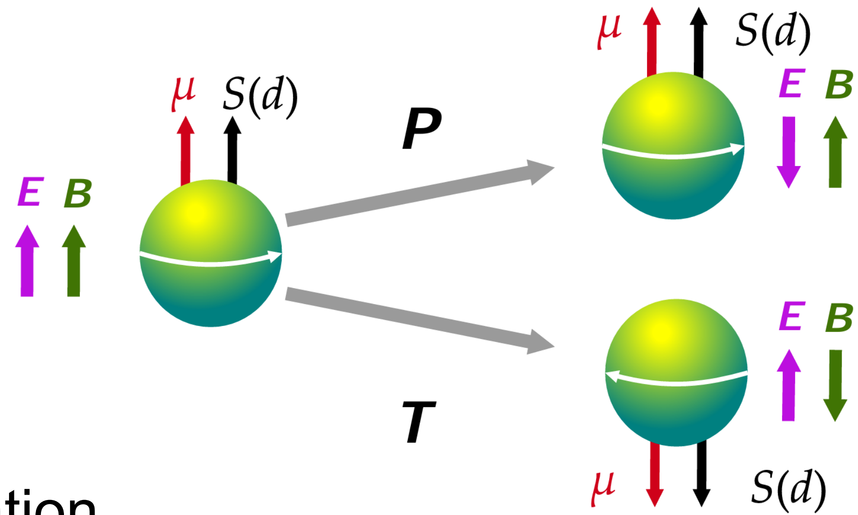
Magneton: μ_B

Gyro-electric(magnetic) factor: $d(g)$

- Interaction with EM field

$$\mathcal{H} = -\boldsymbol{\mu} \cdot \boldsymbol{B} - \boldsymbol{\delta} \cdot \boldsymbol{E}$$

$$\mathcal{H} \xrightarrow{\mathrm{P,T}} \mathcal{H} = -\boldsymbol{\mu} \cdot \boldsymbol{B} \boxed{+ \boldsymbol{\delta} \cdot \boldsymbol{E}}$$



Non-zero EDM is a signal of P/T, and CP violation

Why EDM

- Big matter and anti-matter asymmetry founded in the universe.

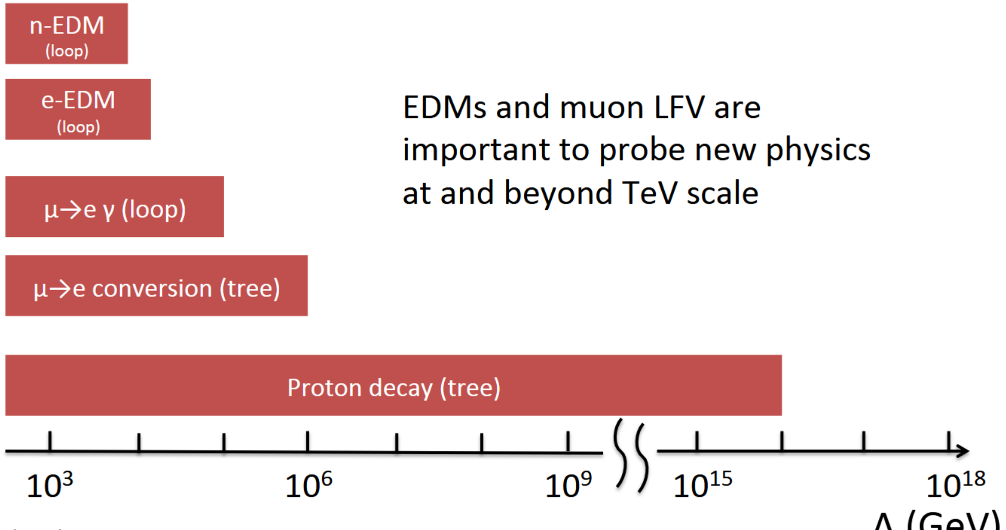
$$(n_B - n_{\bar{B}})/n_\gamma|_{CMB} = (6.08 \pm 0.09)\times 10^{-10}$$

- CP violation has been founded at K, B, D meson system, but not enough to explain matter dominant universe. New CP violation sources beyond SM are needed to explain predominance of matter over antimatter.

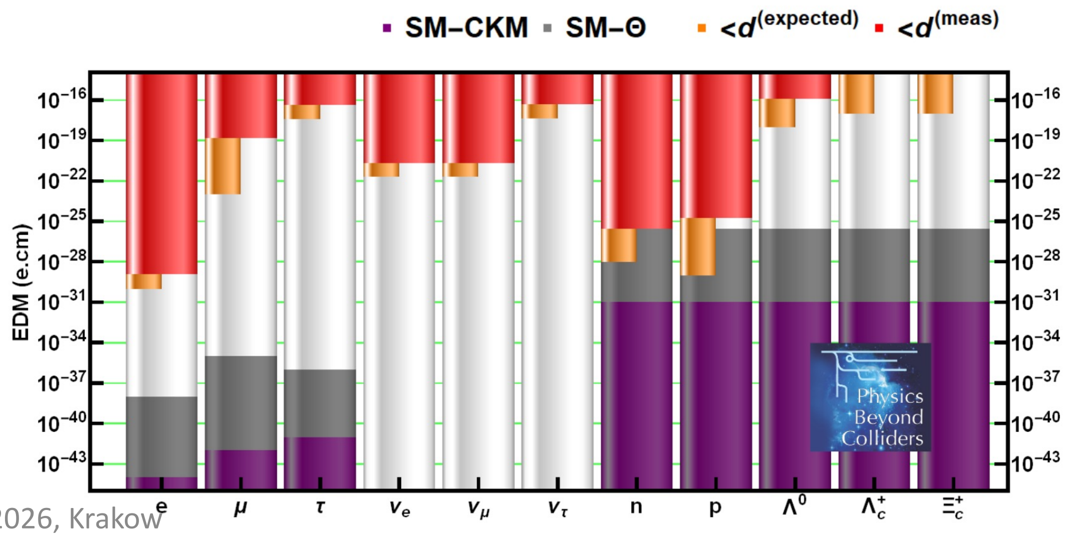
$$\text{SM prediction:} \quad \hat{d}_{CP} = \frac{d_{CP}}{D^{12}} \sim 10^{-18} \ll 10^{-10}$$

- EDM is one of the few low energy measurements sensitive to fundamental particle physics at a scale of few TeV and above.

$$d_e \sim e\frac{m_e}{M^2} = 10^{-23} e \text{ cm} \left(\frac{1 \text{ TeV}}{M}\right)^2$$



EDMs and muon LFV are important to probe new physics at and beyond TeV scale



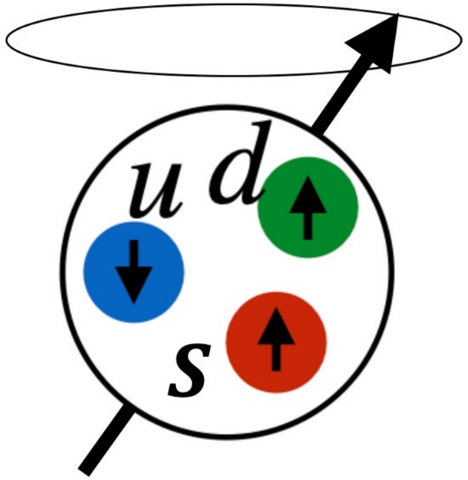
How to access EDM

- EDM and MDM extracted from spin procession in EM field

$$\frac{ds}{dt} = s \times (\mathbf{\Omega}_{\mathbf{MDM}} + \mathbf{\Omega}_{\mathbf{EDM}} + \mathbf{\Omega}_{\mathbf{TH}})$$

$$\mathbf{\Omega}_{\mathbf{MDM}} = \boxed{\frac{g\mu_B}{\hbar}}\left(\mathbf{B} - \frac{\gamma}{\gamma+1}(\boldsymbol{\beta}\cdot\mathbf{B})\boldsymbol{\beta} - \boldsymbol{\beta}\times\mathbf{E}\right)$$

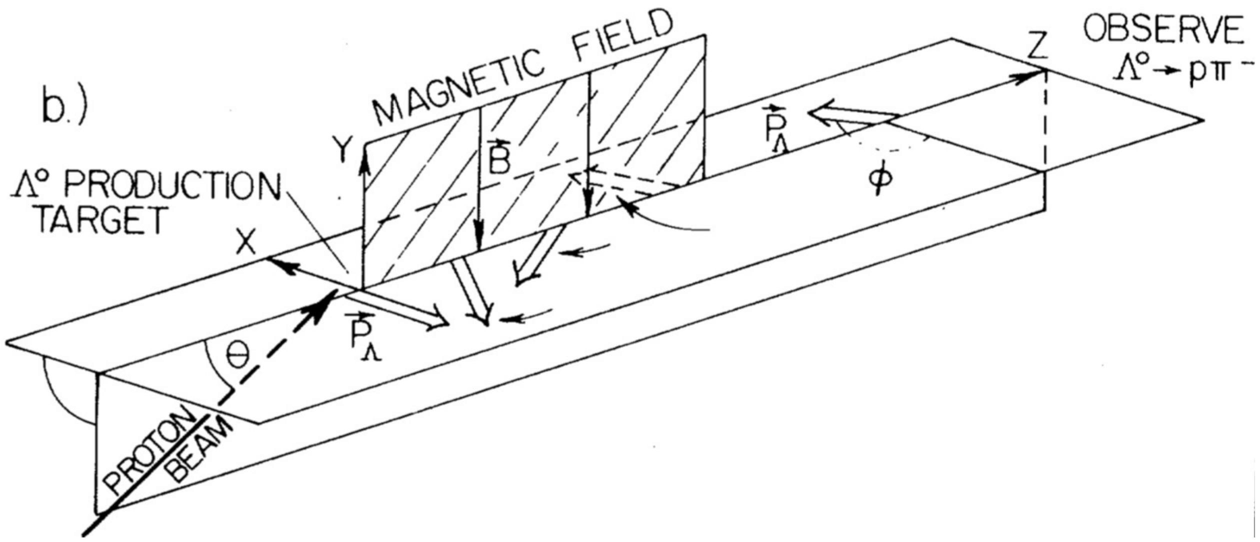
$$\mathbf{\Omega}_{\mathbf{EDM}} = \boxed{\frac{d\mu_B}{\hbar}}\left(\mathbf{E} - \frac{\gamma}{\gamma+1}(\boldsymbol{\beta}\cdot\mathbf{E})\boldsymbol{\beta} - \boldsymbol{\beta}\times\mathbf{B}\right)$$



- Experimental requirement
  - ✓ Sizable polarized particle source
  - ✓ Enough fight length/intense EM field for precession
  - ✓ Excellent detector for polarization measurement via angular analysis

Significant challenge for short-lived particles, i.e. $\Lambda(10^{-10}s), \Sigma^0(10^{-20}s)$

Λ EDM/MDM measurement at Fermilab



Phys. Rev. D23 (1981) 814

$d_\Lambda < 1.5\times 10^{-16} e$ cm @ 95% CL

Phys. Rev. Lett. 41 (1978) 1348

$\mu_\Lambda = (-0.613 \pm 0.004)\mu_N$

- Last direct measurement in 80's @Fermilab
- Fixed-target experiment with 300GeV proton beam on Be
- Magnet: 5m, 15Tm
- Reconstructed 3×10^6 $\Lambda \to p\pi^-$ decays
- Small transverse polarization ~8%

sensitivity depend on polarization and difficult to improve to 10^{-18} e cm

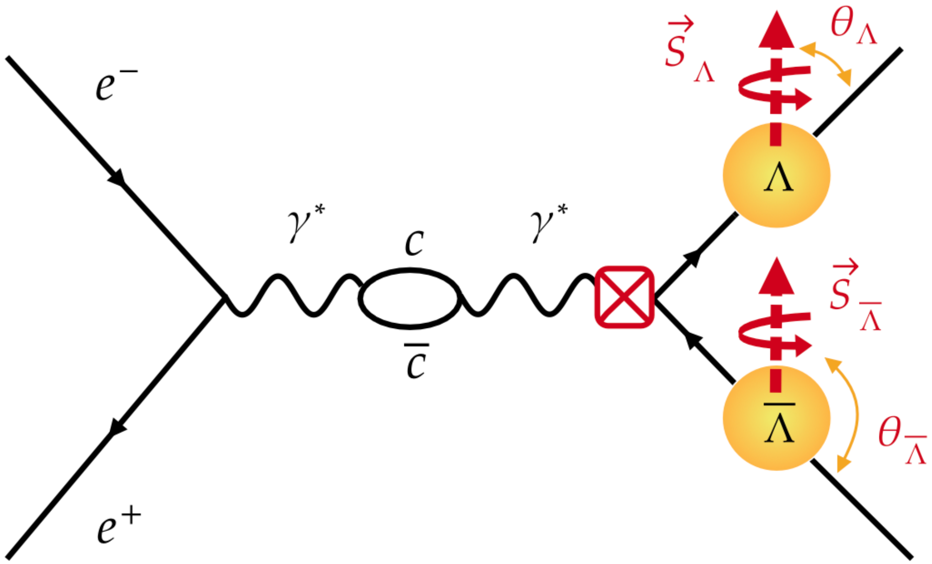
Indirect access to EDM

PHYSICAL REVIEW D VOLUME 47, NUMBER 5 1 MARCH 1993

CP violation in $J/\psi \to \Lambda\bar{\Lambda}$

Xiao-Gang He, J. P. Ma, and Bruce McKellar
Research Center for High Energy Physics, School of Physics, University of Melbourne, Parkville, Victoria 3052 Australia
(Received 19 November 1992)

We study CP violation in $J/\psi \to \Lambda\bar{\Lambda}$ decay. This decay provides a good place to look for CP violation. Some observables are very sensitive to the Λ electric dipole moment d_Λ and therefore can be used to improve the experimental upper bound on d_Λ. CP violations in the lepton pair decays of J/ψ and Υ are also discussed.



$$L_{c-\Lambda} = -\frac{2}{3M^2} e d_\Lambda (p_1^\mu - p_2^\mu)\bar{c}\gamma_\mu c \bar{\Lambda} i\gamma_5 \Lambda$$

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

measure time-like dipole form factor with $q = m_{J/\psi}$

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

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

Λ EDM measurement at BESIII

arXiv:2506.19180

- 3M $J/\psi \to \Lambda\bar{\Lambda}$ 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

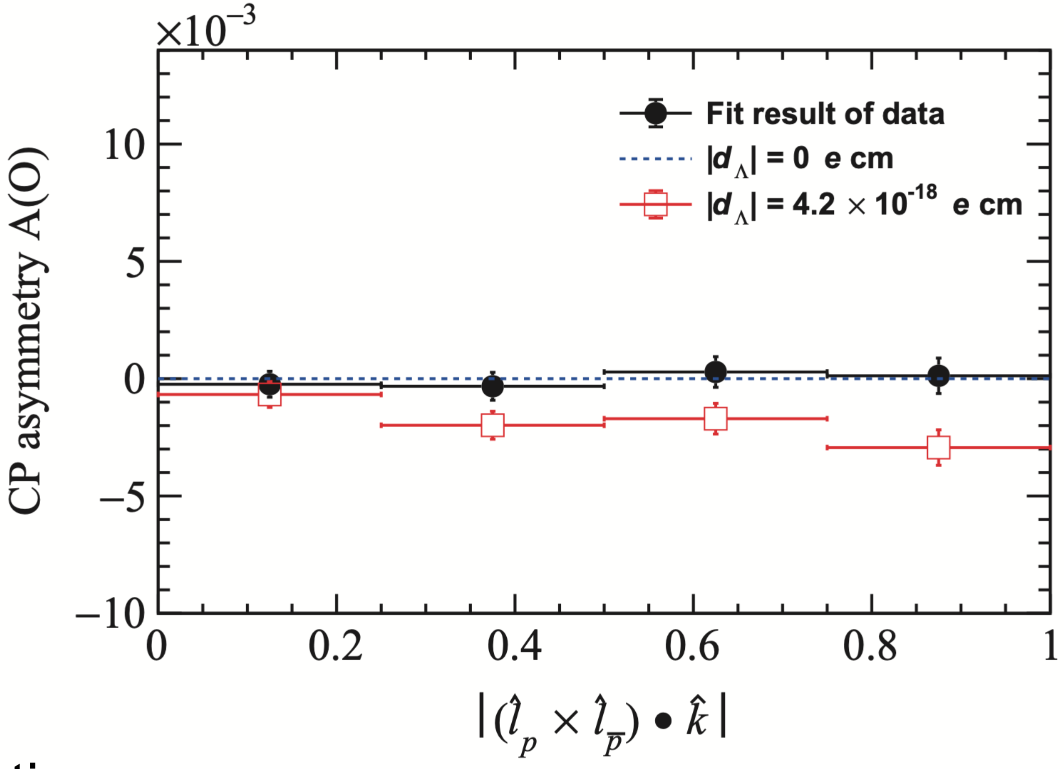
EDM visualization

arXiv:2506.19180

- Non-zero EDM could affect angular distribution, asymmetry visualized in 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

- Also can be visualized in another angular distribution, with different senstivity

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

Complementary to neutron EDM

Phys.Rev.Lett. 136 (2026) 051902

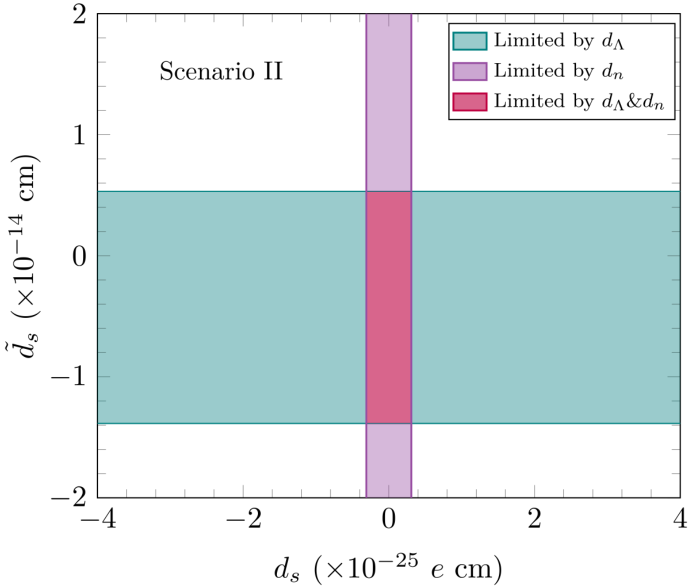
Perturbative QCD Prediction of the Hyperon Electric Dipole Moment from *CP*-Violating Dipole Interactions

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

(Received 15 October 2025; revised 4 January 2026; accepted 12 January 2026; published 4 February 202

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



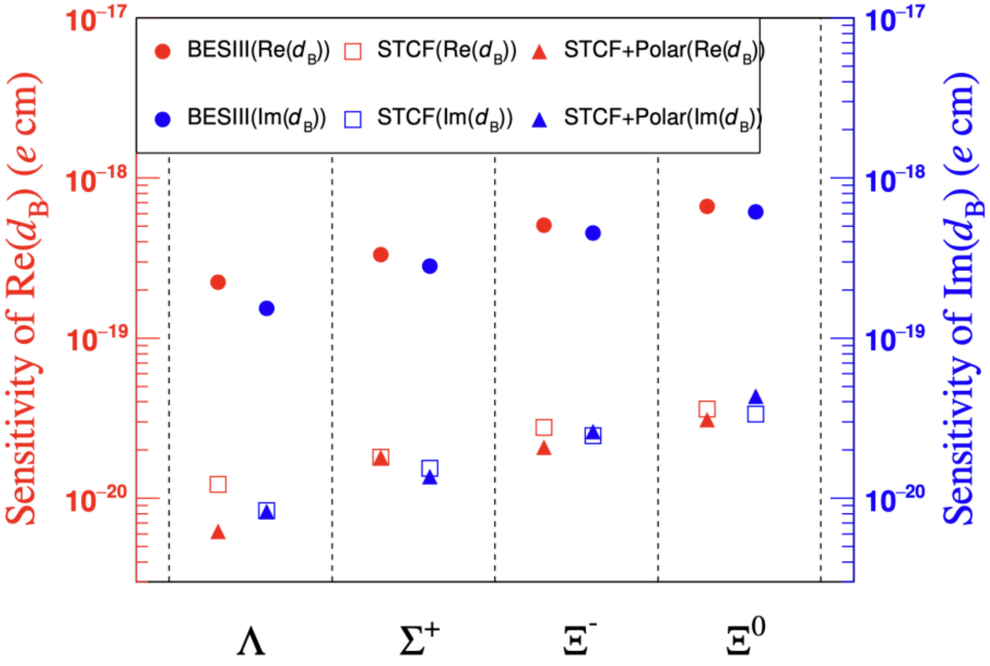
$$|\tilde{d}_s| \lesssim 1.4 \times 10^{-14}\ \text{cm}$$

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

$$d_n = -(0.20 \pm 0.01) d_u + (0.78 \pm 0.03) d_d + (0.0027 \pm 0.016) d_s - (0.55 \pm 0.28) e\tilde{d}_u - (1.1 \pm 0.55) e\tilde{d}_d$$

Sensitivities of hyperon EDM at BESIII

reminder: $H_T = \frac{2e}{3M_{J/\psi}^2} g_V d_B$



(a)Sensitivity of $Re(d_B)$ and $Im(d_B)$

J. Fu, H.B. Li, J. Wang, F. Yu, and J. Zhang, PhysRevD.108.L091301

SM: $\sim 10^{-26}$ e cm

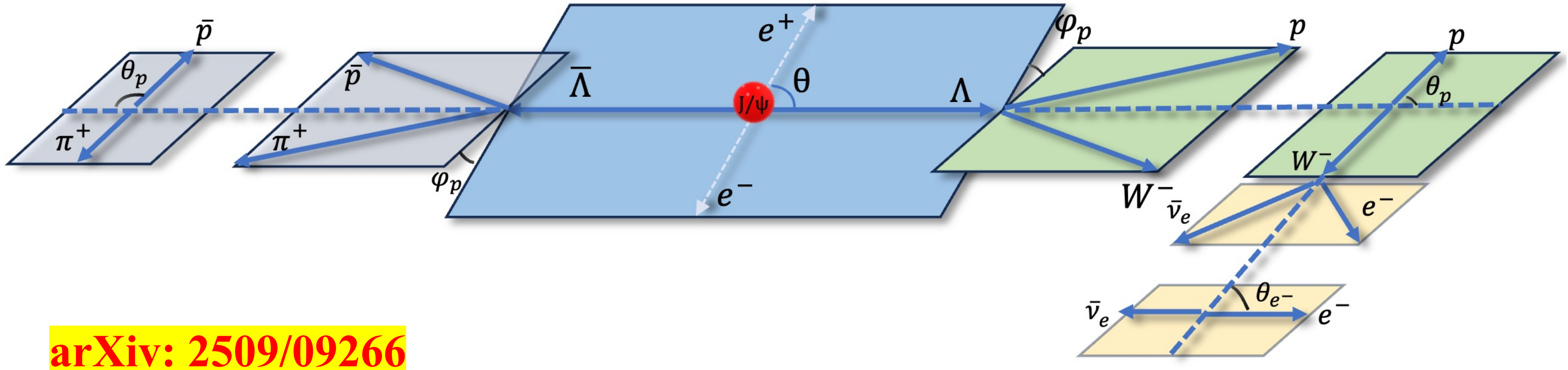
BESIII: milestone for hyperon EDM measurement
Λ 10^{-19}e cm (FermiLab 10^{-16} e cm)
first achievement for Σ^+,Ξ^- and Ξ^0 at level of 10^{-19}e cm
a litmus test for new physics

STCF: improved by 2 order of magnitude

Hyperon rare decay

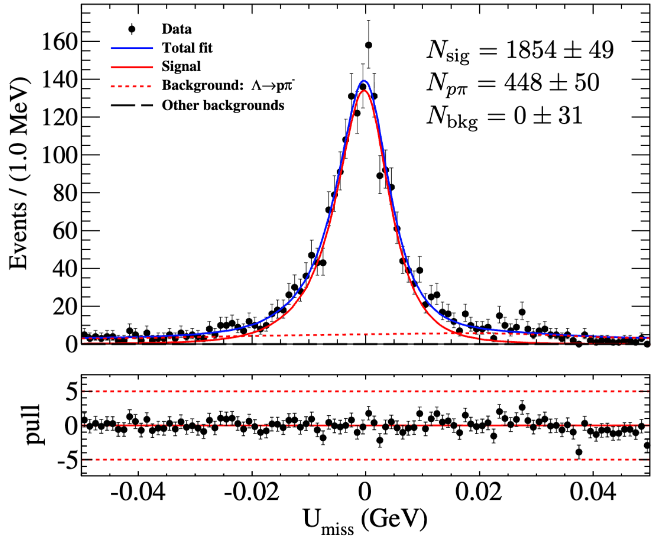
Hyperon semi-leptonic decay: $\Lambda \to p e \bar{\nu}_e$

See Varvara's talk



arXiv: 2509/09266

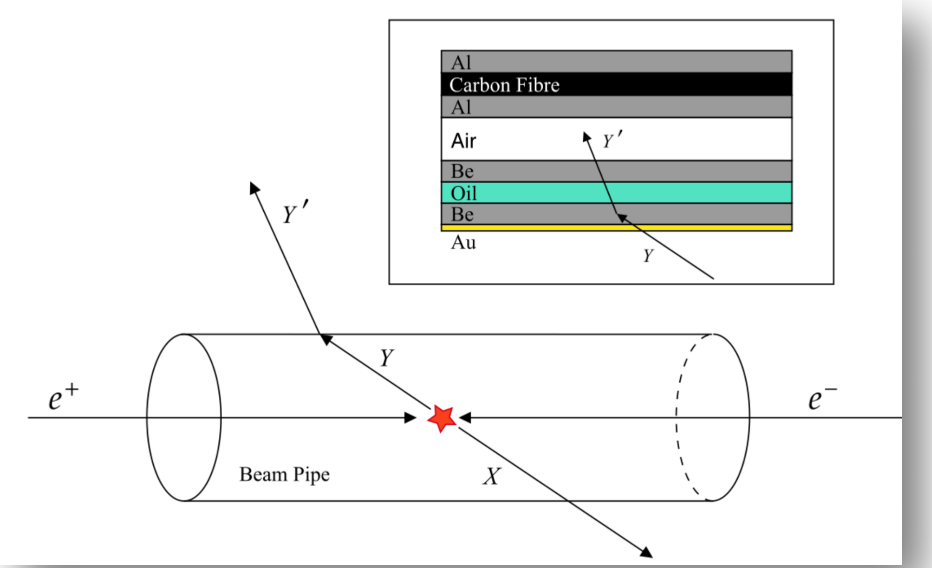
Observable	This work	Previous result	Refs.
$\mathcal{B}(\Lambda \to p e^- \bar{\nu}_e)$	$(8.16 \pm 0.22 \pm 0.15) \times 10^{-4}$	$(8.34 \pm 0.14) \times 10^{-4}$	[8]
g_{av}^-	$0.742^{+0.075}_{-0.057} \pm 0.009$	0.718 ± 0.015	[8]
g_{av}^+	$-0.706^{+0.069}_{-0.073} \pm 0.014$	–	
$\langle g_{av} \rangle$	$0.729^{+0.048}_{-0.047} \pm 0.007$	–	
g_w^-	$0.93 \pm 0.51 \pm 0.17$	0.15 ± 0.30	[12]
g_w^+	$0.89 \pm 0.49 \pm 0.20$	–	
$\langle g_w \rangle$	$0.89 \pm 0.35 \pm 0.14$	–	
$\lvert V_{us} \rvert_{\mathrm{SU(3)}}$	0.2199 ± 0.0094	0.2224 ± 0.0034	[9, 34]
$\lvert V_{us} \rvert_{\mathrm{LQCD}}$	0.2332 ± 0.0042		
$\lvert V_{us} \rvert \cdot \sqrt{f_1^2 + 3g_1^2}$	0.4543 ± 0.0076	–	
$\langle g_{av} \rangle$	$0.706^{+0.089}_{-0.086}$	–	
$\langle g_w \rangle$	$0.77^{+0.53}_{-0.49}$	–	
$\langle g_{av2} \rangle$	$-0.19^{+0.65}_{-0.63}$	–	



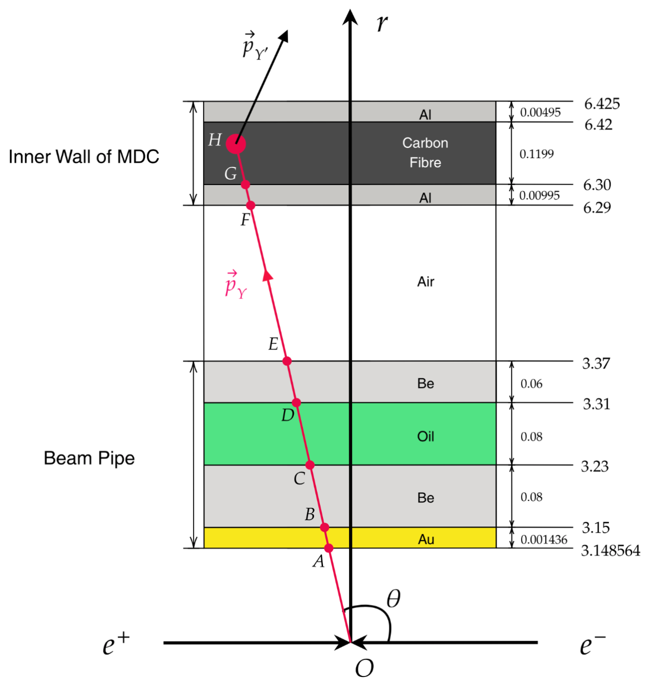
- Based on 10 billion J/ψ
- First measurement of absolute branching fraction
- First measurement of Λ weak electricity coupling g_2/f_1
- A hyperon-based route to $|V_{us}|$, complementary to kaon decays

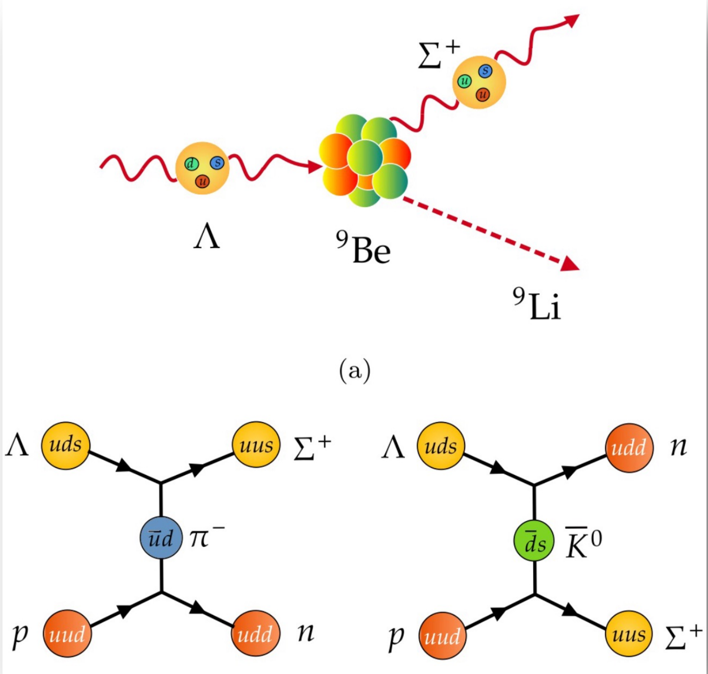
Hyperon-Nucleon interaction

Hyperon nucleon interaction



Hyperon pairs produced in e+e- collision inside the beam pipe



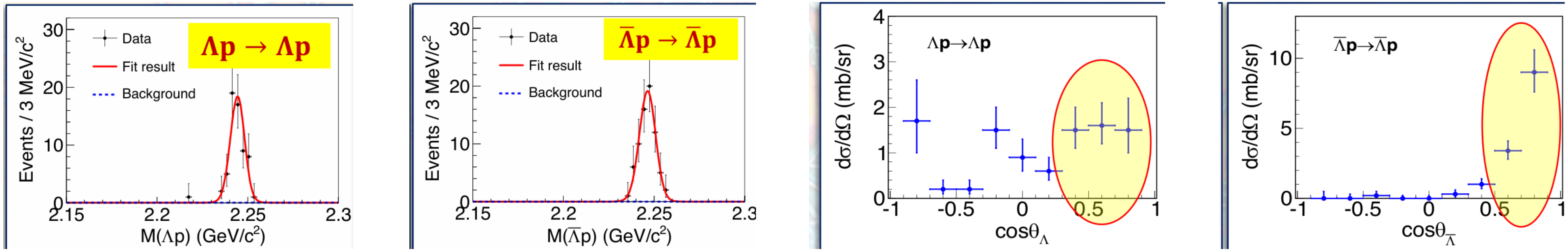


Material of the beam pipe:
Gold (Au)
Beryllium (Be)
Oil ($^{12}\mathrm{C}$: $^{1}\mathrm{H} = 1:2.13$)

An example: Lambda hyperons interact with Be nucleus

PRL 127, 012003 (2021)
Chinese Physics C Vol. 48, No. 7 (2024) 073003

Observation anti-hyperon elastic scattering



BESIII: PRL 132, 231902 (2024)

$$\sigma(\Lambda p \to \Lambda p) = (12.2 \pm 1.6_{stat} \pm 1.1_{sys})\ \text{mb and}$$
$$\sigma(\bar{\Lambda} p \to \bar{\Lambda} p) = (17.5 \pm 2.1_{stat} \pm 1.6_{stat})\ \text{mb}$$

- Total elastic cross sections measured in $-0.9 \leq \cos\theta_\Lambda \leq 0.9$
- $\bar{\Lambda}$p → $\bar{\Lambda}$p is observed for the first time
- Λp shows a slight forward tendency; $\bar{\Lambda}$p shows a strong forward peak

First observation of antihyperon-proton annihilation

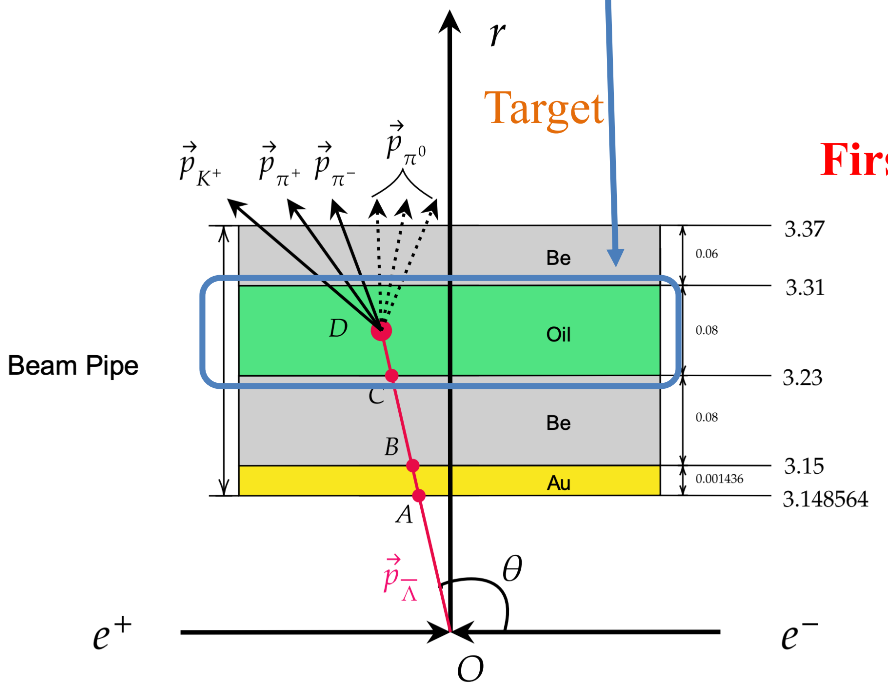
Reaction chain: $J/\psi \to \Lambda\bar{\Lambda}$, $\bar{\Lambda} + p \to K^+\pi^+\pi^- + k\pi^0$ $(k = 1,2,3)$

BESIII: PRL 136, 171904 (2026)

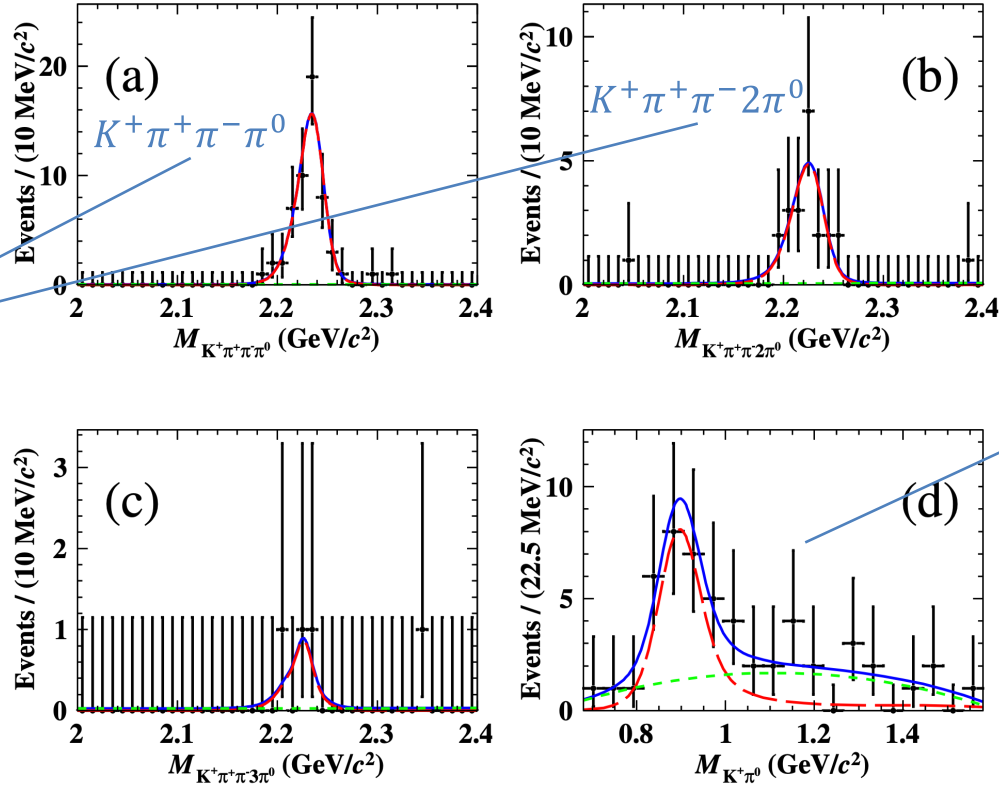
Two-body decay, $P_{\bar{\Lambda}} \approx 1.074$ GeV/c

hydrogen in the cooling oil, at rest protons

The center-of-mass energy of the incident $\bar{\Lambda}$ and a static p is about 2.243 GeV.



First observation



Intermediate $K^*(892)^+$ in $k = 1$ channel

Channel	Cross section (upper limit)
$\bar{\Lambda}p \to K^+\pi^+\pi^-\pi^0$	$8.5^{+1.2}_{-1.1} \pm 0.4$
$\bar{\Lambda}p \to K^+\pi^+\pi^-2\pi^0$	$7.9^{+1.9}_{-1.7} \pm 0.4$
$\bar{\Lambda}p \to K^+\pi^+\pi^-3\pi^0$	$3.1^{+2.2}_{-1.5} \pm 0.2$ (< 7.2)
$\bar{\Lambda}p \to K^*(892)^+\pi^+\pi^-$	$12.5^{+3.8}_{-3.4} \pm 1.2$

Summary

Hyperon physics plays an important role at BESIII:

- **Precision measurements of hyperon decay parameters, polarization and CP:**
  - complementary to CPV studies with Kaons
  - Hyperon semi-leptonic decay: a new approach to extract $|V_{us}|$

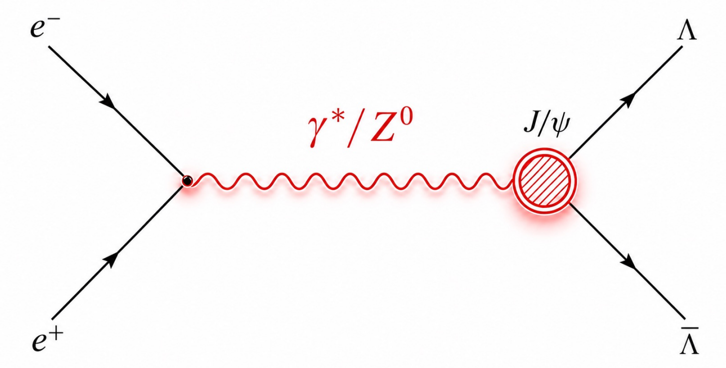
- **Novel method to study hyperon-nucleon interactions.**
  - A idea place to study anti-hyperon nucleon interaction.

- **Hyperon electric dipole moments measurements:**
  - The sensitivity of Λ EDM at BESIII is 1000 times higher than the world's best measurement under the same statistical condition.
  - BESIII has the opportunity of first measurements of the EDM of Σ^+, Ξ^-, Ξ^0 hyperons , and the sensitivity are at the order of 10^{-19}(BESIII) and 10^{-20}(STCF).

THANK YOU !

Backup

Polarization in J/ψ production



- J/ψ polarization with unpolarized beam

$$P_L = (\rho_{++} - \rho_{--})/(\rho_{++} + \rho_{--})$$

$\rho_{mm'}$ spin density matrix for J/ψ

$$P_L = \mathcal{A}^0_{LR} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = \frac{-\sin^2\theta_W^{\mathrm{eff}} + 3/8}{2\sin^2\theta_W^{\mathrm{eff}}\cos^2\theta_W^{\mathrm{eff}}}\frac{M^2_{J/\psi}}{m_Z^2}$$

$\sim 10^{-4}$ in SM

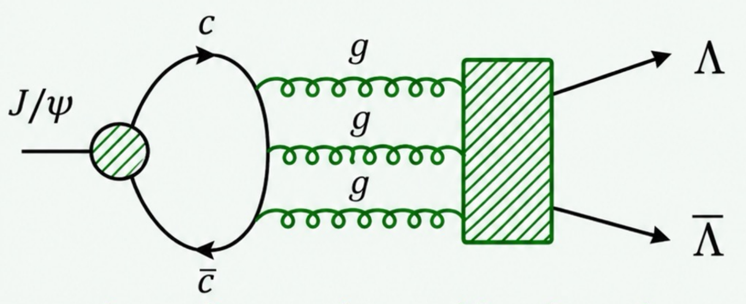
- J/ψ polarization with longitudinally polarized beam P_e

$$\xi = \frac{\sigma_R(1+P_e)/2 - \sigma_L(1-P_e)/2}{\sigma_R(1+P_e)/2 + \sigma_L(1-P_e)/2} = \frac{\mathcal{A}^0_{LR} + P_e}{1 + P_e\mathcal{A}^0_{LR}} \approx P_e$$

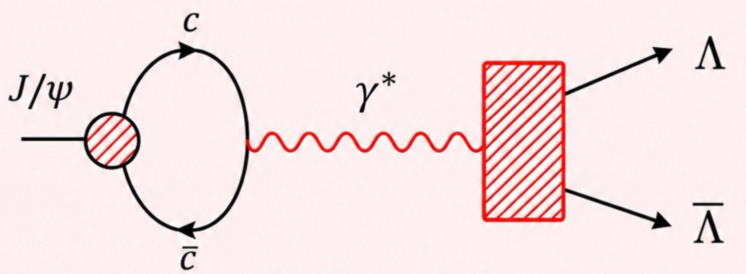
dominated by P_e

a way for precise measurement of beam polarization

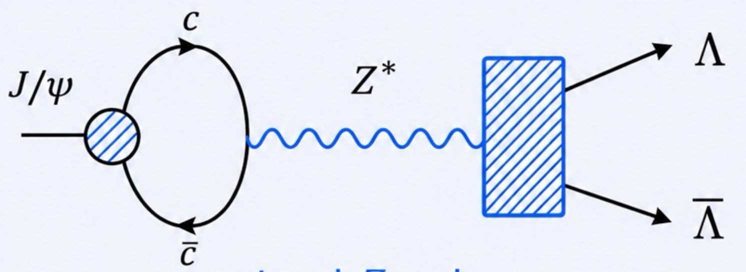
$J/\psi \to \Lambda\bar{\Lambda}$ decay



three-gluon exchange (**dominant**)



virtual photon exchange



virtual Z exchange

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

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

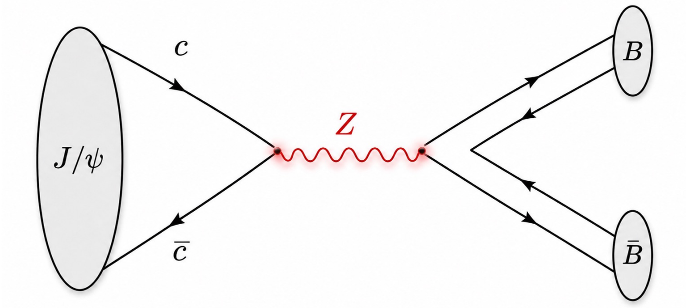
F_V and H_σ represent Λ polarization

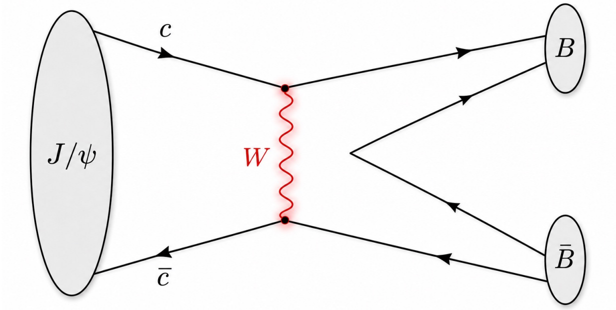
F_A: P violation

H_T: P and CP violation

P violation form factor F_A

- Primarily from Z and W exchange between $c\bar{c}$ and light quark pairs





- Related to effective weak mixing angle and QCD model parameters

$$F_A \approx -\frac{1}{6} D g_V \frac{g^2}{4\cos^2\theta_W^{\text{eff}}} \frac{1 - 8\sin^2\theta_W^{\text{eff}}/3}{m_Z^2} \approx -1.07 \times 10^{-6}$$

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

Running? \ F_A^B	$F_A^n\,(\times 10^{-6})$	$F_A^p\,(\times 10^{-7})$	$F_A^{\Sigma^+}\,(\times 10^{-7})$	$F_A^{\Sigma^0}\,(\times 10^{-9})$	$F_A^{\Sigma^-}\,(\times 10^{-7})$	$F_A^{\Xi^0}\,(\times 10^{-6})$	$F_A^{\Xi^-}\,(\times 10^{-7})$	$F_A^{\Lambda}\,(\times 10^{-7})$
No	0.79	−11.0	−8.22	−49.9	7.22	−0.55	−8.93	−5.84
t	1.18	−7.78	−8.06	4.99	8.16	1.31	9.77	8.95
$t+s$	1.25	−8.39	−8.66	1.25	8.69	1.39	10.3	9.44

Yong Du et al, Phys.Rev.D 110(2024)076019

CP violation form factor H_T

- Several CPV sources contributed to H_T

- Assume hyperon EDM form factor as major contribution

$$H_T(q^2) = \frac{2e}{3M_{J/\psi}^2} g_V d_\Lambda(q^2) \qquad (q = M_{J/\psi})$$

neglect q dependence, d_Λ for hyperon EDM

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

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

Angular distribution

J. Fu, H.B.Li *et al*. Phys. Rev. D 108, L091301 (2023)

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

$$D^{*j=1/2}_{\lambda_1,\lambda_3}(\phi_1, \theta_1) D^{j=1/2}_{\lambda_1',\lambda_3'}(\phi_1, \theta_1) \mathcal{H}^*_{\lambda_3} \mathcal{H}_{\lambda_3'}$$
$$D^{*j=1/2}_{\lambda_2,\lambda_4}(\phi_2, \theta_2) D^{j=1/2}_{\lambda_2',\lambda_4'}(\phi_2, \theta_2) \bar{\mathcal{H}}^*_{\lambda_4} \bar{\mathcal{H}}_{\lambda_4'}$$

Type I:

$e^+e^- \rightarrow J/\psi \rightarrow \Lambda\bar{\Lambda}, \quad \Lambda \rightarrow p\pi^-$

$e^+e^- \rightarrow J/\psi \rightarrow \Sigma^+\bar{\Sigma}^-, \ \Sigma^+ \rightarrow p\pi^0$

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

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

Angular distribution

J. Fu, H.B.Li *et al*. Phys. Rev. D 108, L091301 (2023)

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

$$D^{*j=1/2}_{\lambda_1,\lambda_3}(\phi_1,\theta_1) D^{j=1/2}_{\lambda_1',\lambda_3'}(\phi_1,\theta_1) \mathcal{H}^*_{\lambda_3} \mathcal{H}_{\lambda_3'}$$
$$D^{*j=1/2}_{\lambda_2,\lambda_4}(\phi_2,\theta_2) D^{j=1/2}_{\lambda_2',\lambda_4'}(\phi_2,\theta_2) \bar{\mathcal{H}}^*_{\lambda_4} \bar{\mathcal{H}}_{\lambda_4'}$$
$$D^{*j=1/2}_{\lambda_3,\lambda_5}(\phi_3,\theta_3) D^{j=1/2}_{\lambda_3',\lambda_5}(\phi_3,\theta_3) \mathcal{F}^*_{\lambda_5} \mathcal{F}_{\lambda_5}$$
$$D^{*j=1/2}_{\lambda_4,\lambda_6}(\phi_4,\theta_4) D^{j=1/2}_{\lambda_4',\lambda_6}(\phi_4,\theta_4) \bar{\mathcal{F}}^*_{\lambda_6} \bar{\mathcal{F}}_{\lambda_6}$$

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

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

Type II:

$$e^+e^- \to J/\psi \to \Xi^-\bar{\Xi}^+, \quad \Xi^- \to \Lambda\pi^-$$
$$e^+e^- \to J/\psi \to \Xi^0\bar{\Xi}^0, \quad \Xi^0 \to \Lambda\pi^0$$

Angular distribution

J. Fu, H.B.Li *et al*. Phys. Rev. D 108, L091301 (2023)

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

$$D^{*j=1/2}_{\lambda_1,\lambda_3}(\phi_1,\theta_1) D^{j=1/2}_{\lambda_1',\lambda_3'}(\phi_1,\theta_1) \mathcal{H}^*_{\lambda_3}\mathcal{H}_{\lambda_3'}$$
$$D^{*j=1/2}_{\lambda_2,\lambda_4}(\phi_2,\theta_2) D^{j=1/2}_{\lambda_2',\lambda_4'}(\phi_2,\theta_2) \bar{\mathcal{H}}^*_{\lambda_4}\bar{\mathcal{H}}_{\lambda_4'}$$
$$D^{*j=1/2}_{\lambda_3,\lambda_5}(\phi_3,\theta_3) D^{j=1/2}_{\lambda_3',\lambda_5}(\phi_3,\theta_3) \mathcal{F}^*_{\lambda_5}\mathcal{F}_{\lambda_5}$$
$$D^{*j=1/2}_{\lambda_4,\lambda_6}(\phi_4,\theta_4) D^{j=1/2}_{\lambda_4',\lambda_6}(\phi_4,\theta_4) \bar{\mathcal{F}}^*_{\lambda_6}\bar{\mathcal{F}}_{\lambda_6}$$

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

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

- Lee-Yang parameters in hyperon weak decays defined by helicity amplitude *H* and *F*

$$\alpha = (|H_{1/2}|^2 - |H_{-1/2}|^2)/(|H_{1/2}|^2 + |H_{-1/2}|^2)$$
$$\beta = 2\mathrm{Im}(H_{1/2}H^*_{-1/2})/(|H_{1/2}|^2 + |H_{-1/2}|^2)$$
$$\gamma = 2\mathrm{Re}(H_{1/2}H^*_{-1/2})/(|H_{1/2}|^2 + |H_{-1/2}|^2)$$

- CP-violating observables

$$A_{CP} = (\alpha + \bar{\alpha})/(\alpha - \bar{\alpha})$$
$$B_{CP} = (\beta + \bar{\beta})/(\alpha - \bar{\alpha})$$

F_A and H_T not necessary

Several measurements from BESIII with world-leading precision

EDM sensitivity

J. Fu, H.B.Li *et al*. Phys. Rev. D 108, L091301 (2023)

- Simultaneously determine all free parameters from full angular analysis

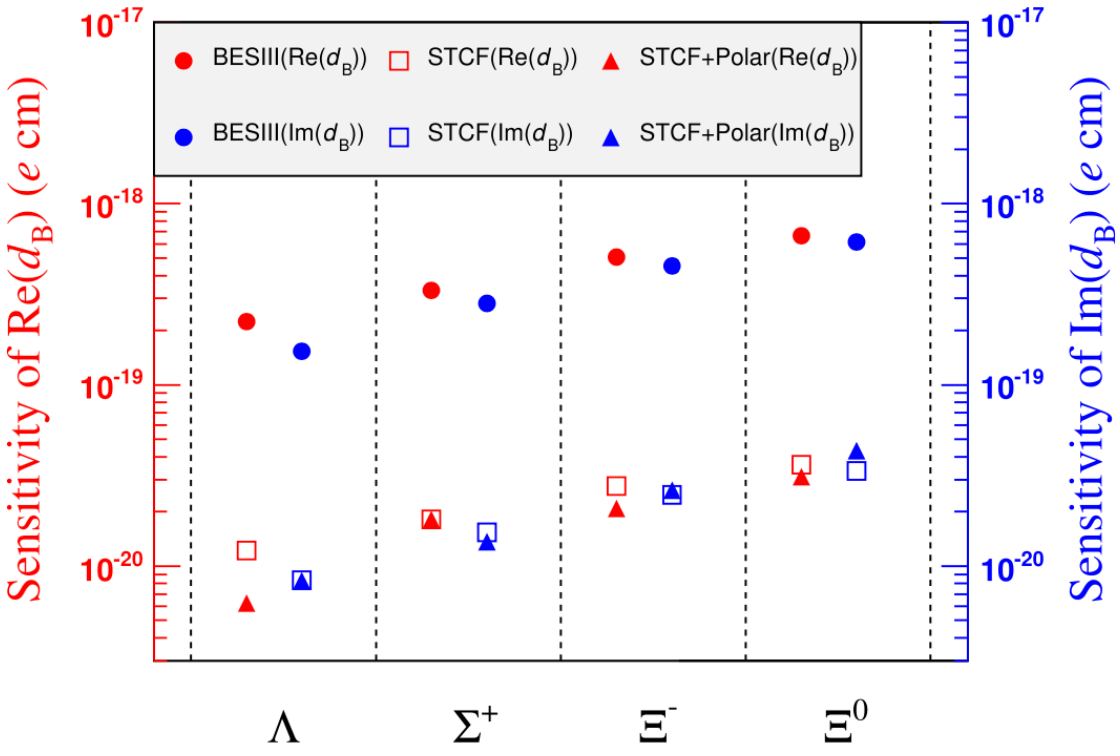
  i.e. $J/\psi \rightarrow \Lambda\bar{\Lambda}$

  Set of helicity angles

  $\xi^i = (\theta^i_\Lambda, \theta^i_p, \theta^i_{\bar{p}}, \phi^i_p, \phi^i_{\bar{p}})$

  Fitted parameters

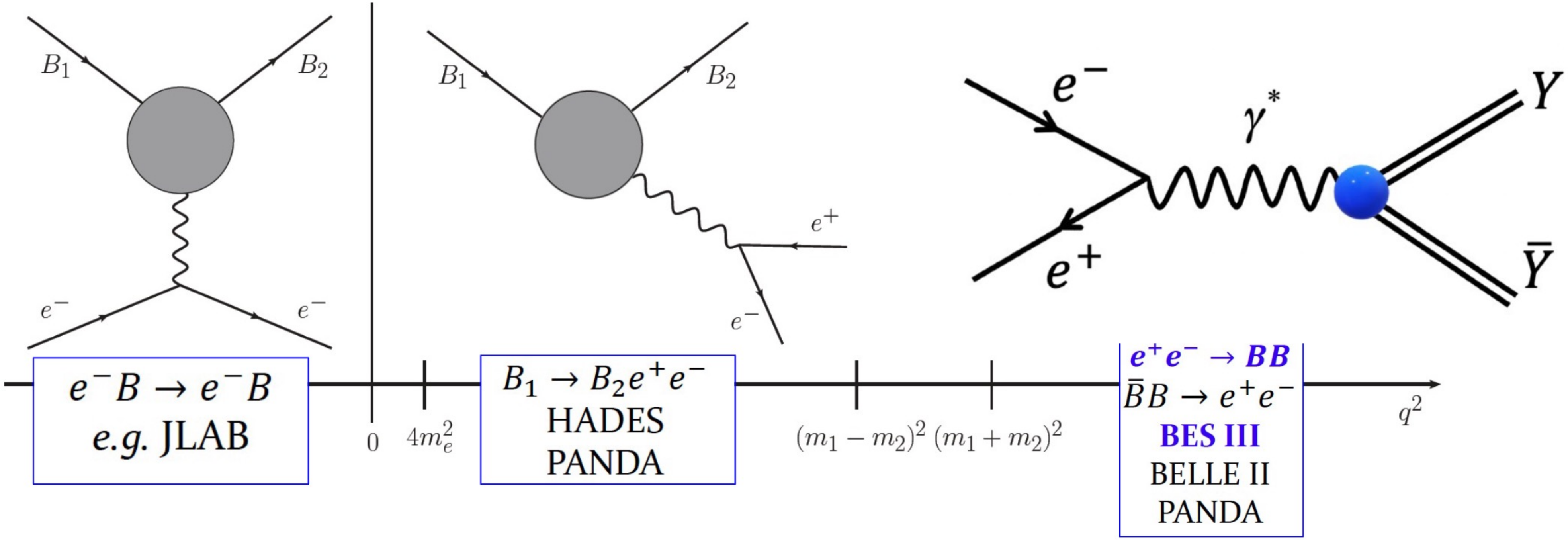
  $\vec{\lambda} = (P_L, G_2, F_A, H_T, \alpha_\Lambda, \alpha_{\overline{\Lambda}})$



- Sensitivity at BESIII and STCF

  10^{-19}~10^{-21} e cm

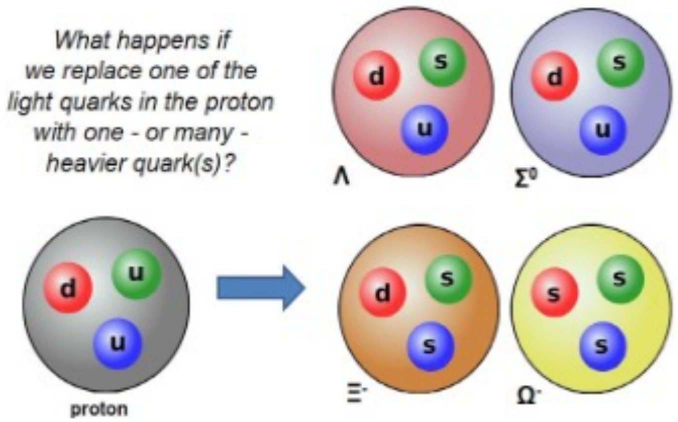
Electromagnetic Form Factors (EMFFs)

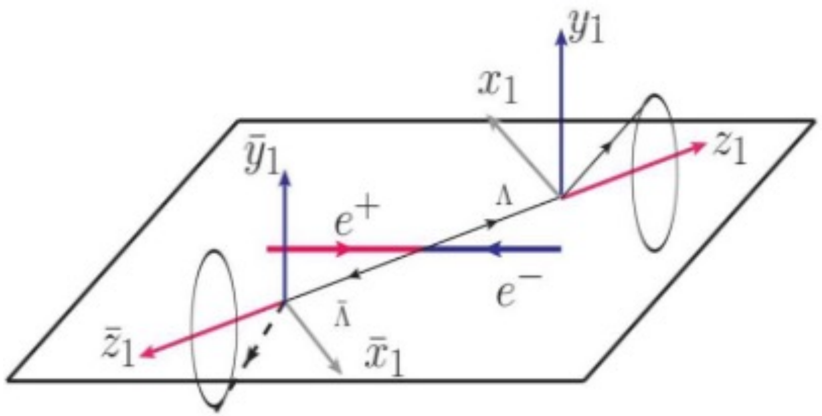


- $eB \to eB$ scattering
- Stable baryon beam
- Momentum transfer $q^2 = -Q^2 < 0$
- $Q^2 \to 0$ (0.00021 GeV^2)

- $e^+e^- \to B\bar{B}$ or $B\bar{B} \to e^+e^-$
- Baryons produced paired
- Momentum transfer $q^2 > 0$
- $q^2 \geq M^2_{B\bar{B}}$ for current running experiment

Hyperon form factors





- **Complex form** of TL EMFFs:

  $$G_E = |G_E|e^{i\Phi_E},\ G_M = |G_M|e^{i\Phi_M}$$

  Relative phase: $\Delta\Phi = \Phi_E\text{-}\Phi_M$
- Analyticity requires $\lim_{s\to\infty} \Delta\Phi = 0$, since SL and TL EMFFs should converge to the same value
- $\Delta\Phi \neq 0$ when $s > 0$ results in the **polarization** effect of the hyperons: $P_y \propto \sin\Delta\Phi$
- **Angular** distribution of daughter baryon from Hyperon weak decay is
  - $\frac{d\sigma}{d\Omega} \propto 1 + \alpha_\Lambda P_y \cdot \hat{q}$
  - α_Λ: asymmetry parameter (P-violation)

ΔΦ and the polarization of hyperon can be measured!

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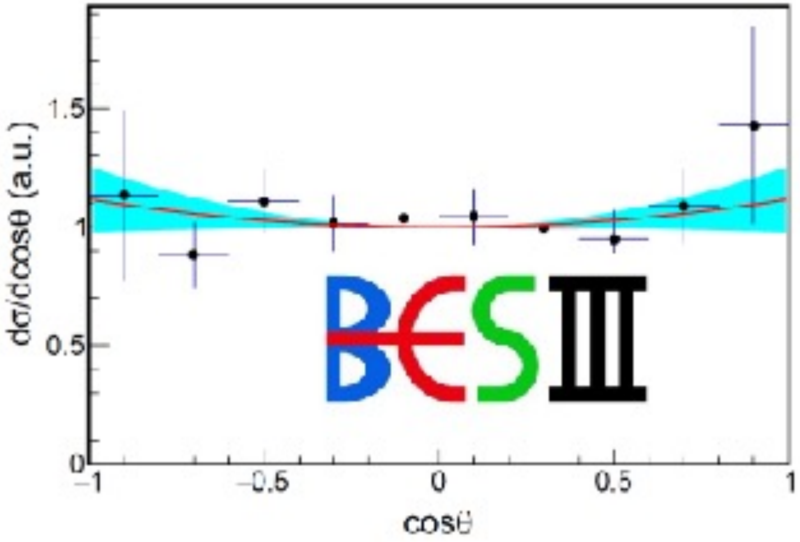
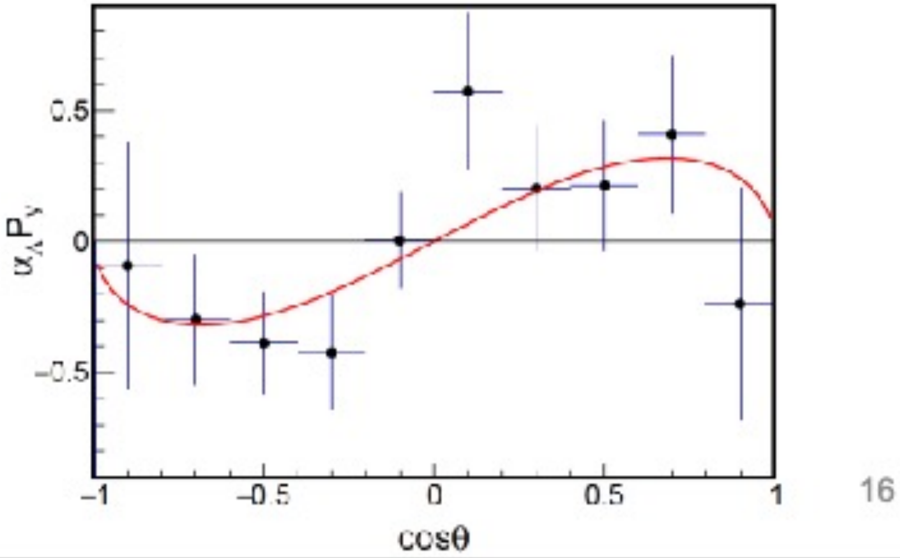
First complete measurement of Λ structure

- New BESIII data at 2.396 GeV with 555 exclusive $\bar{\Lambda}\Lambda$ events in sample.
  - $R = |G_E/G_M| = \mathbf{0.96 \pm 0.14 \pm 0.02}$
  - $\Delta\Phi = \mathbf{37^o \pm 12^o \pm 6^o}$
  - $\sigma = 118.7 \pm 5.3 \pm 5.1$ pb

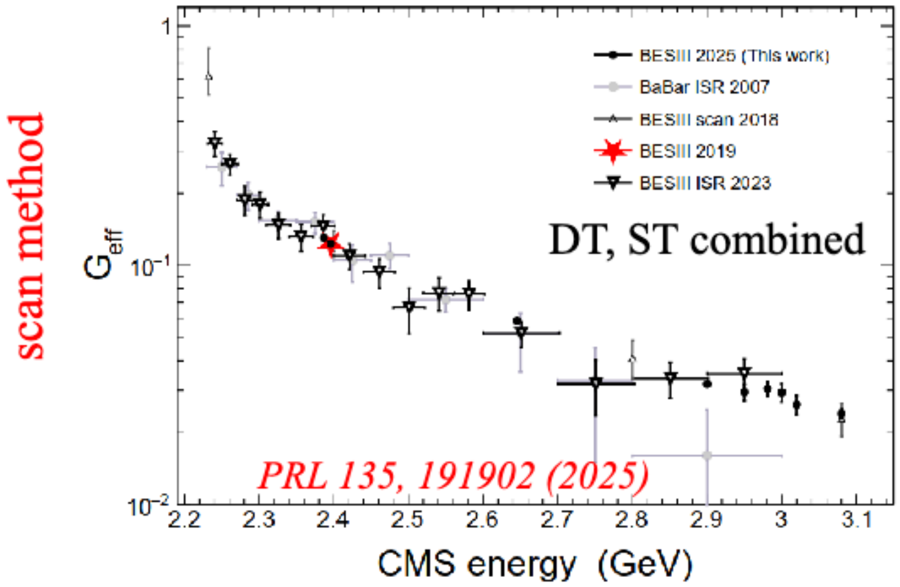
Phys. Rev. Lett. 123, 122003 (2019)

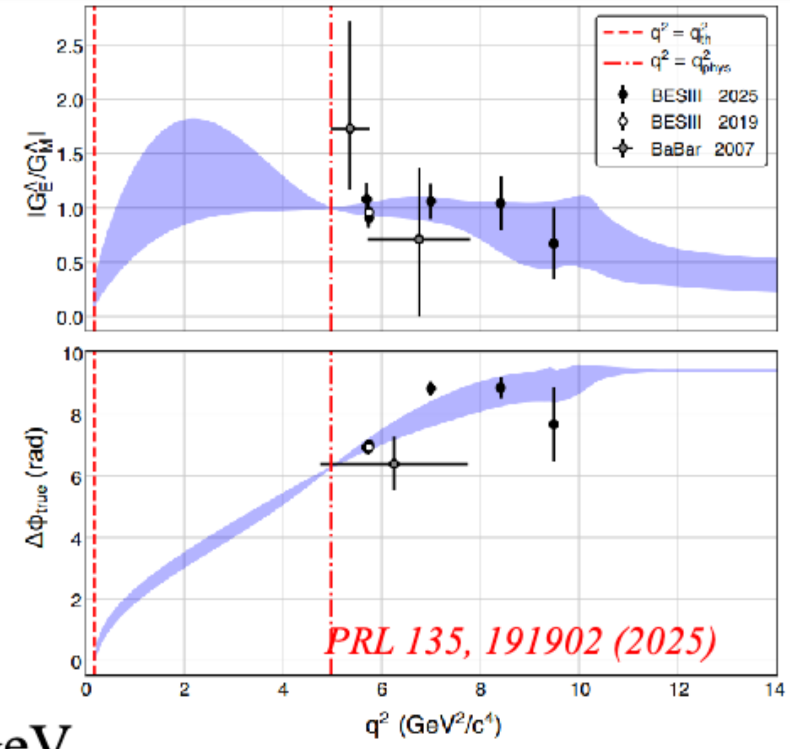
- Most **precise** result on R and σ
- **First** conclusive result on $\Delta\Phi$





Complete measurement of Λ structure





- $R = |G_E(q^2)/G_M(q^2)|$ remains constant, while $\Delta\Phi$ changes by more than 90° between 2.396 and 2.6544 GeV.

$$\langle r_E \rangle^2 = 6\mu \frac{dR(q^2)}{dq^2}\bigg|_{q^2=0} = -0.076 \pm 0.043 \text{ fm}$$

an asymmetric charge distribution where the *ds* quark pair lies close to the center of the Λ hyperon.

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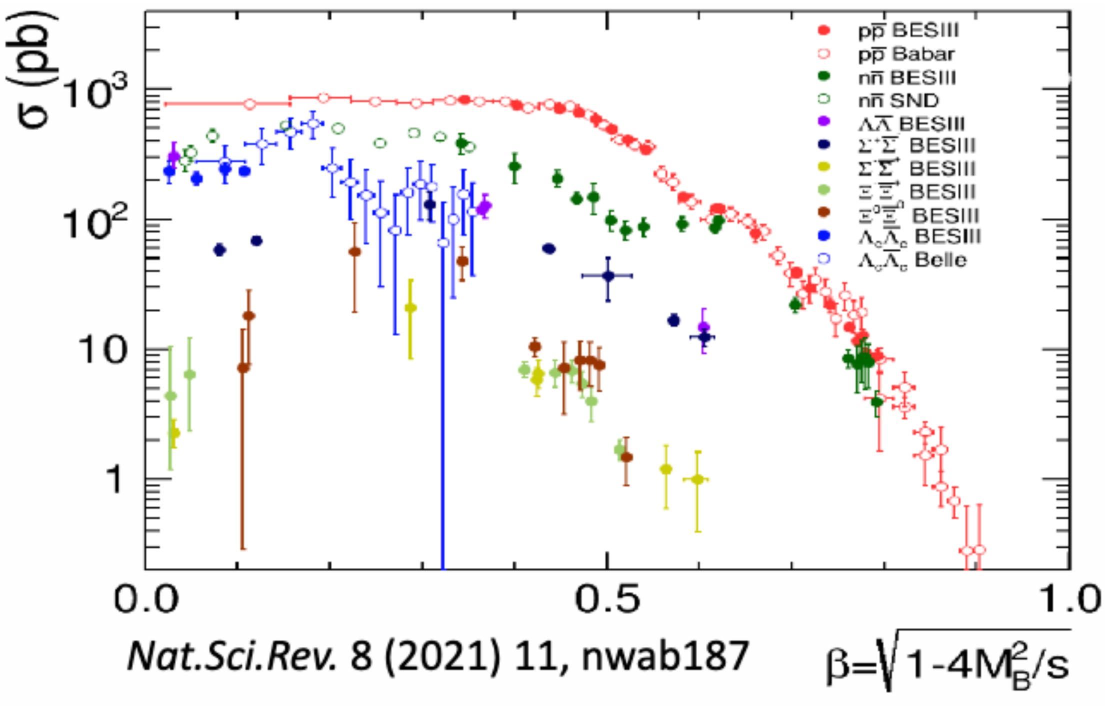
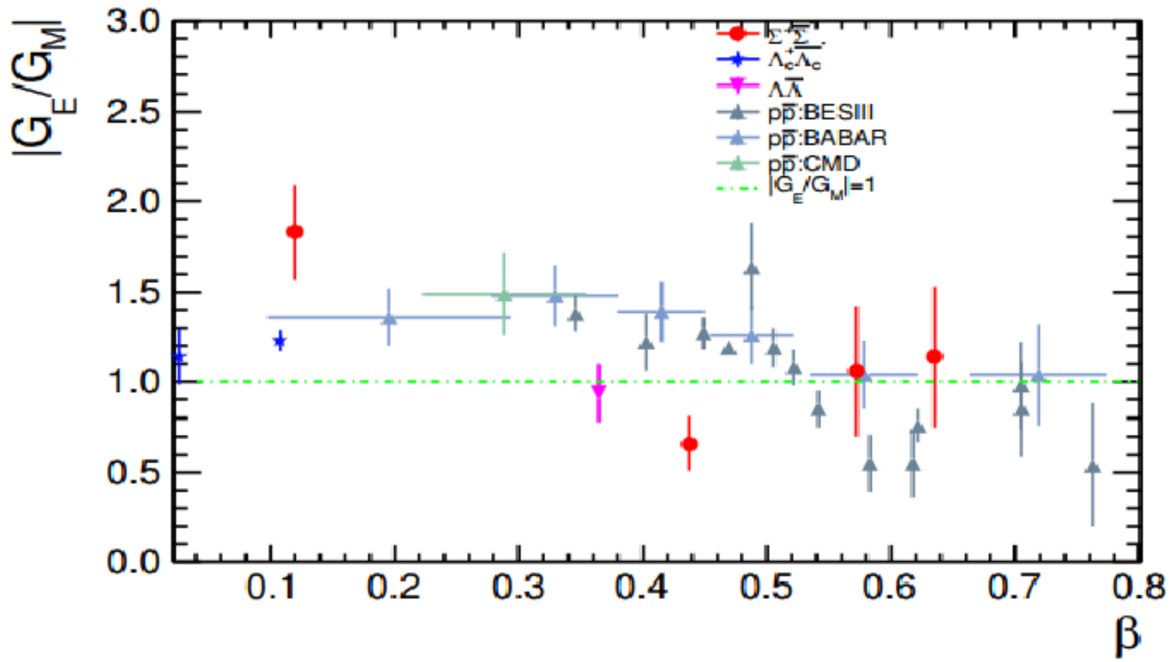
Results of EMFFs at BESIII



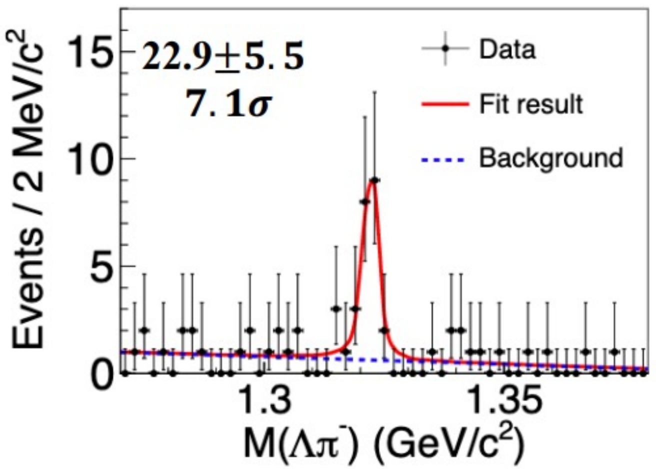


- Abnormal threshold effects observed in various baryon pair production: $p\bar{p}$, $\Lambda\bar{\Lambda}$, $\Lambda_c^+\bar{\Lambda}_c^-$ …
- Oscillation structures observed
- $|G_E/G_M|$ ratio significantly larger than 1 at low beta for p, Λ_c^+, Σ^+, indicating large D-wave near threshold
- Relative phase angle of form factor $\Delta\phi$($\sin\Delta\phi$) measured for Λ, Λ_c^+, etc

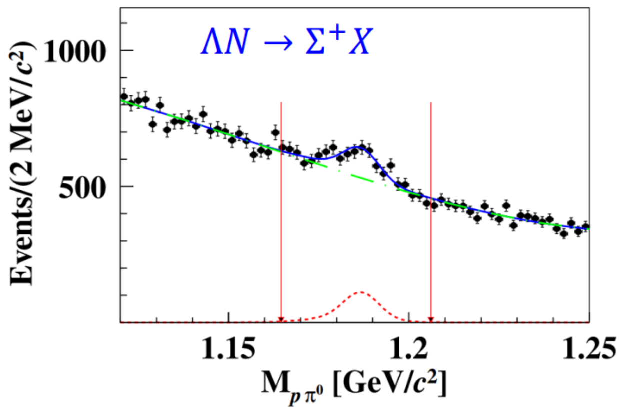
$\Xi^0 + n \rightarrow \Xi^- + p$ and $\Lambda + {}^9\text{Be} \rightarrow \Sigma^+ + n$

- First study for Ξ^0n and ΛN inelastic scattering through $J/\psi \rightarrow \Xi^0\bar{\Xi}^0$ and $\Lambda\bar{\Lambda}$

BESIII: PRL 130 (2023) 251902



BESIII: PRC 109(2024)L052201



$N_{DT} = 795 \pm 101$

- Total elastic cross sectionsare measured, results are consistent with theoretical prediction

σ(Ξ^0n → Ξ^-p) = (7.4 ± 1.8(stat.) ± 1.5(syst.)) mb
σ(Ξ^0 + ^{9}Be → Ξ^- + p + ^{8}Be) = (22.1 ± 5.3(stat.) ± 4.5(syst.)) mb
σ(Λ + ^{9}Be → Σ^+ + X) = 37.3 ± 4.7(stat.) ± 3.5(syst.) mb