中国科学院大学
UNIVERSITY OF CHINESE ACADEMY OF SCIENCES

Highlight on CPV test of hyperon at BESIII

强子物理在线论坛100期特别活动

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Outline

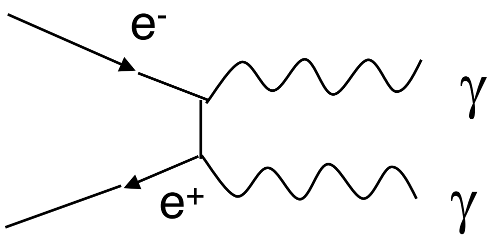
- CP tests in hyperon decays
- Recent results from BESIII
- Hyperon CP test in future plans
- Summary and outlooks

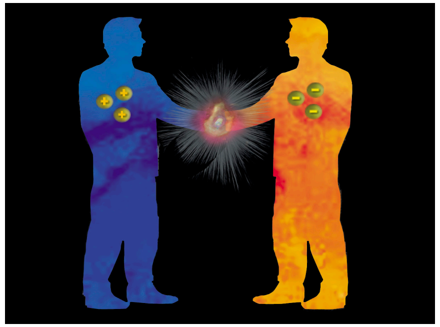
CP tests in hyperon decays

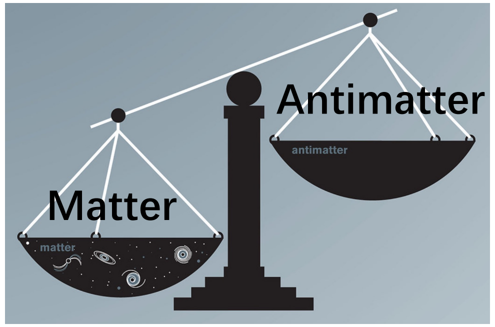
Matter-antimatter asymmetry in the universe

The Big Bang model predicts:

- Matter and antimatter are produced in equal amounts
- Matter and antimatter annihilated into energy







However the very fact that we exist in a matter-dominated universe.

Sakharov three conditions require C and CP violation processes exist.

Andrei Sakharov
(1921-1989)

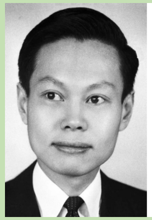
Sakharov three conditions:

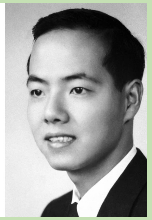
1. Baryon number B violation
2. C and CP symmetry violation
3. Interactions out of thermal equilibrium

Pisma Zh. Eksp. Teor. Fiz., 1967, 5: 32-35.

A brief history of Parity and CP violation

Nobel Prize 1957





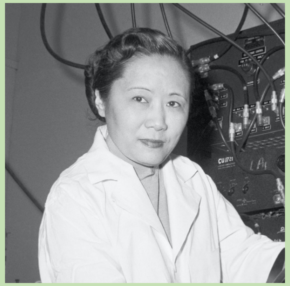
C. N. Yang T. D. Lee

$\theta - \tau$ puzzle [1]

First proposed Parity violation in weak interaction

Confirmed by

1957



Chien-Shiung Wu

No CPV founded in baryon sector!

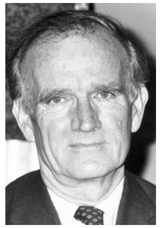
K meson *CP* violation[2]

B meson *CP* violation [3,4]

D meson *CP* violation [5]

1964

James Watson Cronin



Val Logsdon Fitch

Nobel Prize 1980

2001

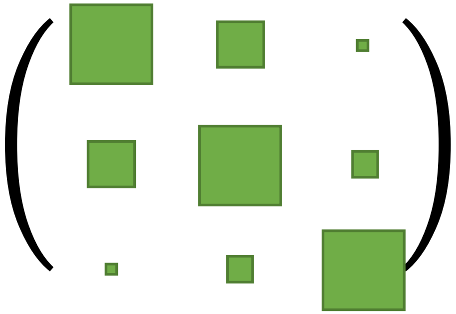
2019

[1] Phys. Rev. 104 (1956) 254-258
[2] Phys. Rev. Lett., 1964, 13: 138-140
[3] Phys. Rev. Lett., 2001, 87: 091801
[4] Phys. Rev. Lett., 2001, 87: 091802
[5] Phys. Rev. Lett., 2019, 122(21): 211803

CPV in Standard Model: CKM matrix

CPV from phase δ

$$V_{\text{CKM}} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & \boxed{s_{13}e^{-i\delta}} \\ -s_{12}c_{23}-c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23}-s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ \boxed{s_{12}s_{23}-c_{12}c_{23}s_{13}e^{i\delta}} & -c_{12}s_{23}-s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix}$$



Dirac Medal 2010

Nobel Price 2008

δ_s strong phase $\qquad \phi_w$ weak phase

For decay $A = A_1 e^{i\delta_s^1} e^{i\phi_w^1} + A_2 e^{i\delta_s^2} e^{i\phi_w^2} \xrightarrow{CP} \bar{A} = A_1 e^{i\delta_s^1} e^{-i\phi_w^1} + A_2 e^{i\delta_s^2} e^{-i\phi_w^2}$

Make $r = A_2/A_1$, $\delta = \delta_s^2 - \delta_s^1$, $\phi = \phi_w^2 - \phi_w^1$

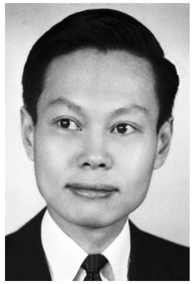
Thus $A_{CP} = \frac{|A|^2-|\bar{A}|^2}{|A|^2+|\bar{A}|^2} = \frac{|A_1|^2\left|1+re^{i(\delta+\phi)}\right|^2-|A_1|^2\left|1+re^{i(\delta-\phi)}\right|^2}{|A_1|^2\left|1+re^{i(\delta+\phi)}\right|^2+|A_1|^2\left|1+re^{i(\delta-\phi)}\right|^2}$

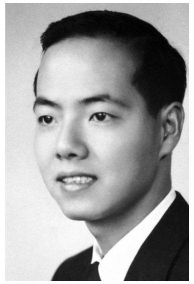
$$= \frac{2r\cos(\delta+\phi)-2r\cos(\delta-\phi)}{2(1+r^2+r\cos(\delta+\phi)+r\cos(\delta-\phi))} = \frac{2r\sin\delta\sin\phi}{1+r^2+2r\cos\delta\cos\phi}$$

$\neq 0$, if $\delta \neq 0$ and $\phi \neq 0$

- Strong and weak phase difference $\neq 0$
- At least two amplitudes, CPV arised from interference between amplitudes.

CPV in hyperon decay





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:

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

The decay parameters are defined as:

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

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

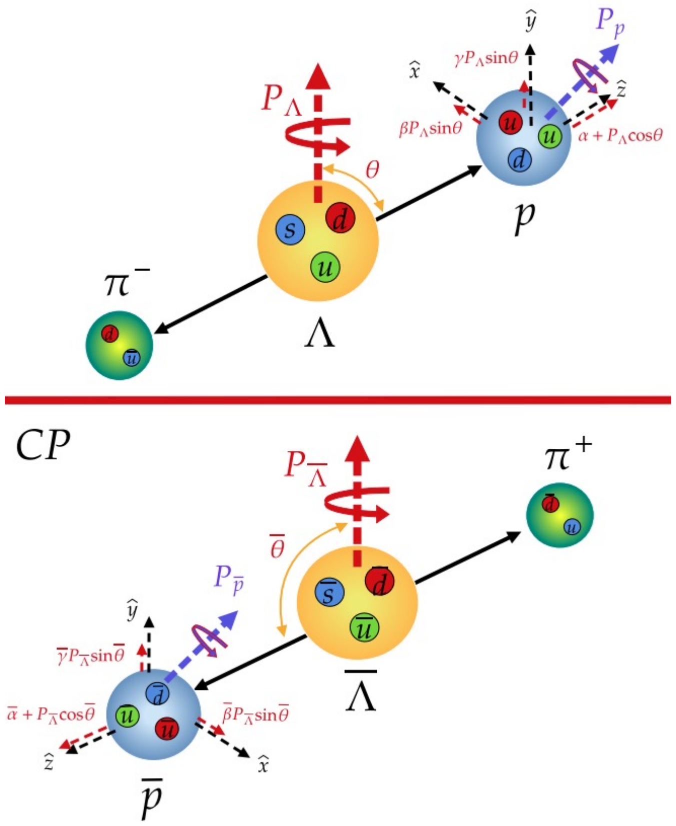
$$S = \Sigma^i S_i e^{i(\phi_i^S+\delta_i^S)}, \qquad P = \Sigma^i P_i e^{i(\phi_i^P+\delta_i^P)}$$

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: $S \xRightarrow{CP} -S$ $\quad \alpha \xRightarrow{CP} \bar{\alpha} = -\alpha$

$P \xRightarrow{CP} P$ $\quad \beta \xRightarrow{CP} \bar{\beta} = -\beta$



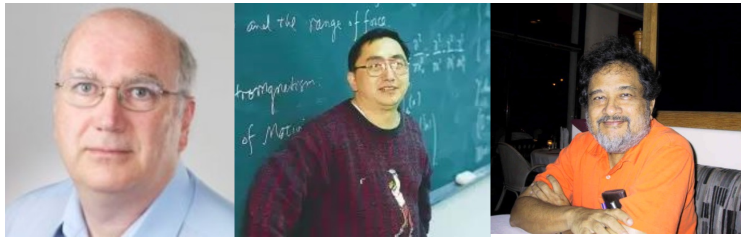
CPV observables

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

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

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

CP observable in hyperon decay



John F. Donoghue Xiao-Gang He Sandip Pakvasa

PHYSICAL REVIEW D VOLUME 34, NUMBER 3 1 AUGUST 1986

Hyperon decays and *CP* nonconservation

John F. Donoghue
Department of Physics and Astronomy, University of Massachusetts, Amherst, Massachusetts 01003

Xiao-Gang He and Sandip Pakvasa
Department of Physics and Astronomy, University of Hawaii at Manoa, Honolulu, Hawaii 96822

(Received 7 March 1986)

We study all modes of hyperon nonleptonic decay and consider the *CP*-odd observables which result. Explicit calculations are provided in the Kobayashi-Maskawa, Weinberg-Higgs, and left-right-symmetric models of *CP* nonconservation.

PRD 34,833 1986

SM Prediction of Λ decay

			SM Prediction of Λ decay
Not sensitive to *CPV*	**Decay width difference**	$\Delta=\frac{\Gamma-\bar{\Gamma}}{\Gamma+\bar{\Gamma}}\approx\sqrt{2}\frac{T_{\frac{3}{2}}}{T_{\frac{1}{2}}}\sin\Delta_s\sin\phi_{CP}$	-5.4×10^{-7}
Easiest to measure	**Decay parameter difference**	$A=\frac{\Gamma\alpha+\bar{\Gamma}\bar{\alpha}}{\Gamma\alpha-\bar{\Gamma}\bar{\alpha}}\approx\tan\Delta_s\tan\phi_{CP}$	-0.5×10^{-4}
Polarization of decayed baryon needs to be measured	**Decay parameter difference**	$B=\frac{\Gamma\beta+\bar{\Gamma}\bar{\beta}}{\Gamma\alpha-\bar{\Gamma}\bar{\alpha}}\approx\tan\phi_{CP}$	3.0×10^{-3}

Ξ^-,Ξ^0,Ω^- cascade decay

BESIII and STCF : a hyperon factory

10 billion J/ψ events collected at BESIII:

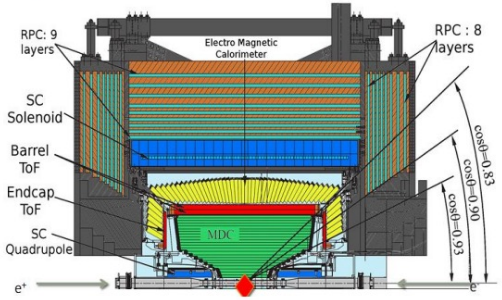
- **Large Br. in J/ψ decay**
- **Quantum entangled pair productions**
- **High efficiency, background free**

Decay	$\mathcal{B}$ (10^{-5})	Events at BESIII
$J/\psi \to \Lambda\bar{\Lambda}$	189 ± 9	18.9×10^6
$J/\psi \to \Sigma^+\bar{\Sigma}^-$	150 ± 24	15.0×10^6
$J/\psi \to \Xi\bar{\Xi}$	97 ± 8	9.7×10^6
$\psi(2S) \to \Sigma\bar{\Sigma}$	23.2 ± 1.2	116×10^3
$\psi(2S) \to \Omega\bar{\Omega}$	5.66 ± 0.30	28×10^3

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

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

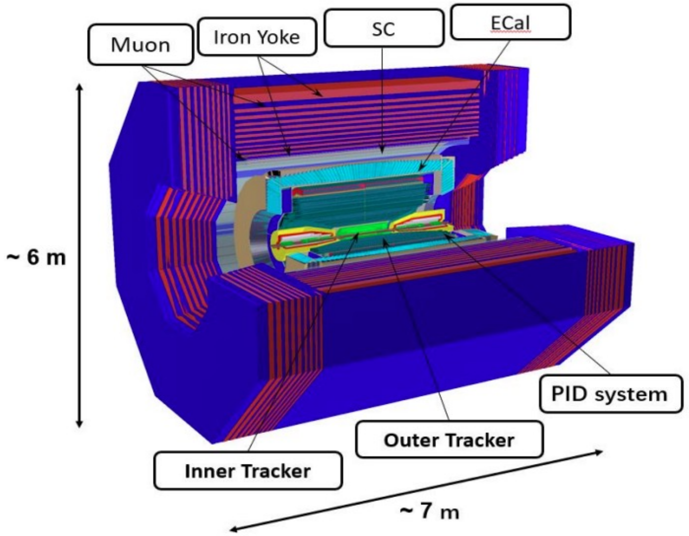
Time Of Flight
Plastic scintillator
σ_T(barrel)=80 ps
σ_T(endcap)=110 ps
(update to 65 ps with MRPC)

BESIII Detector

With 10 billion J/ψ collected at BESIII and $\sim 10^7$ entangled hyperon pairs can be studied.

At future, the STCF will collect 1 trillion J/ψ per year, and will provide $\sim 10^9$ hyperon pairs.

Proposed: Super Tau-Charm Facility (STCF)



ITK: ~0.15% X_0 / layer
σ_{xy}~50 μm

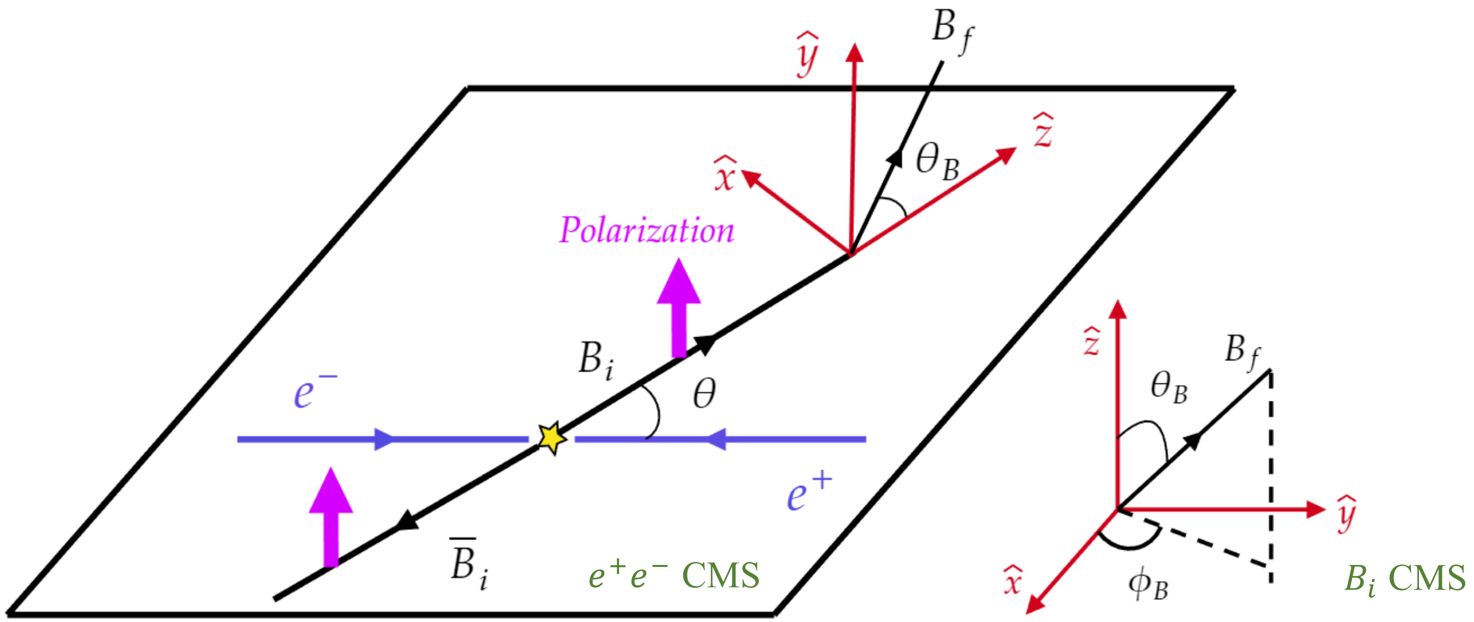
MDC: σ_{xy}~130 μm
σ_p/p~0.5%@1GeV/c
dE/dx~6%

PID: $\pi K(Kp)$ 3~4 σ separation up to 2 GeV/c

EMC: range 0.02~2GeV
σ_E@1GeV: 2.5% in barrel, 4% at endcaps

MUD: 0.4~1.8GeV, π suppression > 30

Polarized hyperon pairs produced in e^+e^- collisions



Two form factors are used to describe the production of hyperon pair: G_E, G_M

$$\alpha_\psi = \frac{s^2|G_M|^2 - 4m^2|G_E|^2}{s^2|G_M|^2 + 4m^2|G_E|^2}, \quad \frac{G_M}{G_E} = \left|\frac{G_M}{G_E}\right| e^{-i\Delta\Phi}$$

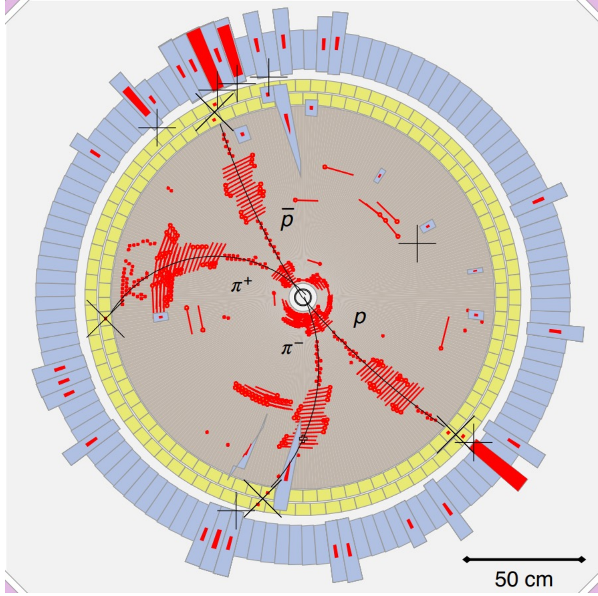
Polarization:

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

- Angular distribution of $\frac{\mathrm{d}\Gamma}{\mathrm{d}\Omega} \propto 1 + \alpha_\psi \cos^2\theta$, $\alpha_\psi \in [-1.0, 1.0]$
- Unpolarized e^+e^- beams $\Rightarrow$ transverse polarized hyperon (if $\Delta\Phi \neq 0$):

Recent results from BESIII

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



- Joint amplitude:

$$M = \frac{ie^2}{q^2} j_\mu \bar{u}(p_1)\left(F_1\gamma_\mu + \frac{F_2}{2m} p_\nu \sigma^{\nu\mu}\gamma_5\right) v(p_2)$$

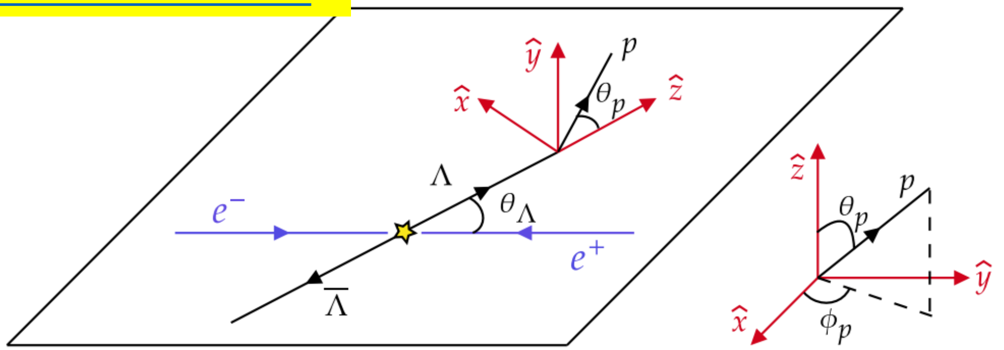
- Differential cross section:

$$d\sigma \sim 1 + \alpha_\psi \cos^2\theta_\Lambda + (\alpha_\psi + \cos^2\theta_\Lambda) s_\Lambda^z s_{\bar{\Lambda}}^z + \sin^2\theta_\Lambda s_\Lambda^x s_{\bar{\Lambda}}^x - \alpha_\psi \sin^2\theta_\Lambda s_\Lambda^y s_{\bar{\Lambda}}^y + \sqrt{1-\alpha_\psi^2}\cos\Delta\Phi \sin\theta_\Lambda \cos\theta_\Lambda (s_\Lambda^x s_{\bar{\Lambda}}^z + s_\Lambda^z s_{\bar{\Lambda}}^x) + \boxed{\sqrt{1-\alpha_\psi^2}\sin\Delta\Phi \sin\theta_\Lambda \cos\theta_\Lambda (s_\Lambda^y + s_{\bar{\Lambda}}^y)}$$

SPIN CORRELATIONS

POLARIZATIONS

- The spin vector of Λ is denoted by $\boldsymbol{s}_\Lambda$
- Only $< s^y >$ could be non-zero, if $\sin\Delta\Phi \neq 0$



Nuovo Cim. A 109, 241 (1996)
Phys. Rev.185 D 75, 074026 (2007)
Nucl. Phys. A190 771, 169 (2006)
Phys. Lett. B 772, 16(2017)

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

BESIII has publish 2 works based on 1.3 billion and 10 billion J/ψ data sample:

[1] 1.3 billion: Nature Phys.15(2019)631

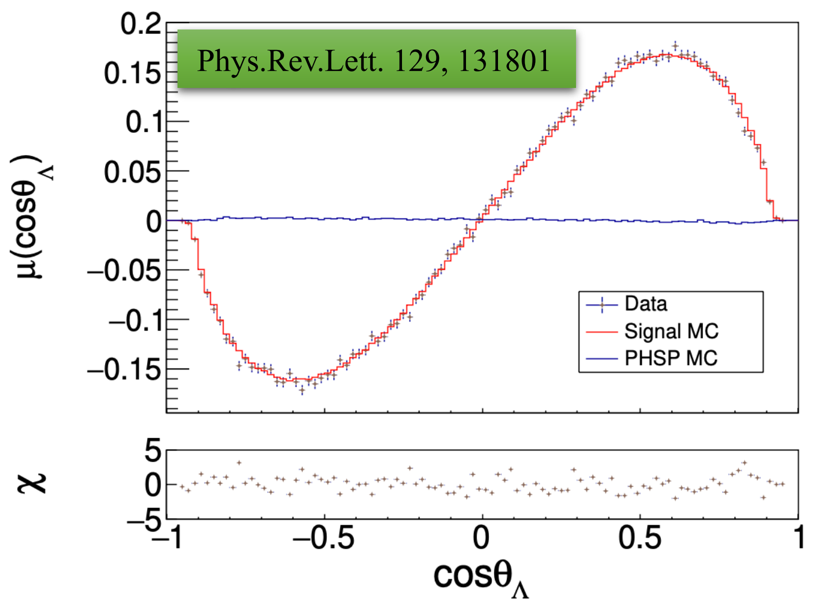
[2] 10 billion: Phys.Rev.Lett. 129 (2022) 13, 131801

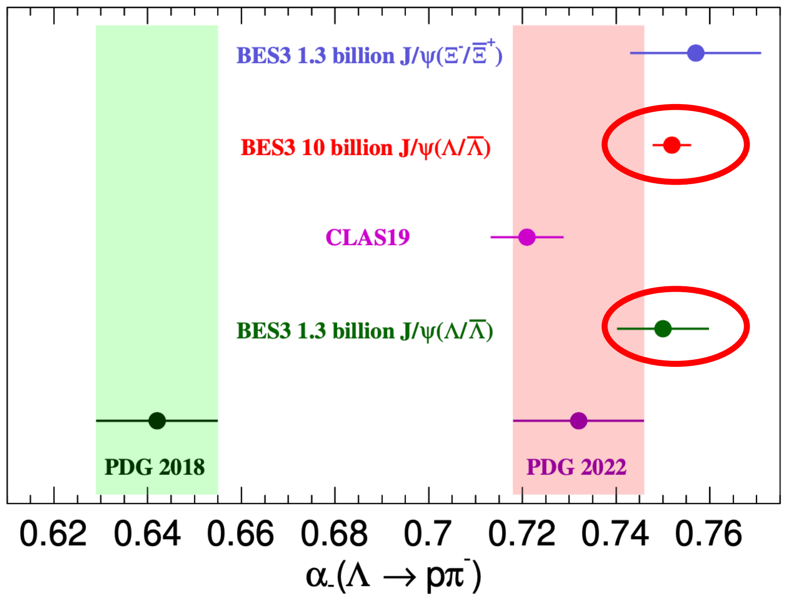
- Most precise values for Λ decay parameter
- One of the most precise CP test in the hyperon sector:

$$A_{CP} = \frac{\alpha + \bar{\alpha}}{\alpha - \bar{\alpha}} = -0.0025 \pm 0.0046 \pm 0.0011$$

Standard mode prediction : $A_{CP} \sim 10^{-4}$ (PRD 34, 833 (1986))

Par.	BESIII 10 billion [2]	BESIII 1.3 billion [1]
$\alpha_{J/\psi}$	$0.4748 \pm 0.0022 \pm 0.0031$	$0.461 \pm 0.006 \pm 0.007$
$\Delta\Phi$	$0.7521 \pm 0.0042 \pm 0.0066$	$0.740 \pm 0.010 \pm 0.009$
α_-	$0.7519 \pm 0.0036 \pm 0.0024$	$0.750 \pm 0.009 \pm 0.004$
α_+	$-0.7559 \pm 0.0036 \pm 0.0030$	$-0.758 \pm 0.010 \pm 0.007$
A_{CP}	$-0.0025 \pm 0.0046 \pm 0.0012$	$0.006 \pm 0.012 \pm 0.007$
α_{avg}	$0.7542 \pm 0.0010 \pm 0.0024$	-





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

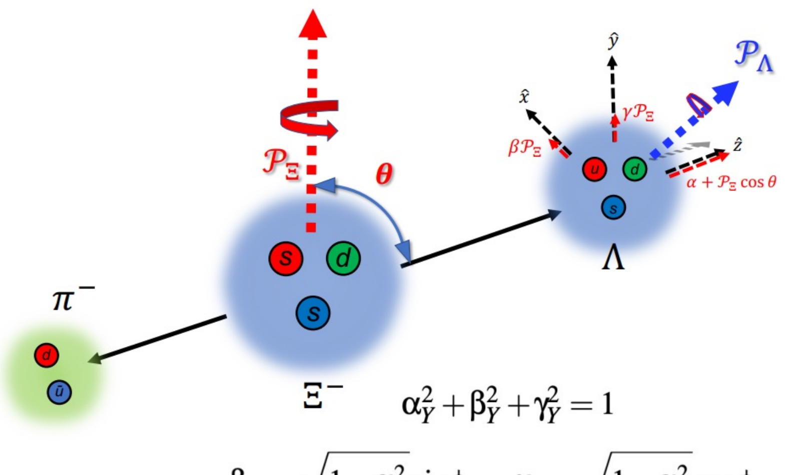
- For the sequential weak decays, the formula of sequential decays is:

$$\mathcal{W}(\boldsymbol{\xi}, \boldsymbol{\omega}) = \sum_{\mu,\bar{\nu}=0}^{3} \boxed{C_{\mu\bar{\nu}}} \sum_{\mu',\bar{\nu}'=0}^{3} \boxed{a_{\mu\mu'}^{B_1} a_{\bar{\nu}\bar{\nu}'}^{\bar{B}_1} a_{\mu'0}^{B_2} a_{\bar{\nu}'0}^{\bar{B}_2}}$$

PRD99(2019)056008
PRD100(2019)114005

- Angular distribution $d\Gamma \propto W(\xi, \omega)$
  - ξ: 9 kinematic variables, denoted by 9 helicity angles
  - $\omega = (\alpha_\psi, \Delta\Phi, \alpha_\Xi, \alpha_{\bar{\Xi}}, \phi_\Xi, \phi_{\bar{\Xi}}, \alpha_\Lambda, \alpha_{\bar{\Lambda}})$: 8 free parameters

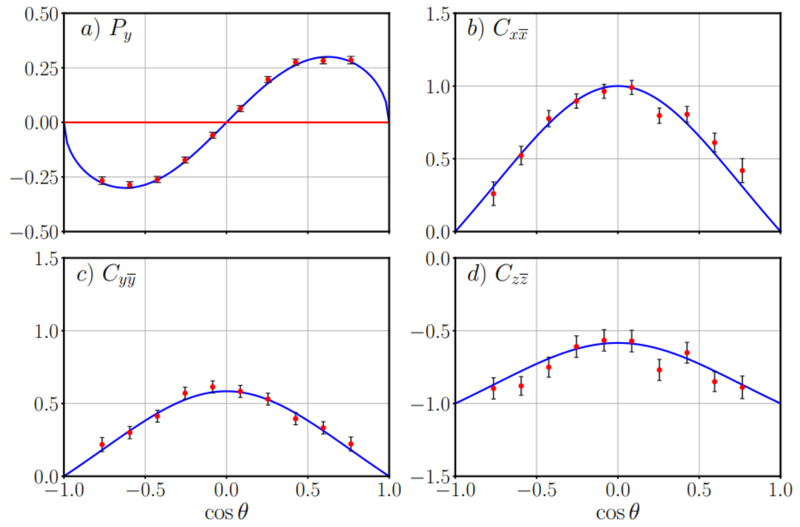
first measurement



$\alpha_Y^2 + \beta_Y^2 + \gamma_Y^2 = 1$

$\beta_Y = \sqrt{1-\alpha_Y^2}\sin\phi_Y, \quad \gamma_Y = \sqrt{1-\alpha_Y^2}\cos\phi_Y$

More parameters in sequential decay!



- Data sample: 1.3 billion J/ψ events.
- Final dataset: $73.2 \cdot 10^3$ events with 199 backgrounds.

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

Nature 606 (2022) 7912, 64-69

Parameter	This work	Previous result
α_ψ	0.586±0.012±0.010	0.58±0.04±0.08
$\Delta\Phi$	1.213±0.046±0.016 rad	–
α_Ξ	−0.376±0.007±0.003	−0.401±0.010
ϕ_Ξ	0.011±0.019±0.009 rad	−0.037±0.014 rad
$\bar{\alpha}_\Xi$	0.371±0.007±0.002	–
$\bar{\phi}_\Xi$	−0.021±0.019±0.007 rad	–
α_Λ	0.757±0.011±0.008	0.750±0.009±0.004
$\bar{\alpha}_\Lambda$	−0.763±0.011±0.007	−0.758±0.010±0.007
$\xi_P-\xi_S$	(1.2±3.4±0.8)×10^{-2} rad	–
$\delta_P-\delta_S$	(−4.0±3.3±1.7)×10^{-2} rad	(10.2±3.9)×10^{-2} rad
A^Ξ_{CP}	(6±13±6)×10^{-3}	–
$\Delta\phi^\Xi_{CP}$	(−5±14±3)×10^{-3} rad	–
A^Λ_{CP}	(−4±12±9)×10^{-3}	(−6±12±7)×10^{-3}
$\langle\phi_\Xi\rangle$	0.016±0.014±0.007 rad	

First measurement of the Ξ^- polarization in J/ψ decay

First direct and simultaneously measurement of the charged Ξ decay parameters

First measurement of weak phase difference in Ξ decay

Three independent *CP* tests

HyperCP: $\phi_{\Xi,HyperCP} = -0.042 \pm 0.011 \pm 0.011$

BESIII: $<\phi_\Xi>$ =0.016±0.014±0.007

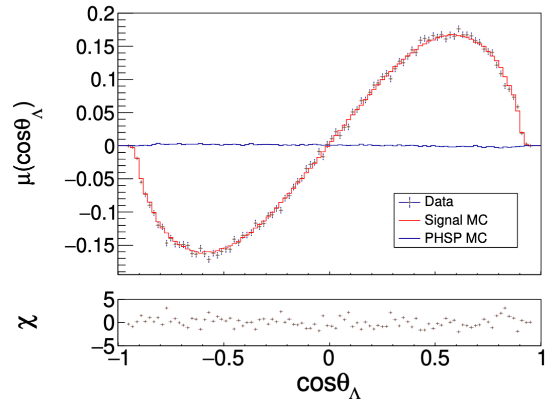
We obtain the same precision for ϕ as HyperCP with ***three orders of magnitude*** smaller data sample!

HyperCP: PRL 93(2004) 011802

Polarization behavior in different hyperon pair productions

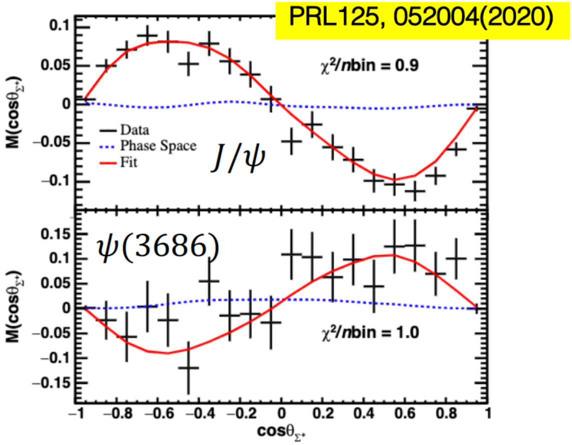
$J/\psi \to \Lambda\bar{\Lambda}$

PRL129, 131801(2022)



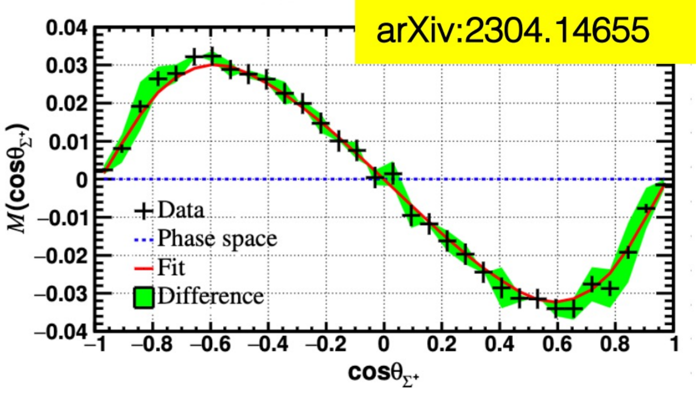
$$\Delta\Phi = (0.7521 \pm 0.0042 \pm 0.0066)\, rad$$
$$A_{CP} = -0.0025 \pm 0.0046 \pm 0.0012$$

$\psi \to \Sigma^+\bar{\Sigma}^- \to p\pi^0\bar{p}\pi^0$



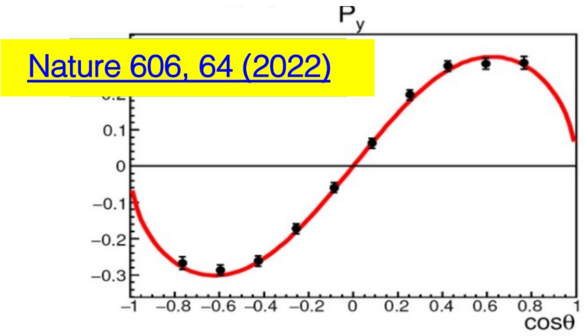
$$\Delta\Phi(J/\psi) = (-15.5 \pm 0.7 \pm 0.5)^\circ$$
$$\Delta\Phi(\psi(2S)) = (21.7 \pm 4.0 \pm 0.8)^\circ$$
$$A_{CP} = -0.004 \pm 0.037 \pm 0.010$$

$J/\psi \to \Sigma^+\bar{\Sigma}^- \to n\pi^+\bar{p}\pi^0$



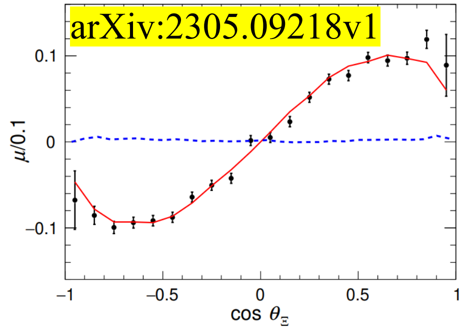
$$\Delta\Phi = (-0.277 \pm 0.004 \pm 0.004)\, rad$$
$$A_{CP} = -0.080 \pm 0.052 \pm 0.028$$

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



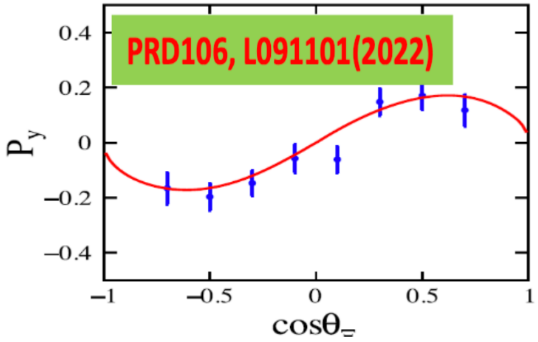
$$\Delta\Phi = (1.213 \pm 0.046 \pm 0.016)\, rad$$
$$A_{CP} = -0.006 \pm 0.013 \pm 0.006$$

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



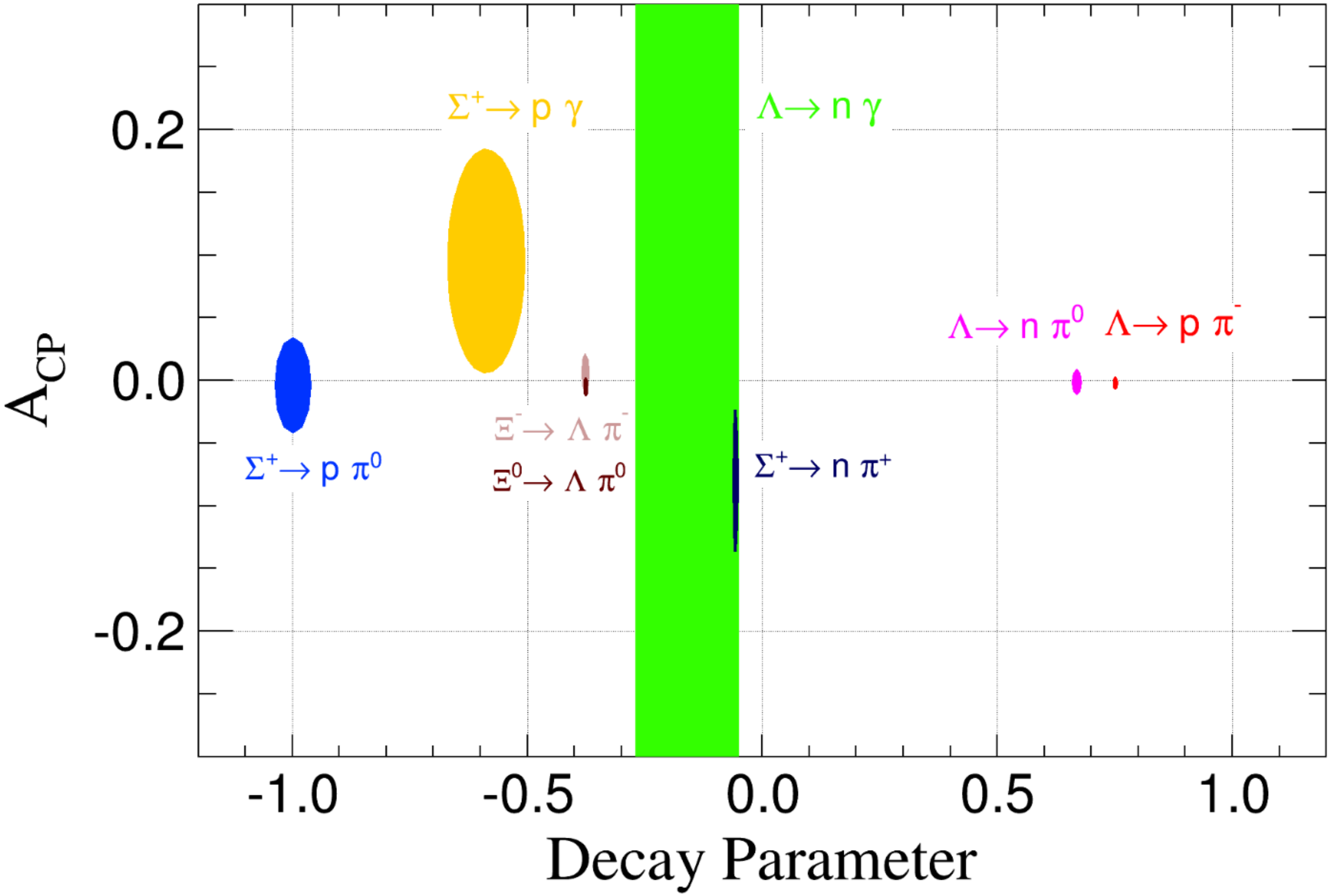
$$\Delta\Phi = (1.168 \pm 0.019 \pm 0.018)\, rad$$
$$A_{CP} = -0.0054 \pm 0.0065 \pm 0.0031$$

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



$$\Delta\Phi = (0.667 \pm 0.111 \pm 0.058)\, rad$$
$$A_{CP} = -0.015 \pm 0.051 \pm 0.010$$

Summary of BESIII achievement on hyperon decay



Summary of BESIII achievement on hyperon decay

Parameters	$\Lambda\bar{\Lambda}$	$\Sigma^+\bar{\Sigma}^-$	$\Xi^-\bar{\Xi}^+$	$\Xi^0\bar{\Xi}^0$
	PRL 129, 131801(2022)	PRL 125,052004(2020)	Nature 606,64(2022)	Phys.Rev.D 108 (2023) 3, L031106
α_{Ξ^-/Ξ^0}	-	-	$-0.376 \pm 0.007 \pm 0.003$	$-0.3750 \pm 0.0034 \pm 0.0016$
$\alpha_{\bar{\Xi}^+/\bar{\Xi}^0}$	-	-	$0.371 \pm 0.007 \pm 0.002$	$0.3790 \pm 0.0034 \pm 0.0021$
ϕ_{Ξ^-/Ξ^0}	-	-	$0.011 \pm 0.019 \pm 0.009$	$0.0051 \pm 0.0096 \pm 0.0018$
$\phi_{\bar{\Xi}^+/\bar{\Xi}^0}$	-	-	$-0.021 \pm 0.019 \pm 0.007$	$-0.0053 \pm 0.0097 \pm 0.0019$
$A_{CP}(\Xi^-/\Xi^0)$	-	-	$0.006 \pm 0.013 \pm 0.006$	$-0.0054 \pm 0.0065 \pm 0.0031$
$\Delta\phi_{CP}(\Xi^-/\Xi^0)$	-	-	$-0.005 \pm 0.014 \pm 0.003$	$-0.0001 \pm 0.0069 \pm 0.0009$
$\alpha_{\Lambda/\Sigma^+}$	$0.7519 \pm 0.0036 \pm 0.0024$	$-0.998 \pm 0.037 \pm 0.009$	$0.757 \pm 0.011 \pm 0.008$	$0.7551 \pm 0.0052 \pm 0.0023$
$\alpha_{\bar{\Lambda}/\bar{\Sigma}^-}$	$-0.7559 \pm 0.0036 \pm 0.0030$	$0.990 \pm 0.037 \pm 0.011$	$-0.763 \pm 0.011 \pm 0.007$	$-0.7448 \pm 0.0052 \pm 0.0023$
$A_{CP}(\Lambda/\Sigma^+)$	$-0.0025 \pm 0.0046 \pm 0.0012$	$-0.004 \pm 0.037 \pm 0.010$	$-0.004 \pm 0.012 \pm 0.009$	$0.0069 \pm 0.0058 \pm 0.0018$

BESIII best measurements: $A_{CP}^{\Lambda} = -0.0025 \pm 0.0046 \pm 0.0012$

Systematic uncertainties are well controlled!

- Excellent performance of BESIII detectors.
- Data-driven method to study data-MC inconsistency.

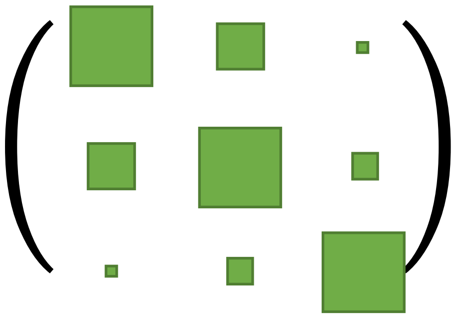
Hyperon CP test in future plans

CPV in Standard Model

CKM mechanism:

$\boxed{CPV \text{ from phase } \delta}$

$$V_{\text{CKM}} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & \boxed{s_{13}e^{-i\delta}} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ \boxed{s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta}} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix}$$



Dirac Medal 2010

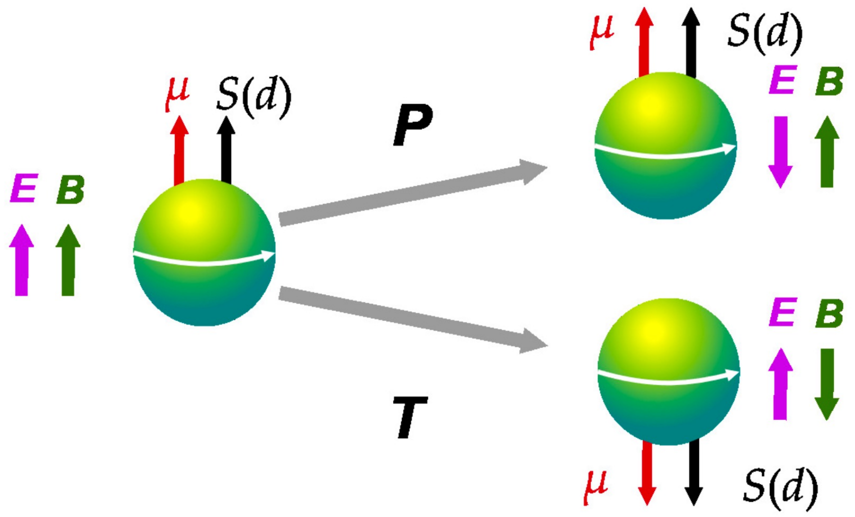
Nobel Price 2008

Strong CP

- $\bar{\theta}$ term： $\mathcal{L}_{\bar{\theta}} = -\frac{\alpha_s}{16\pi^2}\bar{\theta}\mathrm{Tr}(G^{\mu\nu}\tilde{G}_{\mu\nu})$
- Mainly through measuring the Electric Dipole Moment (EDM) of atomic nuclei, atoms, and molecular systems,
- The current most stringent constraints come from the EDM experiments of neutrons and 199Hg： $\bar{\theta} < 10^{-10}$

Electric Dipole Moment

μ: magnetic dipole moment
d: electric dipole moment
S: particle spin



$$\mathcal{H} = -\boldsymbol{\mu}\cdot\mathbf{B} - \boldsymbol{\delta}\cdot\mathbf{E} \xrightarrow{P} \mathcal{H} = -\boldsymbol{\mu}\cdot\mathbf{B} + \boldsymbol{\delta}\cdot\mathbf{E}$$

$$\mathcal{H} = -\boldsymbol{\mu}\cdot\mathbf{B} - \boldsymbol{\delta}\cdot\mathbf{E} \xrightarrow{T} \mathcal{H} = -\boldsymbol{\mu}\cdot\mathbf{B} + \boldsymbol{\delta}\cdot\mathbf{E}$$

Non-zero EDM will violate P and T symmetry:
T violation $\leftrightarrow$ CP violation, if CPT holds.

The contribution of the Standard Model to EDM is very small:

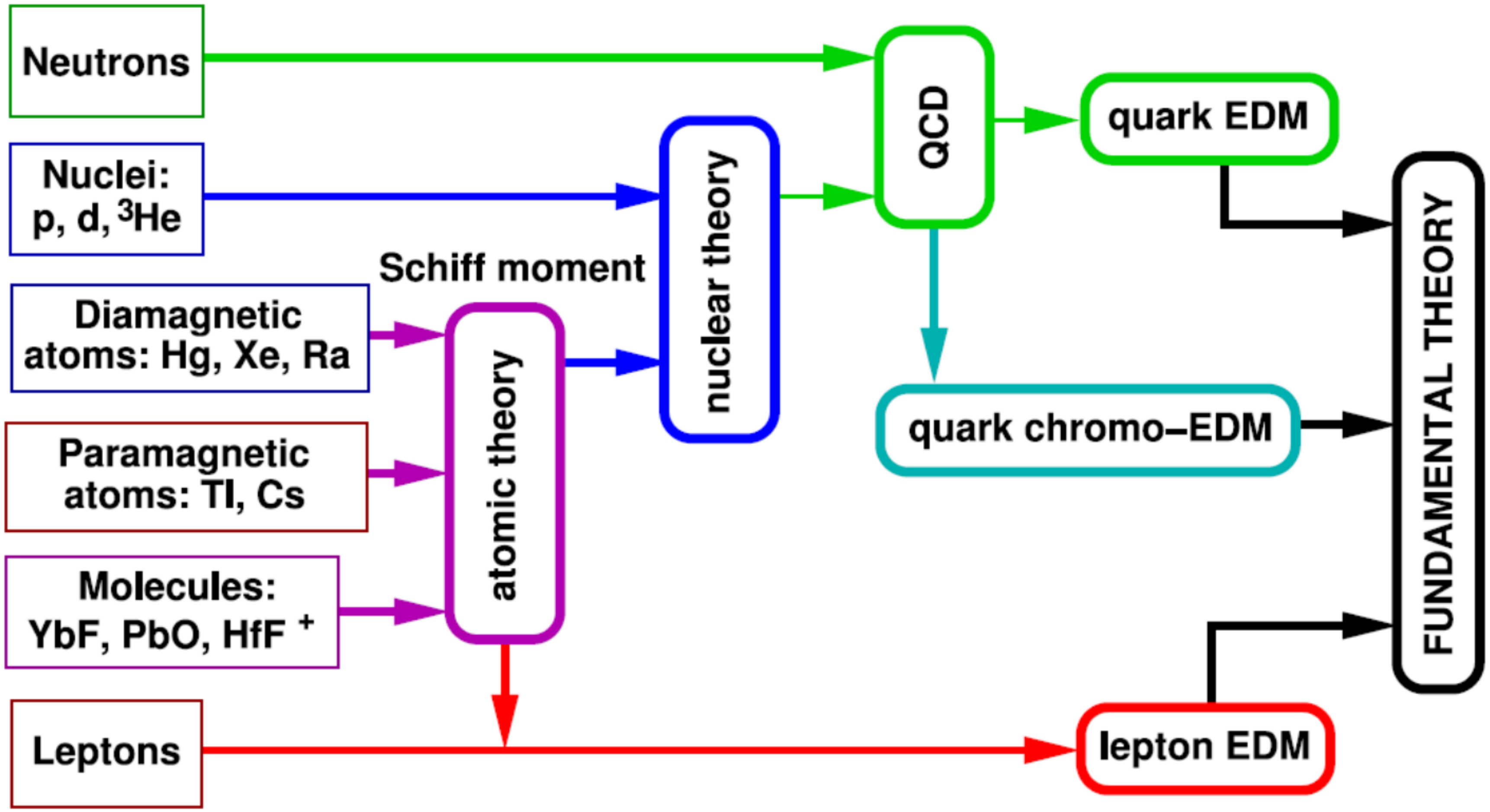
- CKM: highly suppressed by loop level (≥ 3) interaction
- QCD $\bar{\theta}$ term: main SM contributors to the EDM, $\bar{\theta} < 10^{-10}$
  - limited by neutron EDM:

$$d_n < 1.6\times 10^{-26}\ ecm$$

$$\mathcal{L}_{\rm CPV} = \mathcal{L}_{\rm CKM} + \mathcal{L}_{\bar{\theta}} + \mathcal{L}_{\rm BSM}^{\rm eff}$$

Very sensitive to BSM physics, large windows of opportunity for observing New Physics!

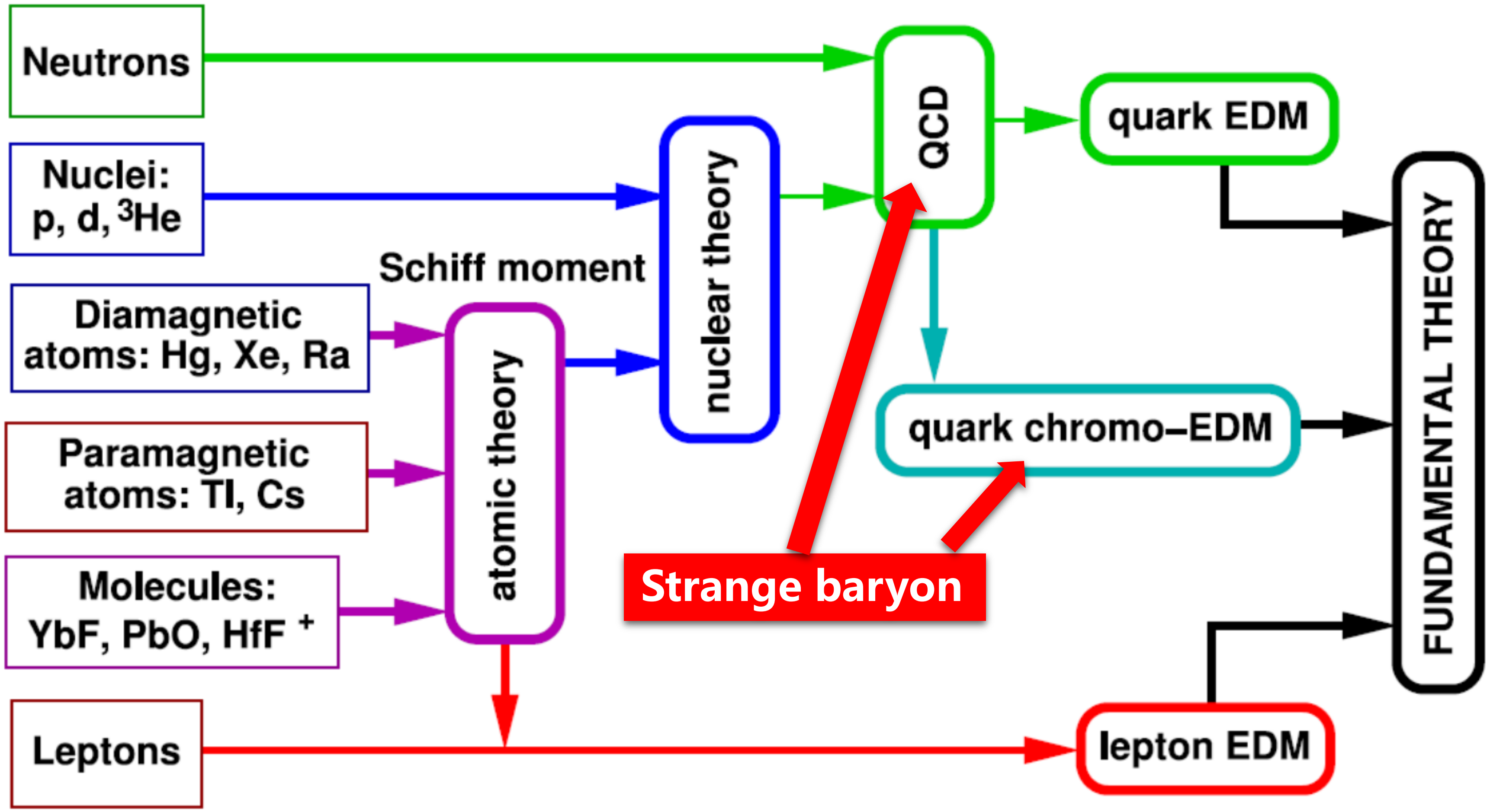
Map of EDM



C. R. Physique 13 168 (2012)

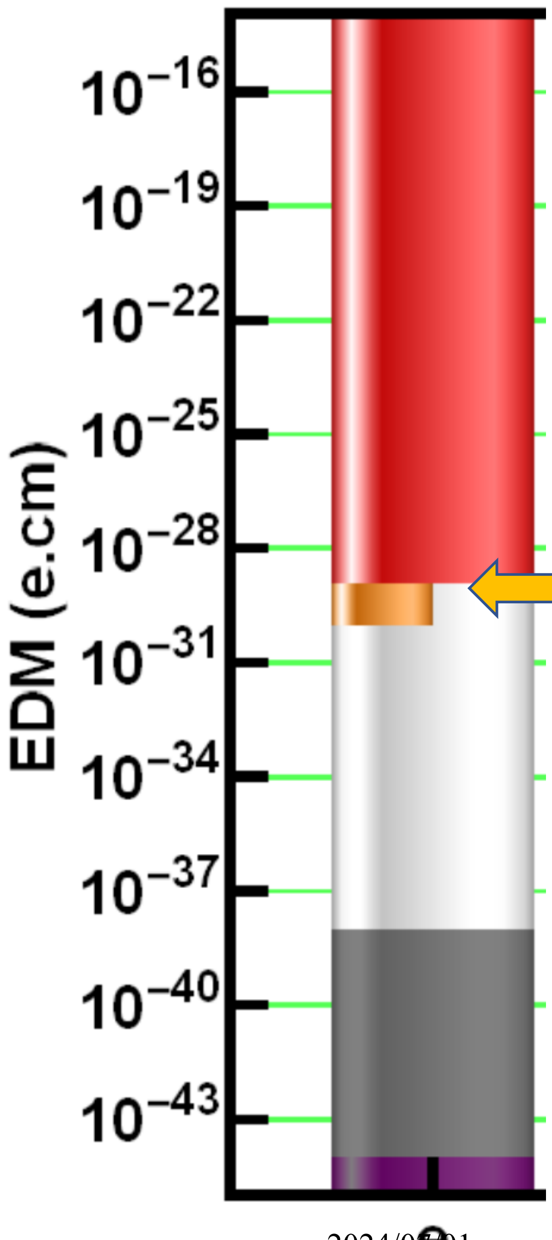
Map of EDM

The identification of the nature of the fundamental CP-violating mechanisms requires the study of EDMs in various systems



C. R. Physique 13 168 (2012)

ILLUSTRATION of EDM STATUS



Best measurements
Limits from experimental results

Expected experimental results
in the next few years

Safe BSM discovery territory

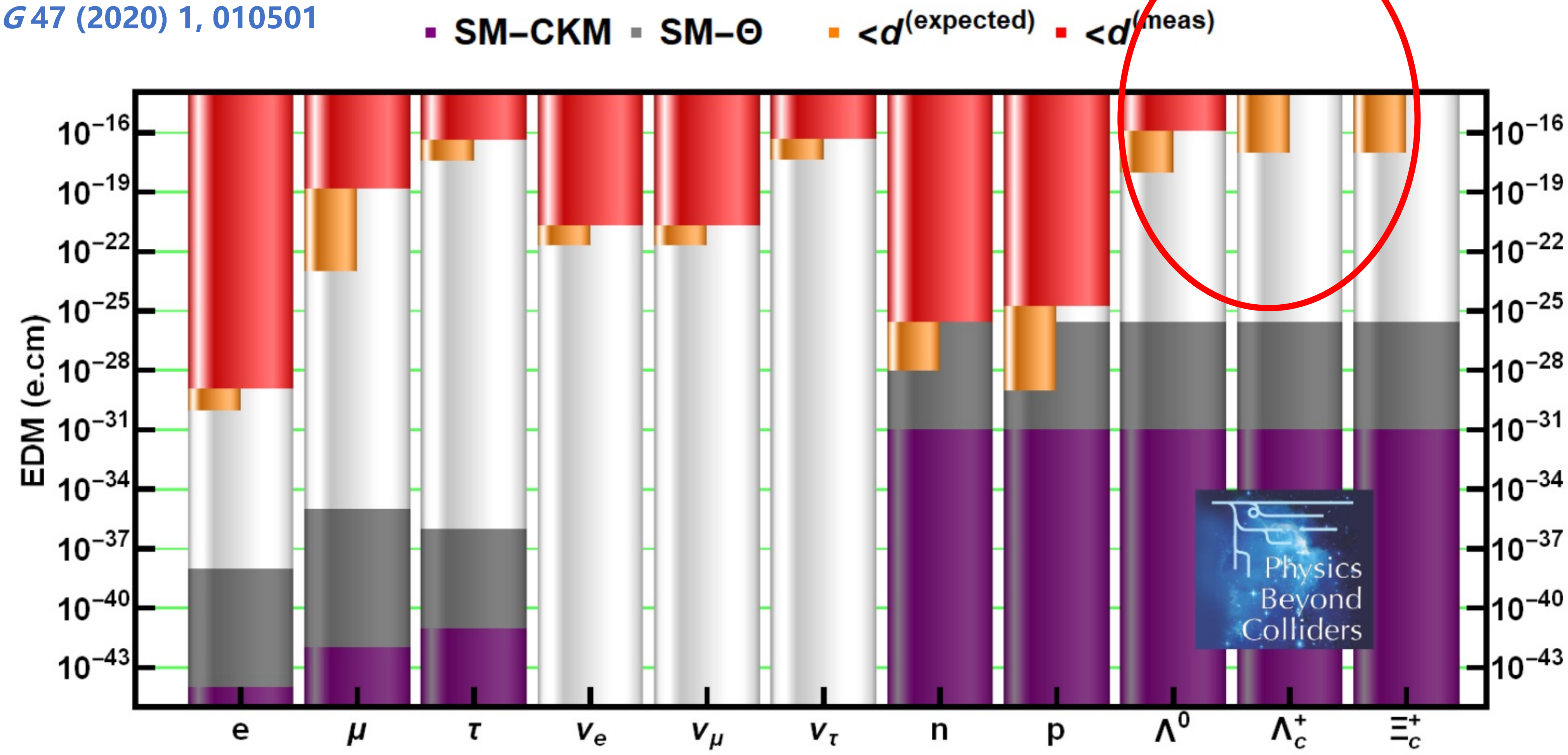
SM estimates from QCD $\bar{\theta}$ term

SM estimates from CKM

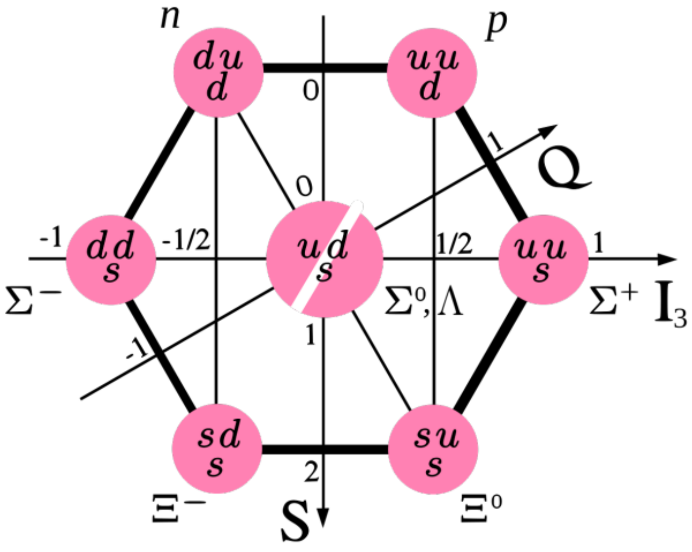
EDM Status

Only Λ hyperon has been measured with a large uncertainty!

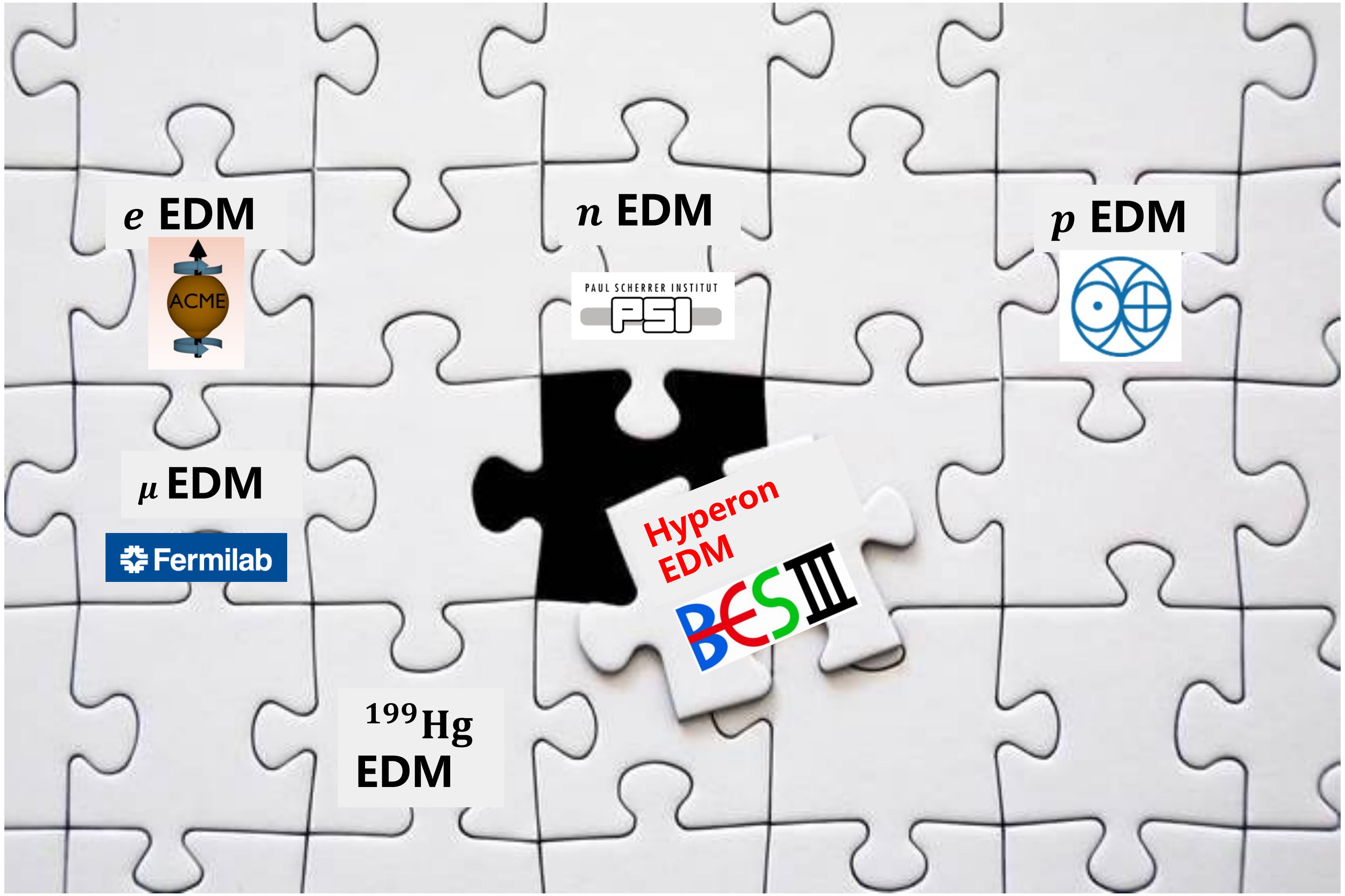
J.Phys.G 47 (2020) 1, 010501



What can BESIII / STCF do for EDM?



$+\ \Omega^-(sss)$ spin-$\frac{3}{2}$



What can BESIII / STCF do for EDM?

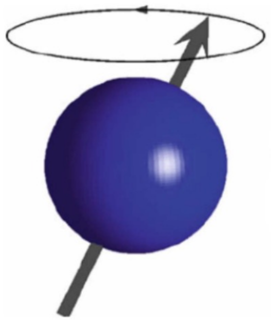
- Direct approach：spin procession 难以用来测量短寿命粒子的EDM

$$\frac{d\mathbf{s}}{dt} = \mathbf{s} \times \boldsymbol{\Omega}$$

$$\boldsymbol{\Omega} = \boldsymbol{\Omega}_{\mathrm{MDM}} + \boldsymbol{\Omega}_{\mathrm{EDM}} + \boldsymbol{\Omega}_{\mathrm{TH}}$$

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

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



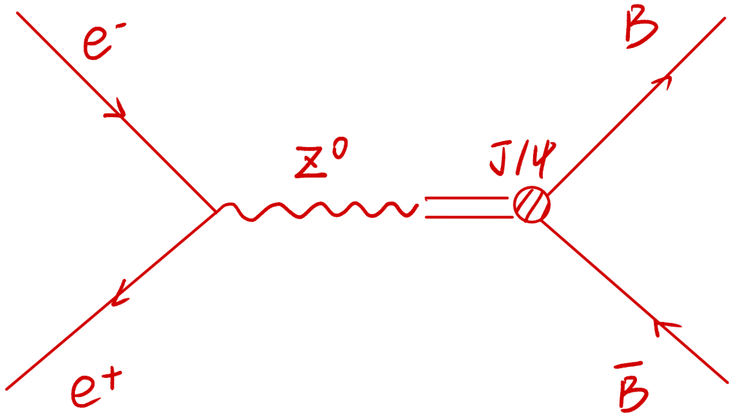
- Indirect approach：time-like dipole form factors ($q^2 \neq 0$)

$$L_{\mathrm{dipole}} = i\frac{d_\Lambda}{2}\bar{\Lambda}\sigma_{\mu\nu}\gamma_5\Lambda F^{\mu\nu}$$

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

X.G.He, J.P. Ma, Bruce McKellar, Phys.Rev.D47(1993)1744
X.G.He, J.P. Ma, Phys.Lett.B 839(2023)137834

Polarization of J/ψ



Considering Z^0 contribution:
J/ψ has longitude polarization:
denoted by P_L

$\rho_{mm'}$: J/ψ spin density matrix

No beam polarization:

$$P_L = \frac{\rho_{++} - \rho_{--}}{\rho_{++} + \rho_{--}}$$

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

With beam polarization:

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

Can be used for precise measurement beam polarization

Spin density matrix of hyperon-antihyperon

Polarization effects encoded in hyperon pair spin density matrix

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

Lorentz invariance introduces P and CP violation form factors in helicity amplitude

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

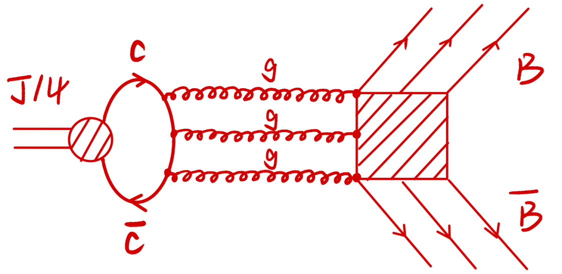
X.G.He, J.P. Ma, Bruce McKellar, Phys.Rev.D47(1993)1744

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

Dynamics in $J/\psi \to B\bar{B}$

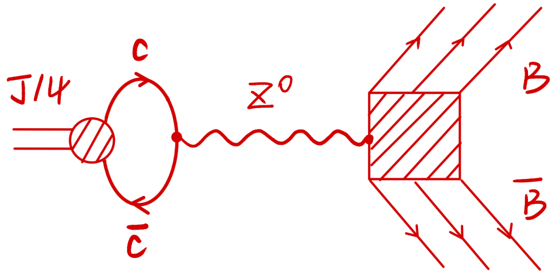
Detailed dynamics in J/ψ decay to hyperon pair, have been studied: X.G.He, J.P. Ma, Phys.Lett.B 839(2023)137834

$$\mathcal{A} = \epsilon_\mu(\lambda)\bar{u}(\lambda_1)\left(\boldsymbol{F_V}\gamma^\mu + \frac{i}{2M_\Lambda}\sigma^{\mu\nu}q_\nu \boldsymbol{H_\sigma} + \gamma^\mu\gamma^5 \boldsymbol{F_A} + \sigma^{\mu\nu}\gamma^5 q_\nu \boldsymbol{H_T}\right)\nu(\lambda_2)$$



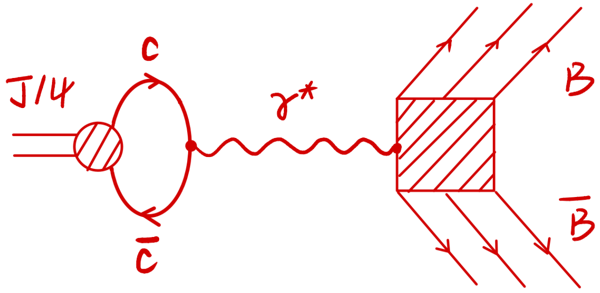
Dominant contribution
arXiv:hep-ph/0412158

Psionic form factor
$\boldsymbol{F_V}$ and $\boldsymbol{H_\sigma}$
can also be represented as $\boldsymbol{G_1}$ and $\boldsymbol{G_2}$



$\boldsymbol{F_A}$: $\boldsymbol{P}$ violation term

Complex form factor, $F_A \neq 0$ indicate P violation



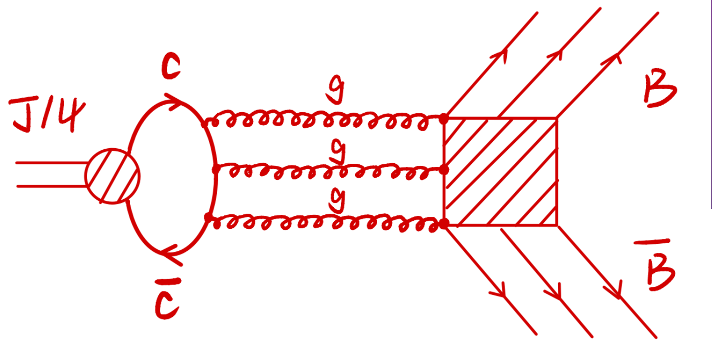
$\boldsymbol{H_T}$: $\boldsymbol{CP}$ violation term

$$H_T(q^2) = \frac{2e}{3m_{J/\psi}^2} g_V d_B(q^2)$$

Assuming $d_B(q^2) \equiv d_B(0)$

$d_B(q^2)$: electric dipole form factor
$d_B(0)$: electric dipole moment
Physics Letters B 551 (2003) 16–26

Psionic form factors G_1, G_2



Psionic form factors

$$F_V = G_1 - \frac{4M^2}{Q^2}(G_1 - G_2) \qquad H_\sigma = \frac{4M^2}{Q^2}(G_1 - G_2)$$

Hyperon polarization parameters

$$\alpha_{J/\psi} = \frac{s\left|G_1\right|^2 - 4m^2\left|G_2\right|^2}{s\left|G_1\right|^2 + 4m^2\left|G_2\right|^2} \qquad \frac{G_1}{G_2} = \left|\frac{G_1}{G_2}\right| e^{-i\Delta\Phi}$$

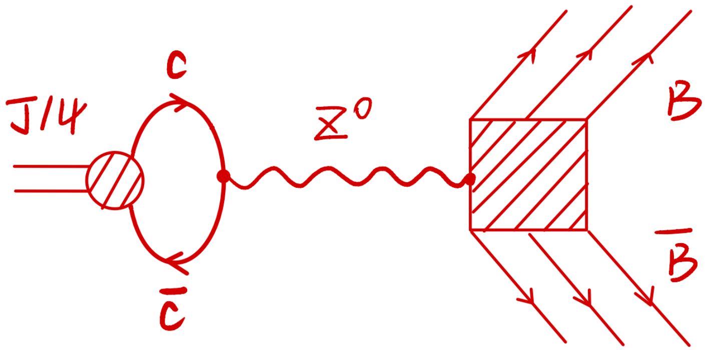
X.G.He, J.P. Ma, Bruce McKellar, Phys.Rev.D47(1993)1744

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

Göran Fäldt, Andrzej Kupsc Physics Letters B 772 (2017) 16–20

- G_1 can be extracted from the measurement of $\Gamma(J/\psi \to B\overline{B})$

P violation form factor F_A



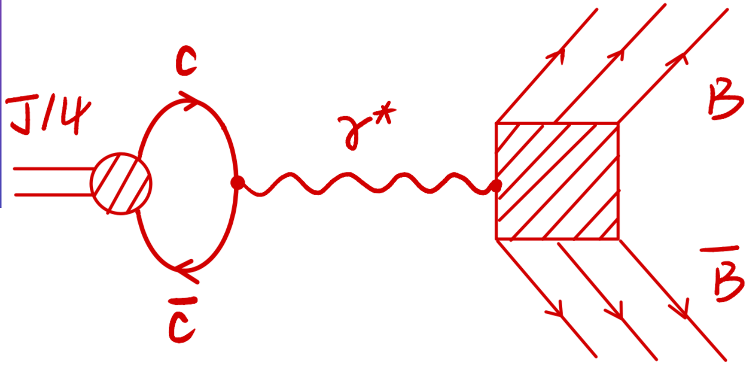
Primarily from Z-boson exchange between $c\bar{c}$ and light quark pairs

Related to weak mixing angle in SM

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

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

CP violation form factor H_T



Several CPV sources contributed to H_T

Take hyperon EDM as the major source for H_T

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

Neglect q dependence, d_B for hyperon EDM

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

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

Full angular helicity amplitude of $e^+e^- \to J/\psi \to B\bar{B}$

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

Angular formular based on helicity amplitude are developed:

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

Total angular distribution of J/ψ to spin-1/2 baryon pair:

- $J/\psi \to B\bar{B}, B = \Lambda^0, \Sigma^-, \Sigma^+$

$$\frac{d\sigma}{d\Omega_k d\Omega_p d\Omega_{\bar{p}}} = \boldsymbol{N} \sum_{[\lambda]} \boldsymbol{R(\lambda_1,\lambda_2;\lambda_1',\lambda_2')}\, \boldsymbol{D^{j=1/2}_{\lambda_1,\lambda_p}(\theta_1,\phi_1) D^{*j=1/2}_{\lambda_1',\lambda_p}(\theta_1,\phi_1) \left|h_{\lambda_p}\right|^2 D^{j=1/2}_{\lambda_2,\lambda_{\bar{p}}}(\theta_2,\phi_2) D^{*j=1/2}_{\lambda_2',\lambda_{\bar{p}}}(\theta_2,\phi_2) \left|h_{\lambda_{\bar{p}}}\right|^2}$$

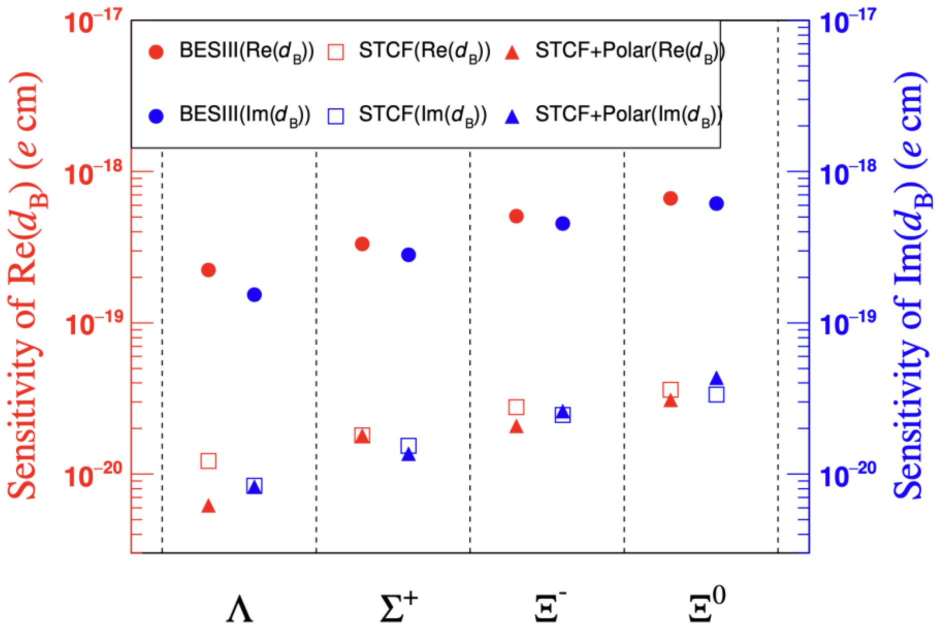
- $J/\psi \to B\bar{B}, B = \Xi^0, \Xi^-$

$$\frac{d\sigma}{d\Omega_k d\Omega_\Lambda d\Omega_{\bar{\Lambda}} d\Omega_p d\Omega_{\bar{p}}} = \boldsymbol{N} \sum_{[\lambda]} \boldsymbol{R(\lambda_1,\lambda_2;\lambda_1',\lambda_2')}\, \boldsymbol{D^{*j=1/2}_{\lambda_1,\lambda_\Lambda}(\theta_1,\phi_1) D^{j=1/2}_{\lambda_1',\lambda'_\Lambda}(\theta_1,\phi_1) \mathcal{H}_{\lambda_\Lambda} \mathcal{H}^*_{\lambda_\Lambda'} D^{*j=1/2}_{\lambda_2,\lambda_{\bar{\Lambda}}}(\theta_2,\phi_2)}$$

$$\boldsymbol{D^{j=1/2}_{\lambda_2',\lambda'_{\bar{\Lambda}}}(\theta_2,\phi_2) \mathcal{H}_{\lambda_{\bar{\Lambda}}} \mathcal{H}^*_{\lambda_{\bar{\Lambda}}'} D^{*j=1/2}_{\lambda_\Lambda,\lambda_p}(\theta_3,\phi_3) D^{*j=1/2}_{\lambda_\Lambda',\lambda_p}(\theta_3,\phi_3) \left|h_{\lambda_p}\right|^2 D^{*j=1/2}_{\lambda_{\bar{\Lambda}},\lambda_{\bar{p}}}(\theta_4,\phi_4) D^{j=1/2}_{\lambda_{\bar{\Lambda}}',\lambda_{\bar{p}}}(\theta_4,\phi_4) \left|h_{\lambda_{\bar{p}}}\right|^2}$$

Sensitivity of hyperon EDM measurements

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



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

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

Sensitivity of CP violation in hyperon decay

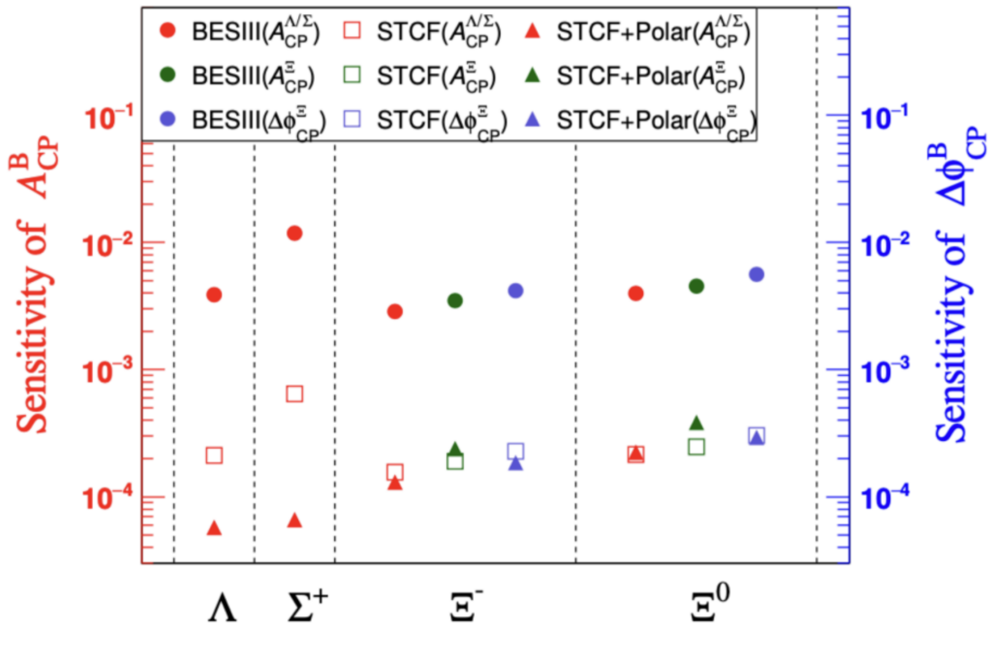
N.G.Deshpande et al, PLB326(1994)307
J.Tandean et al, PRD67(2003)056001
J.F.Donoghue et al, PRD34(1986)833

reminder:

$$A_{CP}^{B} = (\alpha_B + \bar{\alpha}_B)/(\alpha_B - \bar{\alpha}_B)$$

$$\Delta\phi_{CP}^{B} = (\phi_B + \bar{\phi}_B)/2$$

SM: $10^{-4} \sim 10^{-5}$



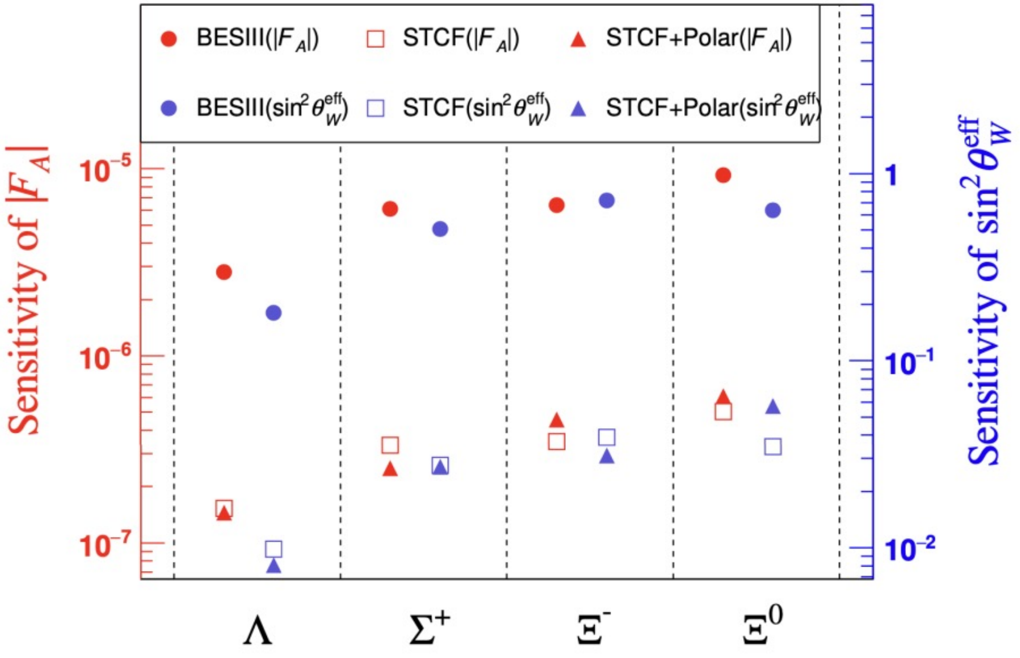
(b)Sensitivity of A_{CP}^{B} and $\Delta\phi_{CP}^{B}$

STCF:

SM prediction can be reached and further improved with a longitudinally polarized electron beam

Sensitivity of F_A and $\sin^2\theta_W^{eff}$ measurements

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



(c)Sensitivity of $|F_A|$ and $\sin^2\theta_W^{\text{eff}}$

SM: $F_A \sim 10^{-6}$

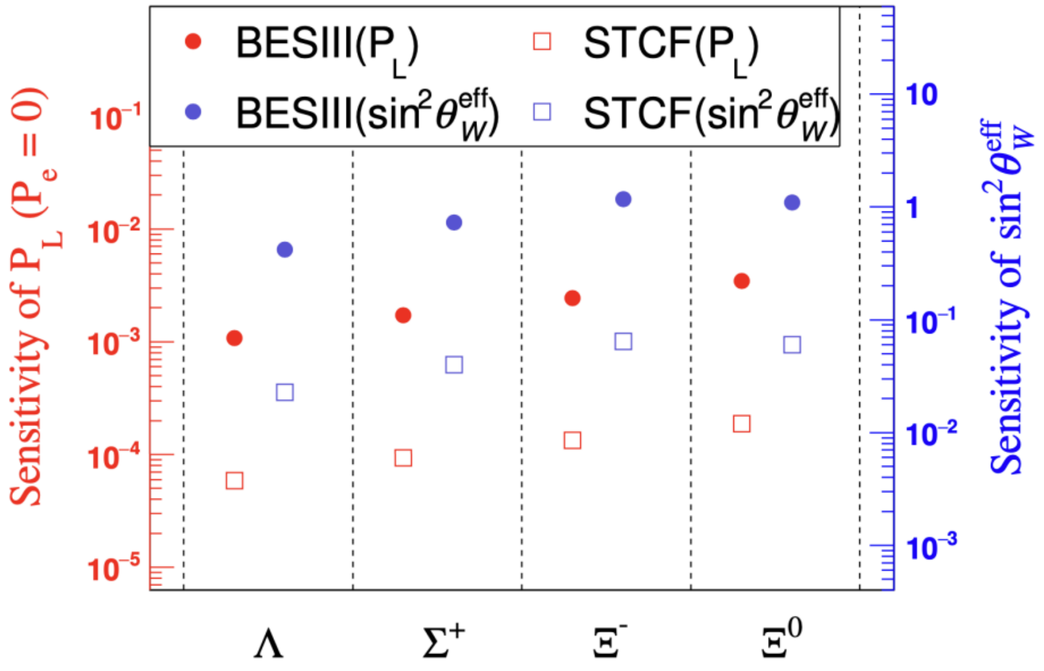
$\sin^2\theta_W^{\text{eff}} \sim 0.235$

STCF:

Weak mixing angle at $Q = M_{J/\psi}$ can be determined at the level of 8×10^{-3}

Sensitivity of P_L and $\sin^2\theta_W^{\text{eff}}$ measurements

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



(d)Sensitivity of P_L

SM: $P_L \sim 10^{-4}$

$\sin^2\theta_W^{\text{eff}} \sim 0.235$

STCF:

Weak mixing angle at $Q = M_{J/\psi}$ can be determined at the level of 2×10^{-2}

Sensitivity of $\sin^2\theta_W^{\mathrm{eff}}$ by simultaneous fit

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

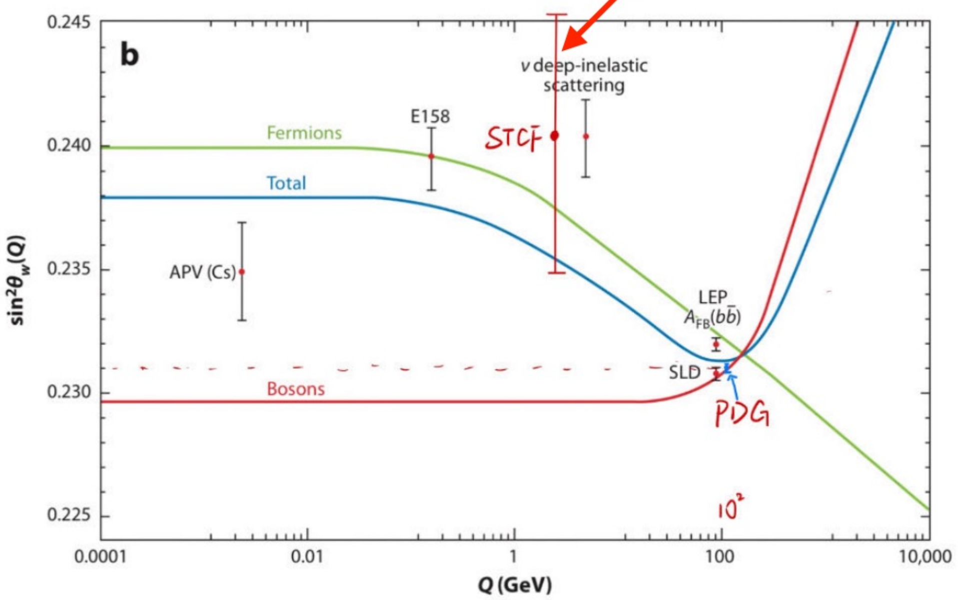


Figure 1

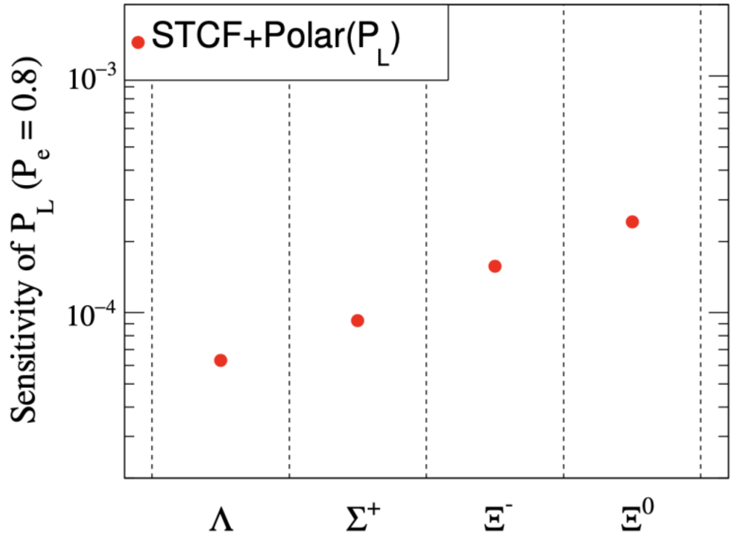
(*a*) $\sin^2\theta_W(\mu)_{\overline{\mathrm{MS}}}$ (29) with an updated atomic parity violation (APV) result. (*b*) $\sin^2\theta_W(Q^2)$, a one-loop calculation dominated by $\gamma - Z^0$ mixing (52). The red and green curves represent the boson and fermion contributions, respectively.

K.S.Kumar et al, Ann.Rev.Nucl.Part.Sci. 63 (2013) 237-267

Weak mixing angle shared by F_A and P_L

Sensitivity improved at the level 5×10^{-3}

Sensitivity of beam polarization measurements



Precisely measured beam polarization (10^{-5}) as input value for $\sin^2\theta_W^{\text{eff}}$ measurement

A. Bondar et al, JHEP 03 (2020) 076

$$\boxed{\mathcal{A}_{\text{LR}} \equiv \frac{\sigma_{\mathcal{P}_e} - \sigma_{-\mathcal{P}_e}}{\sigma_{\mathcal{P}_e} + \sigma_{-\mathcal{P}_e}}} = \mathcal{A}^0_{\text{LR}} \boxed{\mathcal{P}_e}$$

$$\sigma_{\mathcal{P}_e} = \frac{N_{\mathcal{P}_e}}{\mathcal{L}_{\mathcal{P}_e}\varepsilon_{\text{eff}}}$$

$$\sigma_{-\mathcal{P}_e} = \frac{N_{-\mathcal{P}_e}}{\mathcal{L}_{-\mathcal{P}_e}\varepsilon_{\text{eff}}}$$

analysis Bhabha scattering events

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

Summary and Outlooks

- Highlights of hyperon physics at BESIII:
  - Precision measurements of hyperon decay parameters, polarization and CP asymmetry:
    - complementary to CPV studies with Kaons
    - BESIII has already rewritten the PDG book for Λ and Ξ decays
    - results of $\Sigma^{\pm}, \Xi$ with 10 billion J/ψ will be coming soon

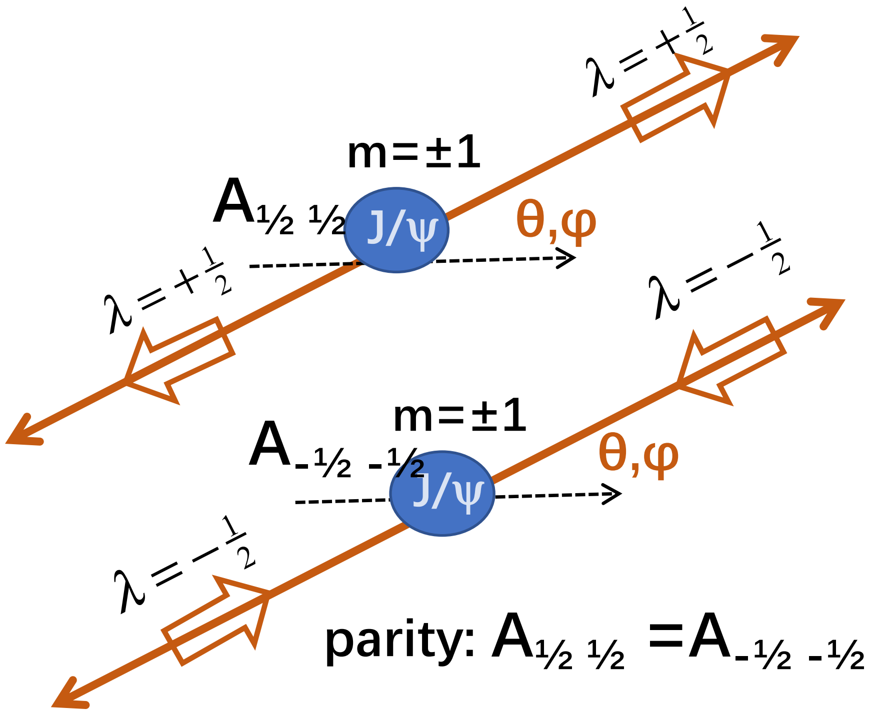
  - Hyperon electric dipole moments measurements
    - First measurements of $\Sigma^{+,0}, \Xi^{-}, \Xi^{0}, \Omega$ hyperons EDM
    - The sensitivity of the hyperon EDM can be reached at the order of 10^{-19}

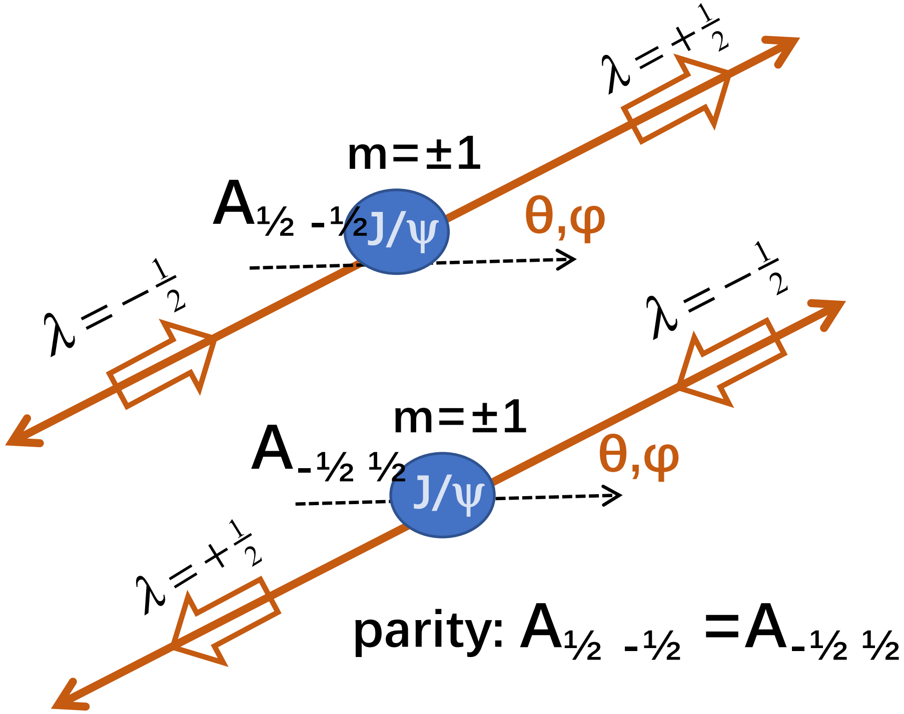

www.thank you.com

Backup

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

Production: 2 independent helicity amplitudes: $A_{½\,½}$, $A_{½\,-½}$





ΔΦ= complex phase between $A_{½\,½}$ and $A_{½\,-½}$

$$\frac{d|\mathcal{M}|^2}{d\cos\theta} \propto (1+\alpha_{J/\psi}\cos^2\theta), \quad \text{with} \quad \alpha_{J/\psi} = \frac{|A_{1/2,-1/2}|^2 - 2|A_{1/2,1/2}|^2}{|A_{1/2,-1/2}|^2 + 2|A_{1/2,1/2}|^2}$$

EM form-factors and Helicity Amplitudes

Phys.Rev.D99,056008

$$h_2 \equiv A_{1/2,-1/2} = A_{-1/2,1/2} = \sqrt{1+\alpha_\psi}\, e^{-i\Delta\Phi}$$

$$h_1 \equiv A_{1/2,1/2} = A_{-1/2,-1/2} = \sqrt{1-\alpha_\psi}/\sqrt{2}$$

Phys.Lett.B772,16

$$\alpha_\psi = \frac{s|G_M|^2 - 4M^2|G_E|^2}{s|G_M|^2 + 4M^2|G_E|^2}$$

$$\frac{G_E}{G_M} = e^{i\Delta\Phi}\left|\frac{G_E}{G_M}\right|$$

where s is the square of $p_B + p_{\bar{B}}$ and M is the mass of $B(\bar{B})$.

Relation:

$$h_2 = \frac{\sqrt{2s}}{\sqrt{s|G_M|^2 + 4M^2|G_E|^2}}\, G_M$$

$$h_1 = \frac{2M}{\sqrt{s|G_M|^2 + 4M^2|G_E|^2}}\, G_E$$

CPV observables in $\Xi^- \to \Lambda\pi$ decay

decay rate difference

$$\frac{\Gamma_{\bar{\Lambda}\pi^+} - \Gamma_{\Lambda\pi^-}}{\Gamma} \equiv 0$$

← $\Lambda\pi$ final states are purely Ispin=1, only $\Delta I=1/2$ transitions allowed, no $\Delta I=3/2$ transition possible

decay asymmetry difference

$$\alpha_{\mp} = \pm\frac{2\,\mathrm{Re}(S^*P)}{|S|^2+|P|^2} = \pm\frac{2|S||P|\cos\left(\Delta_S \pm \phi_{CP}\right)}{|S|^2+|P|^2}$$

$$\frac{\alpha_- + \alpha_+}{\alpha_- - \alpha_+} = \frac{\sin\Delta_S \sin\phi_{CP}}{\cos\Delta_S \cos\phi_{CP}} = \tan\Delta_S \tan\phi_{CP}$$

← in this case, the strong phase ($\Delta_s = \delta_S - \delta_P$) is measureable (see below)

final-state polarization difference

$$\beta_{\mp} = \pm\frac{2\,\mathrm{Im}(S^*P)}{|S|^2+|P|^2} = \pm\frac{2|S||P|\sin\left(\Delta_S \pm \phi_{CP}\right)}{|S|^2+|P|^2}$$

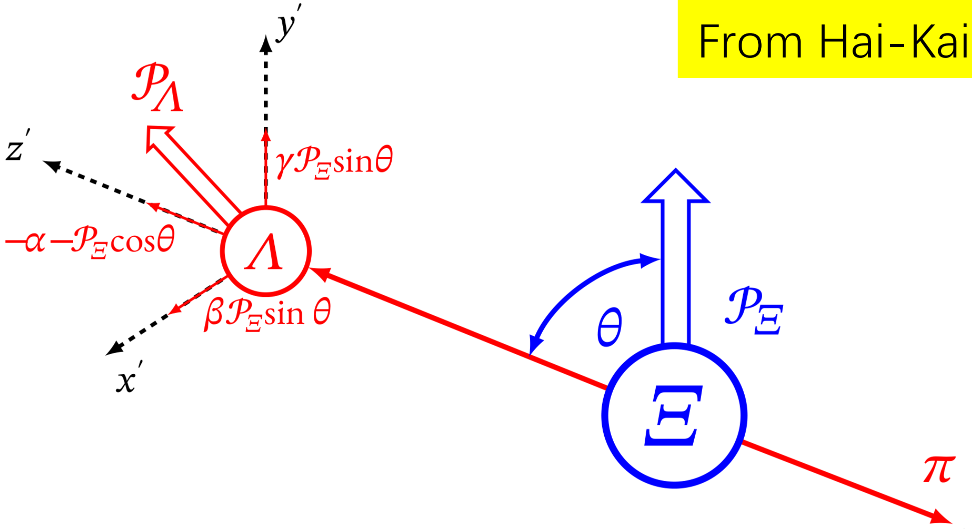
$$\frac{\beta_- + \beta_+}{\alpha_- - \alpha_+} = \frac{\cos\Delta_S \sin\phi_{CP}}{\cos\Delta_S \cos\phi_{CP}} = \tan\phi_{CP}$$

← Strong phase cancels out

$$\frac{\beta_- - \beta_+}{\alpha_- - \alpha_+} = \frac{\sin\Delta_S \cos\phi_{CP}}{\cos\Delta_S \cos\phi_{CP}} = \tan\Delta_S$$

← measures the strong phase

big advantage for Ξ over Λ



From Hai-Kai Sun

$$\alpha=\frac{2\mathrm{Re}(S^*\cdot P)}{|S|^2+|P|^2}\qquad \beta=\frac{2\mathrm{Im}(S^*\cdot P)}{|S|^2+|P|^2}\qquad \gamma=\frac{|S|^2-|P|^2}{|S|^2+|P|^2}$$

$$\beta=\sqrt{1-\alpha^2}\sin\phi_\Xi\qquad \gamma=\sqrt{1-\alpha^2}cos\phi_\Xi$$

$$\alpha^2+\beta^2+\gamma^2=1\qquad tan\phi_\Xi=\frac{\beta}{\gamma}$$

Both α and ϕ_Ξ of $\Xi(\bar{\Xi})$ can be measured via $J/\psi\to\Xi\bar{\Xi}$ at BESIII!

$$\alpha_{\mp}=\pm\frac{2\mathrm{Re}(S^*\cdot P)}{|S|^2+|P|^2}=\pm\frac{|S||P|\cos(\Delta_s\pm\Delta_w)}{|S|^2+|P|^2}\qquad \beta_{\mp}=\pm\frac{2\mathrm{Im}(S^*\cdot P)}{|S|^2+|P|^2}=\pm\frac{|S||P|\sin(\Delta_s\pm\Delta_w)}{|S|^2+|P|^2}$$


Sandip PAKVASA

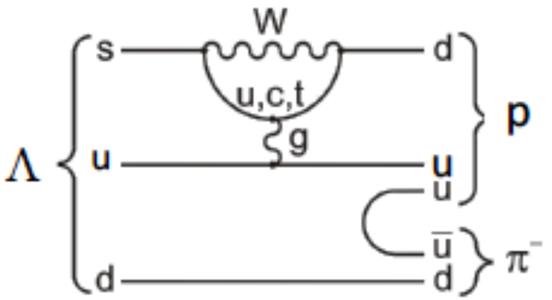

X.G. He


John Donoghue

$$\frac{\beta_- -\beta_+}{\alpha_- -\alpha_+}=\frac{\sin\Delta_s\cos\Delta_w}{\cos\Delta_s\cos\Delta_w}=\tan\Delta_s\qquad \frac{\beta_- +\beta_+}{\alpha_- -\alpha_+}=\frac{\cos\Delta_s\sin\Delta_w}{\cos\Delta_s\cos\Delta_w}=\tan\Delta_w$$

Constraints from Kaon decays

He & Valencia PRD 52, 5257

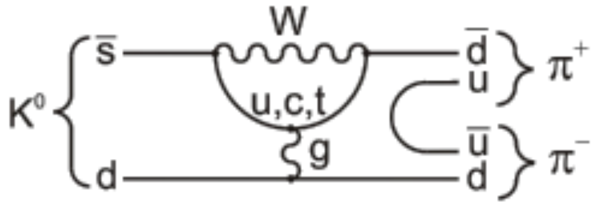


S- and P-waves
(parity violating
& conserving)

$\Lambda \to p\pi^-$	A_{NP}	
S-wave	$<6\times10^{-5}$	parity violating
P-wave	$<3\times10^{-4}$	parity conserving

$A_{SM} \sim 10^{-5}$

$Re(\varepsilon'/\varepsilon)=(1.6+0.3)\times10^{-3}$



S-wave only
(parity violating)

CPV measurement in Kaon system strongly constrains NP in S-waves, but no P-waves.
Thus, searches of CPV in hyperon are complementary to those with Kaons.