P and CP Violation from Octet Baryon Production at the J/ψ Threshold

Yong Du（杜勇）

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Based on

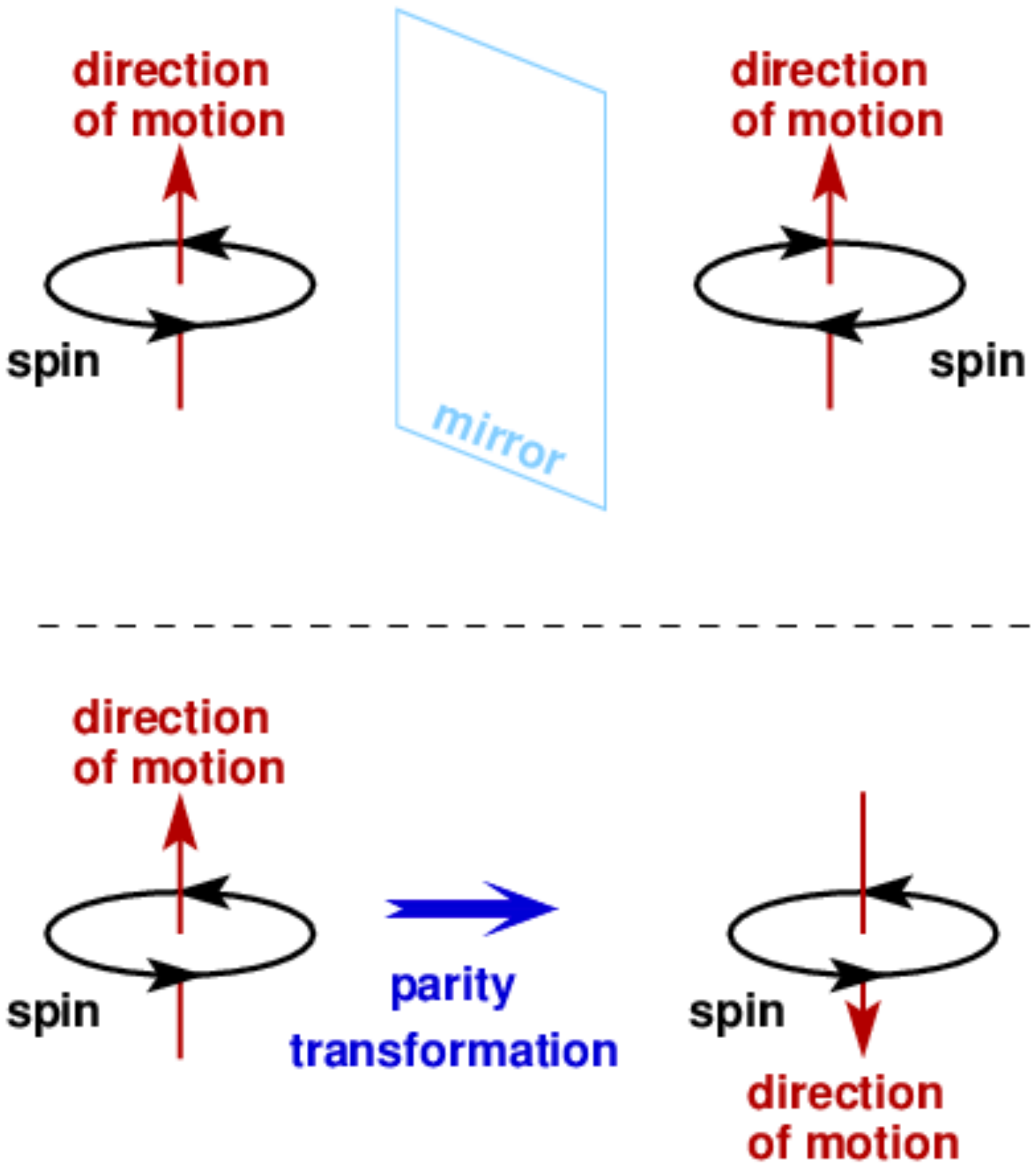
2405.09625, in collaboration with Xin-Yu Du, Xiao-Gang He, Jian-Ping Ma

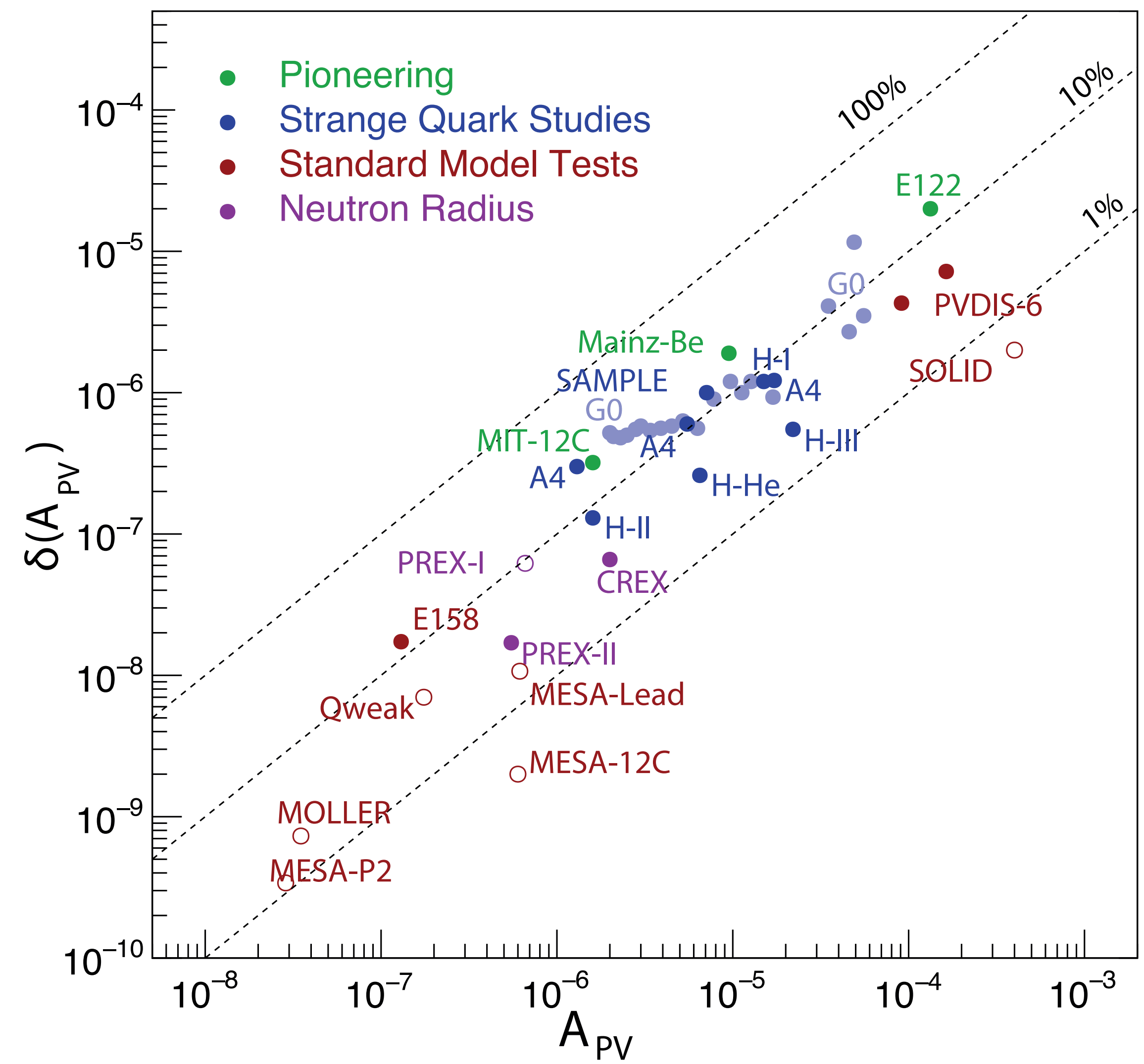
李政道研究所

Tsung-Dao Lee Institute

Motivation

Parity violation firstly proposed by Lee and Yang in 1956 and verified by Wu in 1957



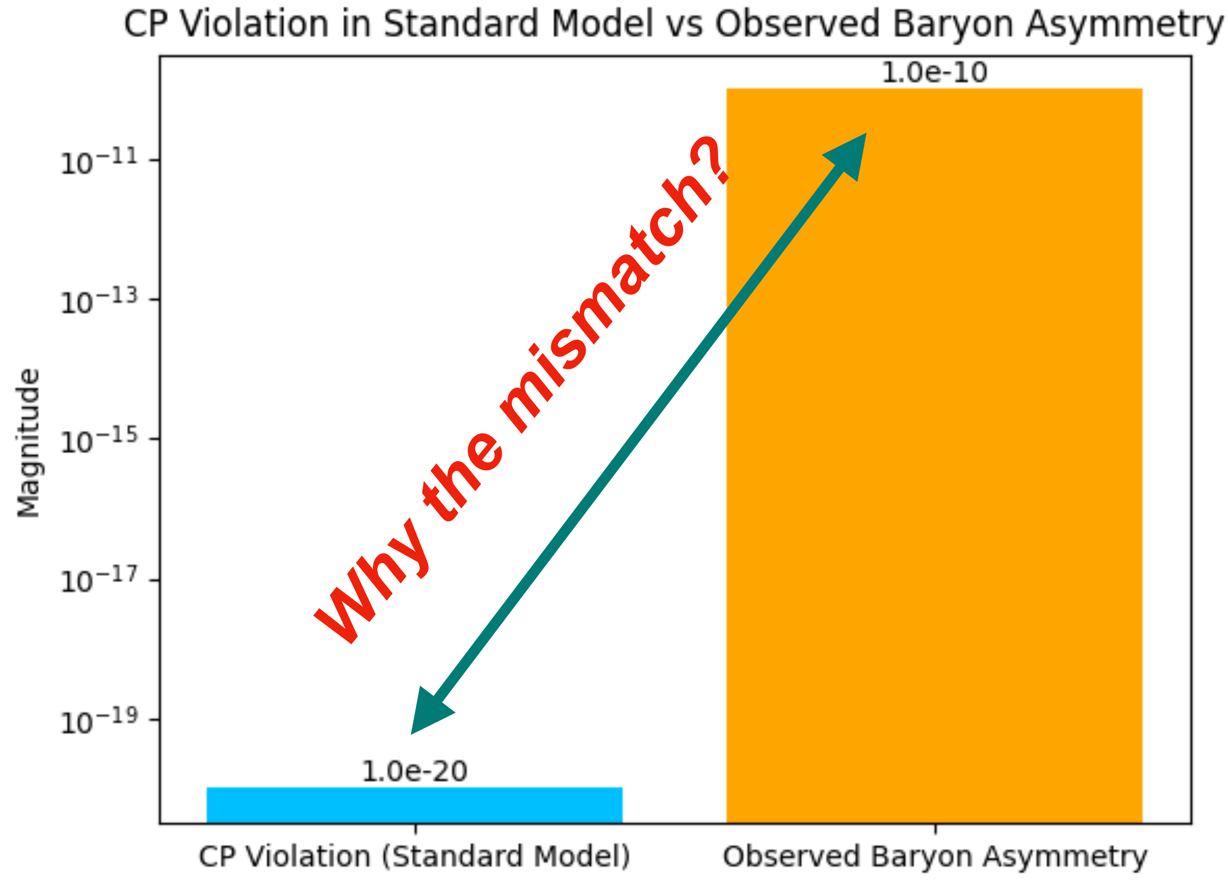


Motivation

Similarly, charge-parity violation (CP) firstly observed in kaon oscillation in 1964, and later studies showed that the SM is insufficient to explain the matter-antimatter asymmetry.

$$\frac{-6\left(m_t^2-m_c^2\right)\left(m_t^2-m_u^2\right)\left(m_c^2-m_u^2\right)\left(m_b^2-m_s^2\right)\left(m_b^2-m_d^2\right)\left(m_s^2-m_d^2\right)J}{\Lambda_{\rm EW}^{12}}\sim 10^{-20}$$

$$\frac{n_B}{s}\sim\mathcal{O}(10^{-10})$$



Motivation

CME (GeV)	Lumi (ab^{-1})	Samples	σ(nb)	No. of Events	Remarks
3.097	1	J/ψ	3400	3.4×10^{12}	
3.670	1	$\tau^+\tau^-$	2.4	2.4×10^{9}	
3.686	1	$\psi(3686)$ $\tau^+\tau^-$ $\psi(3686) \to \tau^+\tau^-$	640 2.5	6.4×10^{11} 2.5×10^{9} 2.0×10^{9}	
3.770	1	$D^0\bar{D}^0$ $D^+\bar{D}^-$ $D^0\bar{D}^0$ $D^+\bar{D}^-$ $\tau^+\tau^-$	3.6 2.8 2.9	3.6×10^{9} 2.8×10^{9} 7.9×10^{8} 5.5×10^{8} 2.9×10^{9}	 Single tag Single tag
4.009	1	$D^{*0}\bar{D}^0 + c.c$ $D^{*0}\bar{D}^0 + c.c$ $D_s^+D_s^-$ $\tau^+\tau^-$	4.0 4.0 0.20 3.5	1.4×10^{9} 2.6×10^{9} 2.0×10^{8} 3.5×10^{9}	$CP_{D^0\bar{D}^0} = +$ $CP_{D^0\bar{D}^0} = -$
4.180	1	$D_s^{+*}D_s^-$+c.c. $D_s^{+*}D_s^-$+c.c. $\tau^+\tau^-$	0.90 3.6	9.0×10^{8} 1.3×10^{8} 3.6×10^{9}	 Single tag
4.230	1	$J/\psi\pi^+\pi^-$ $\tau^+\tau^-$ $\gamma X(3872)$	0.085 3.6	8.5×10^{7} 3.6×10^{9}	
4.360	1	$\psi(3686)\pi^+\pi^-$ $\tau^+\tau^-$	0.058 3.5	5.8×10^{7} 3.5×10^{9}	
4.420	1	$\psi(3686)\pi^+\pi^-$ $\tau^+\tau^-$	0.040 3.5	4.0×10^{7} 3.5×10^{9}	
4.630	1	$\psi(3686)\pi^+\pi^-$ $\Lambda_c\bar{\Lambda}_c$ $\Lambda_c\bar{\Lambda}_c$ $\tau^+\tau^-$	0.033 0.56 3.4	3.3×10^{7} 5.6×10^{8} 6.4×10^{7} 3.4×10^{9}	 Single tag
4.0–7.0	3	300-point scan with 10 MeV steps, 1 fb^{-1}/point			
> 5	2–7	Several ab^{-1} of high-energy data, details dependent on scan results			

STCF CDR, 2303.15790

Q: Tests of both P and CP symmetries at BESIII/STCF in hadronic channels?

Formalism

We consider on-shell production of J/ψ (as the dominant process at STCF) that subsequently decays into a lowest-lying baryon pair ($B = \Lambda, \Sigma^{\pm,0}, \Xi^{0,\pm}$)

$$e^-(p_1) + e^+(p_2) \to J/\psi \to B(k_1, s_1) + \bar{B}(k_2, s_2)$$

As self-explained by the process,

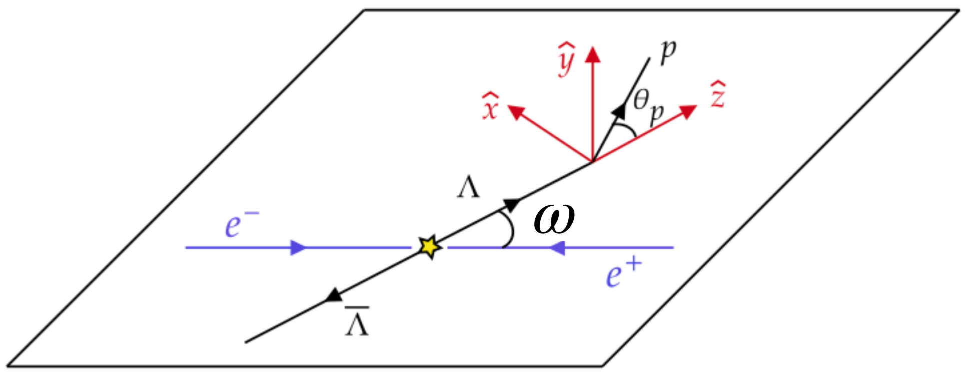
- we do not consider beam polarization for this work (Note that beam polarization is a possible option of STCF and one can of course generalize the discussion that follows), thus the initial spins are averaged over.
- we do not sum over the final spins as the final state differential angular distributions are used to extract P and CP violating effects:

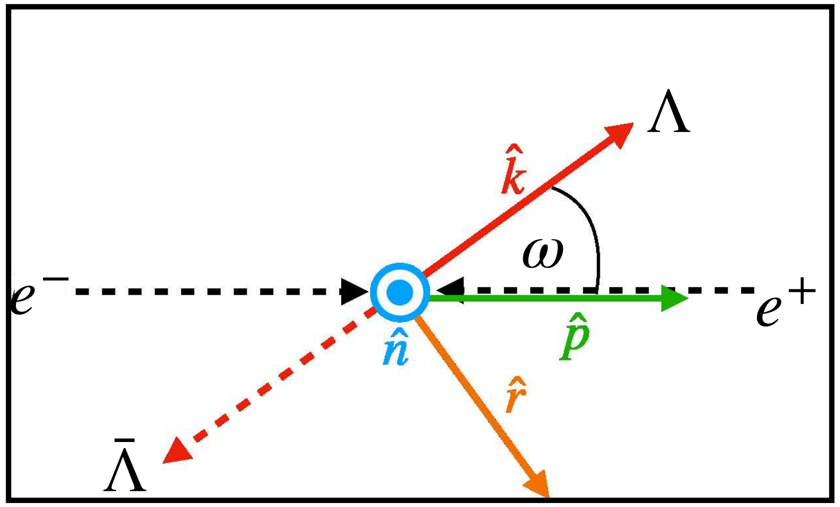
$$S_{fi}(\vec{\boldsymbol{p}}, \vec{\boldsymbol{k}}, \vec{\boldsymbol{s}}_1, \vec{\boldsymbol{s}}_2) = S_{fi}(-\vec{\boldsymbol{p}}, -\vec{\boldsymbol{k}}, \vec{\boldsymbol{s}}_1, \vec{\boldsymbol{s}}_2) \leftarrow \text{P invariance}$$

$$S_{fi}(\vec{\boldsymbol{p}}, \vec{\boldsymbol{k}}, \vec{\boldsymbol{s}}_1, \vec{\boldsymbol{s}}_2) = S_{fi}(\vec{\boldsymbol{p}}, \vec{\boldsymbol{k}}, \vec{\boldsymbol{s}}_2, \vec{\boldsymbol{s}}_1) \leftarrow \text{CP invariance}$$

Formalism

Due to the on-shell production, all J/ψ particles are generated at rest, and we therefore work in the COM frame and adopt the beam basis for the calculation





- On the production side, the J/ψ density matrix is constructed from its polarization vector ($d_J = 0$ if parity is conserved)

$$\rho^{ij}(\vec{p}) = \frac{1}{3}\delta^{ij} - i d_J \epsilon^{ijk}\hat{p}^k - \frac{c_J}{2}\left(\hat{p}^i\hat{p}^j - \frac{1}{3}\delta^{ij}\right)$$

Formalism

- To extract information from the decay of J/ψ, we focus on S_{fi} directly and decompose it in the SU(2)⊗SU(2) spin space:

$$S_{fi}(\hat{p},\hat{k},\vec{s}_1,\vec{s}_2) = a(\omega)\mathbb{I}\otimes\mathbb{I} + B_1(\hat{p},\hat{k})\vec{s}_1\otimes\mathbb{I} + B_2(\hat{p},\hat{k})\mathbb{I}\otimes\vec{s}_2 + C^{ij}(\hat{p},\hat{k})\vec{s}_1\otimes\vec{s}_2$$

Wu, Qian, Yang, Wang, 2402.16574
Wu, Qian, Wang, Zhou, 2406.16298

$$\begin{aligned}
B_1(\hat{\boldsymbol{p}},\hat{\boldsymbol{k}}) &= \hat{\boldsymbol{p}} b_{1p}(\omega) + \hat{\boldsymbol{k}} b_{1k}(\omega) + \hat{\boldsymbol{n}} b_{1n}(\omega),\\
B_2(\hat{\boldsymbol{p}},\hat{\boldsymbol{k}}) &= \hat{\boldsymbol{p}} b_{2p}(\omega) + \hat{\boldsymbol{k}} b_{2k}(\omega) + \hat{\boldsymbol{n}} b_{2n}(\omega),\\
C^{ij}(\hat{\boldsymbol{p}},\hat{\boldsymbol{k}}) &= \delta^{ij} c_0(\omega) + \epsilon^{ijk}\left(\hat{\boldsymbol{p}}^k c_1(\omega) + \hat{\boldsymbol{k}}^k c_2(\omega) + \hat{\boldsymbol{n}}^k c_3(\omega)\right) + \left(\hat{\boldsymbol{p}}^i\hat{\boldsymbol{p}}^j - \frac{1}{3}\delta^{ij}\right) c_4(\omega) + \left(\hat{\boldsymbol{k}}^i\hat{\boldsymbol{k}}^j - \frac{1}{3}\delta^{ij}\right) c_5(\omega)\\
&\quad + \left(\hat{\boldsymbol{p}}^i\hat{\boldsymbol{k}}^j + \hat{\boldsymbol{k}}^i\hat{\boldsymbol{p}}^j - \frac{2}{3}\omega\delta^{ij}\right) c_6(\omega) + \left(\hat{\boldsymbol{p}}^i\hat{\boldsymbol{n}}^j + \hat{\boldsymbol{n}}^i\hat{\boldsymbol{p}}^j\right) c_7(\omega) + \left(\hat{\boldsymbol{k}}^i\hat{\boldsymbol{n}}^j + \hat{\boldsymbol{n}}^i\hat{\boldsymbol{k}}^j\right) c_8(\omega),
\end{aligned}$$

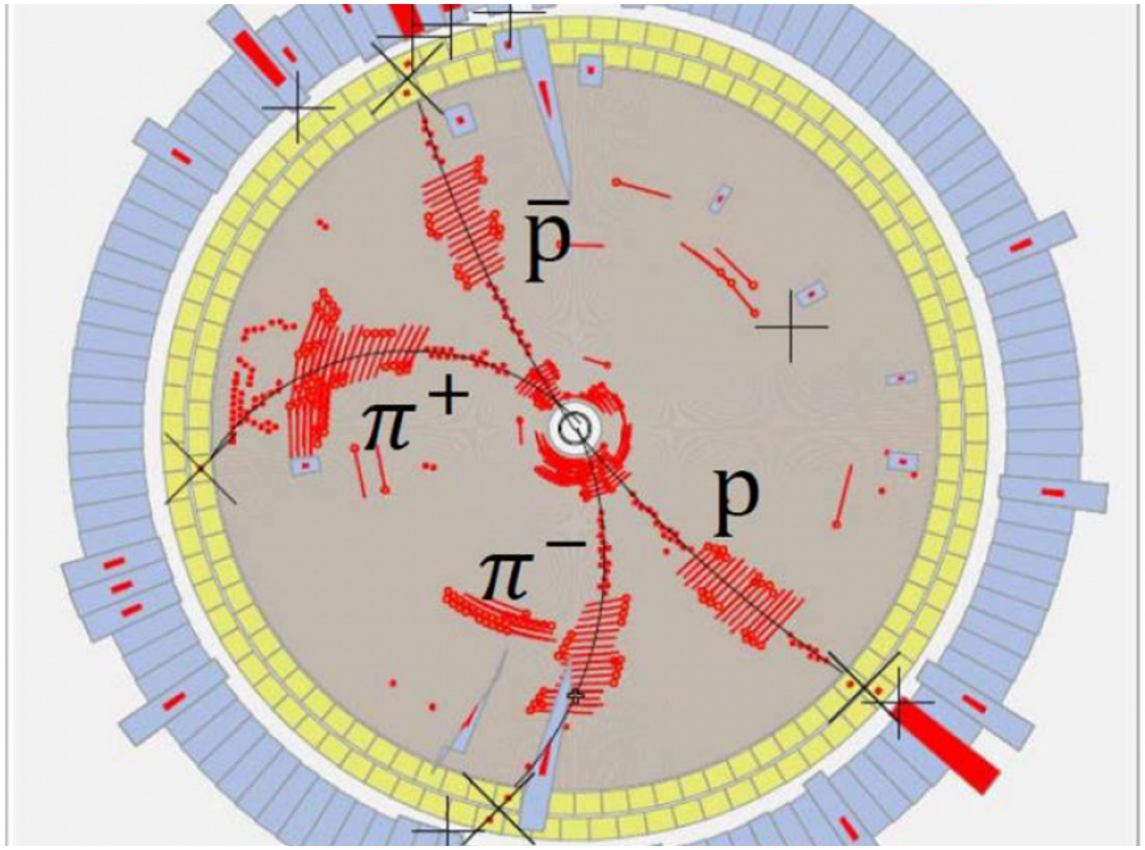
P and CP invariance will impose constraints on these parameters, whose violation would imply P/CP violation.

$$\begin{aligned}
b_{1p}(\omega) &= b_{2p}(\omega) = b_{1k}(\omega) = b_{2k}(\omega) = c_1(\omega) = c_2(\omega) = c_7(\omega) = c_8(\omega) = 0, \quad &&\text{(from P invariance)}\\
b_{1m}(\omega) &= b_{2m}(\omega), \quad m = p,k,n \quad \text{and} \quad c_i(\omega) = 0, \quad i = 1,2,3. &&\text{(from CP invariance)}
\end{aligned}$$

Asymmetric observables

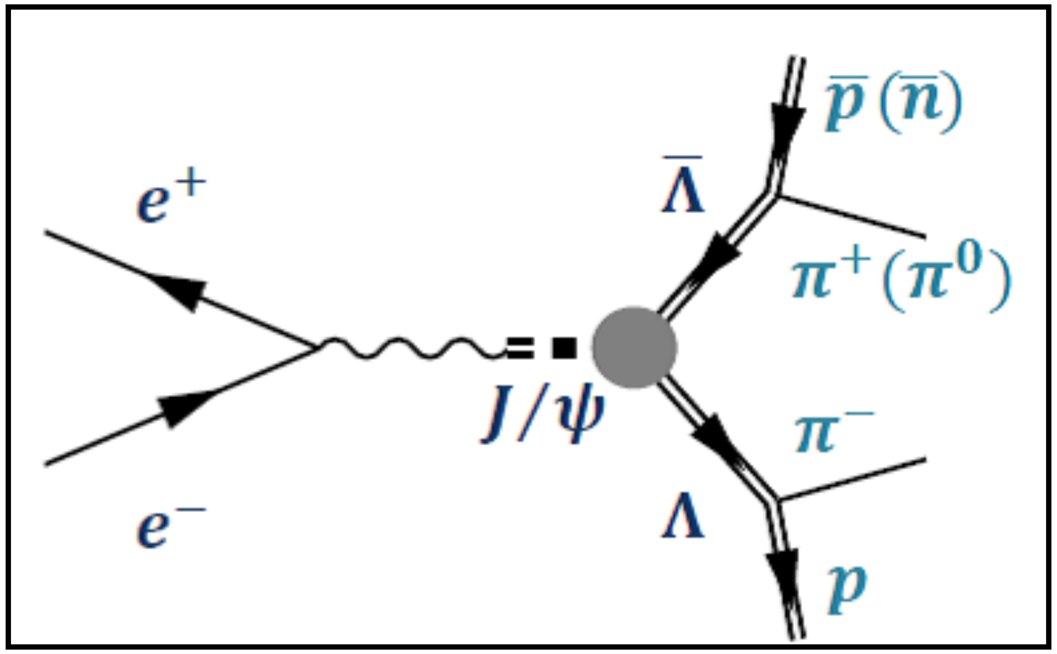
Practically, these parameters determine the differential angular distribution of the decay chain, from which one can construct the asymmetric observables from the observed number of events at the detector:

$$\mathscr{A}(\mathscr{O}) = \frac{N_+ - N_-}{N_+ + N_-} = \frac{3}{2}\langle\mathscr{O}\rangle, \qquad \langle\mathscr{O}\rangle \equiv \frac{1}{\mathscr{N}}\int \frac{d\Omega_{\hat{k}} d\Omega_{\hat{l}_p} d\Omega_{\hat{l}_{\bar{p}}}}{(4\pi)^3}\mathscr{O}\cdot\mathscr{W}$$



Asymmetric observables

For J/ψ decay at BESIII/STCF, its decay amplitude can not be determined perturbatively, we therefore introduce the following form factors based on Lorentz invariance



$$\mathcal{M} = \epsilon_\mu^{J/\psi}(q)\bar{u}\left(k_1\right)\left[\gamma^\mu F_V + \gamma^\mu\gamma_5 F_A + \frac{i}{2m_B}\sigma^{\mu\nu}q_\nu H_\sigma + \sigma^{\mu\nu}q_\nu\gamma_5 H_T\right]v\left(k_2\right)$$

P violating

CP violating

Asymmetric observables

Then only 5 non-vanishing asymmetric observables can be constructed from the differential angular distribution, based on which we define the following derived asymmetries

Parity violation

$$A_{\rm PV}^{(1)} \simeq \frac{4\alpha}{3\mathcal{N}} E_c^2 d_J \left(2y_m \mathrm{Re}\left(G_1 G_2^*\right) + \left|G_1\right|^2\right)$$

$$A_{\rm PV}^{(2)} \simeq \frac{8\alpha\beta}{3\mathcal{N}} E_c^2\, \mathrm{Re}\left(F_A G_1^*\right)$$

CP violation

$$A_{\rm CPV}^{(1)} \simeq -\frac{8\alpha\beta}{3\mathcal{N}} E_c^3\, \mathrm{Im}\left(y_m H_T G_2^*\right)$$

$$A_{\rm CPV}^{(2)} \simeq -\frac{8\alpha\bar{\alpha}}{9\mathcal{N}} \beta y_m E_c^3 \mathrm{Re}\left(H_T G_2^*\right)$$

$$G_1^B = F_V^B + H_\sigma^B, \quad G_2^B = G_1^B - \frac{(k_1-k_2)^2}{4m_B^2} H_\sigma^B,$$

CPV tests with polarized beams?

Sheng Zeng, Yue Xu, Xiao-Rong Zhou, Jia-Jia Qin, Bo Zheng, 2306.15602 (CPC)

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$$A_{\mathrm{PV}}^{(2)} \simeq \frac{8\alpha\beta}{3\mathcal{N}} E_c^2 \, \mathrm{Re}\left(F_A G_1^* \right)$$

CP violation

$$A_{\mathrm{CPV}}^{(1)} \simeq -\frac{8\alpha\beta}{3\mathcal{N}} E_c^3 \, \mathrm{Im}\left(y_m H_T G_2^* \right)$$

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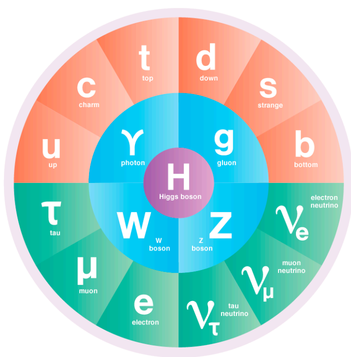
Q: How to get these form factors?

Asymmetric observables

E

$?$



$v_{\rm EW}$

m_W $\quad u, d, c, s, b, g, \gamma, e, \mu, \tau, \nu_{e,\mu,\tau}$

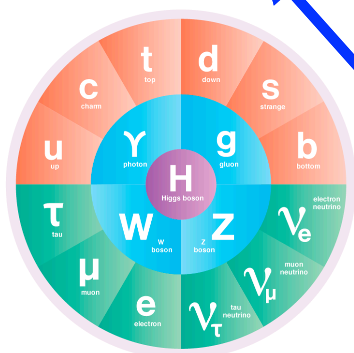
$\Lambda_{\rm QCD}$ $\quad n, p, \pi^{\pm,0}, K^{\pm,0}, \Lambda, \Sigma^{\pm,0}, \cdots$

MeV $\quad {}^{A}N_{Z}$

Asymmetric observables

E

?



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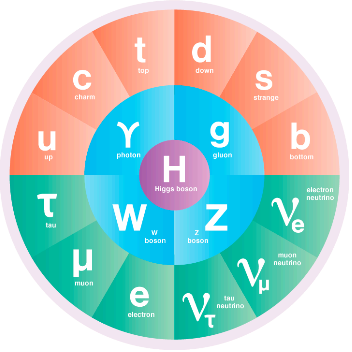
MeV $\quad {}^{A}N_{Z}$

Low energy precision probe to underlying unknown new paradigm/mechanism at the high-energy scale (*e.g.*, BESIII/STCF)

Asymmetric observables

E

?



$v_{\rm EW}$

m_W $\quad u, d, c, s, b, g, \gamma, e, \mu, \tau, \nu_{e,\mu,\tau}$

Matching scale where inputs $G_F, \alpha_{\rm EM}, m_Z$ are precisely known

$$\log \frac{m_Z}{\Lambda_{\rm QCD}} \approx 4.5$$

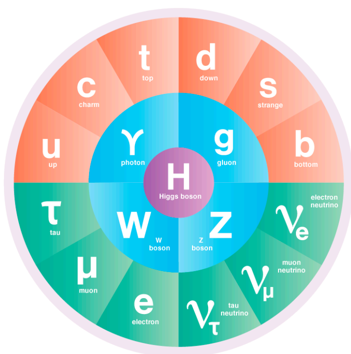
$\Lambda_{\rm QCD}$ $\quad n, p, \pi^{\pm,0}, K^{\pm,0}, \Lambda, \Sigma^{\pm,0}, \cdots$

Experiment scale

MeV $\quad {}^A N_Z$

Asymmetric observables

E



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Experiment scale

MeV — ${}^{A}N_Z$

Standard strategy:

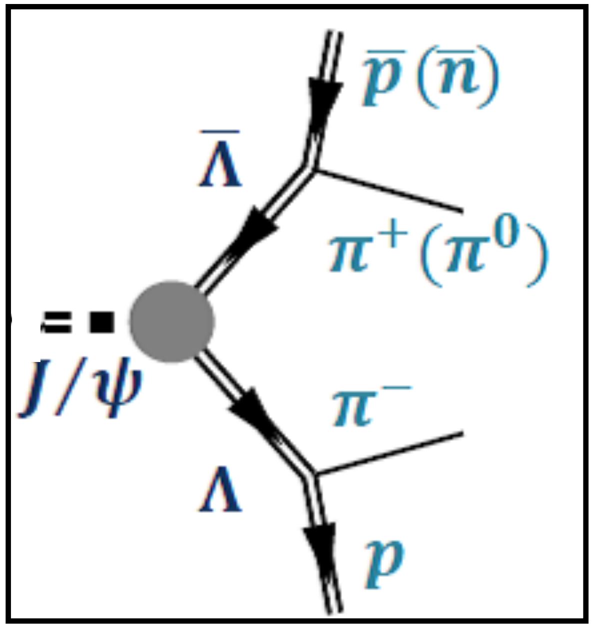
1. RGE down to and then matching at $\Lambda_{\rm QCD}$
2. ME eva. e.g., χPT (lattice/pheno det. of LEC)

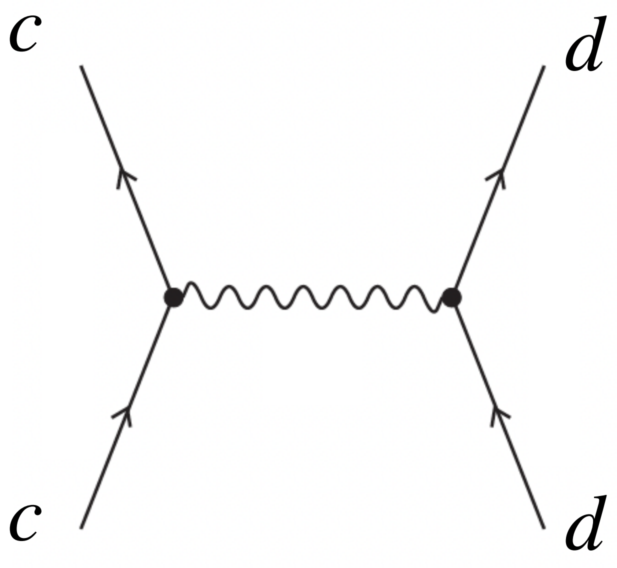
Form factors

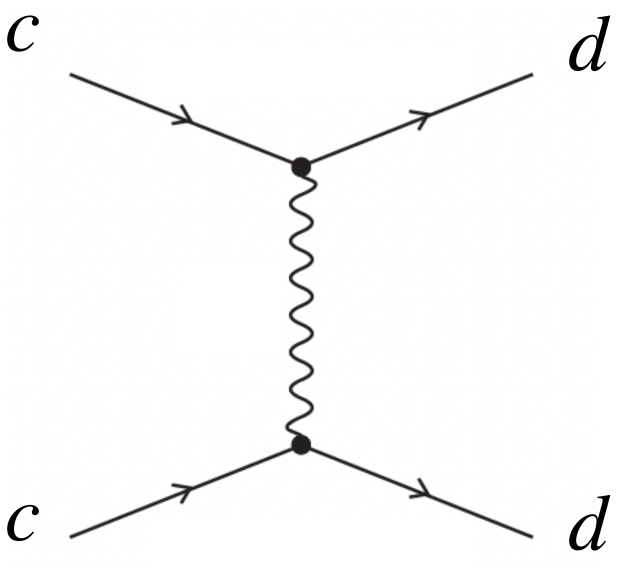
F_A determination:

$$\mathcal{M} = \epsilon_\mu^{J/\psi}(q)\bar{u}(k_1)\left[\gamma^\mu F_V + \gamma^\mu\gamma_5 F_A + \frac{i}{2m_B}\sigma^{\mu\nu}q_\nu H_\sigma + \sigma^{\mu\nu}q_\nu\gamma_5 H_T\right]v(k_2)$$

In the SM of particle physics, this parity-violating form factor F_A *on the decay side* comes from the weak currents.



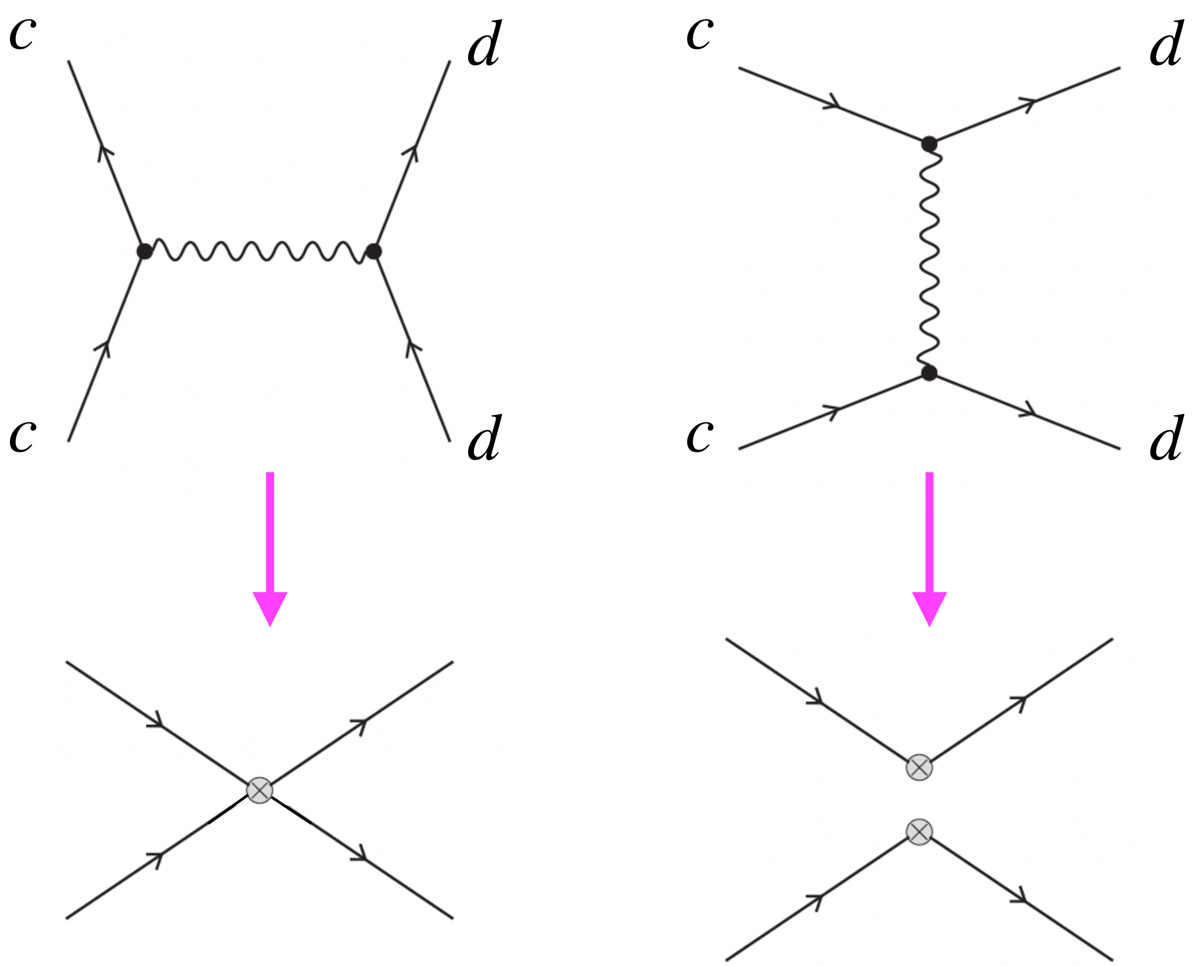




Form factors

F_A determination:

J/ψ produced at an energy $s, t \ll m^2_{W,Z}$, so effectively 4-fermion interactions.



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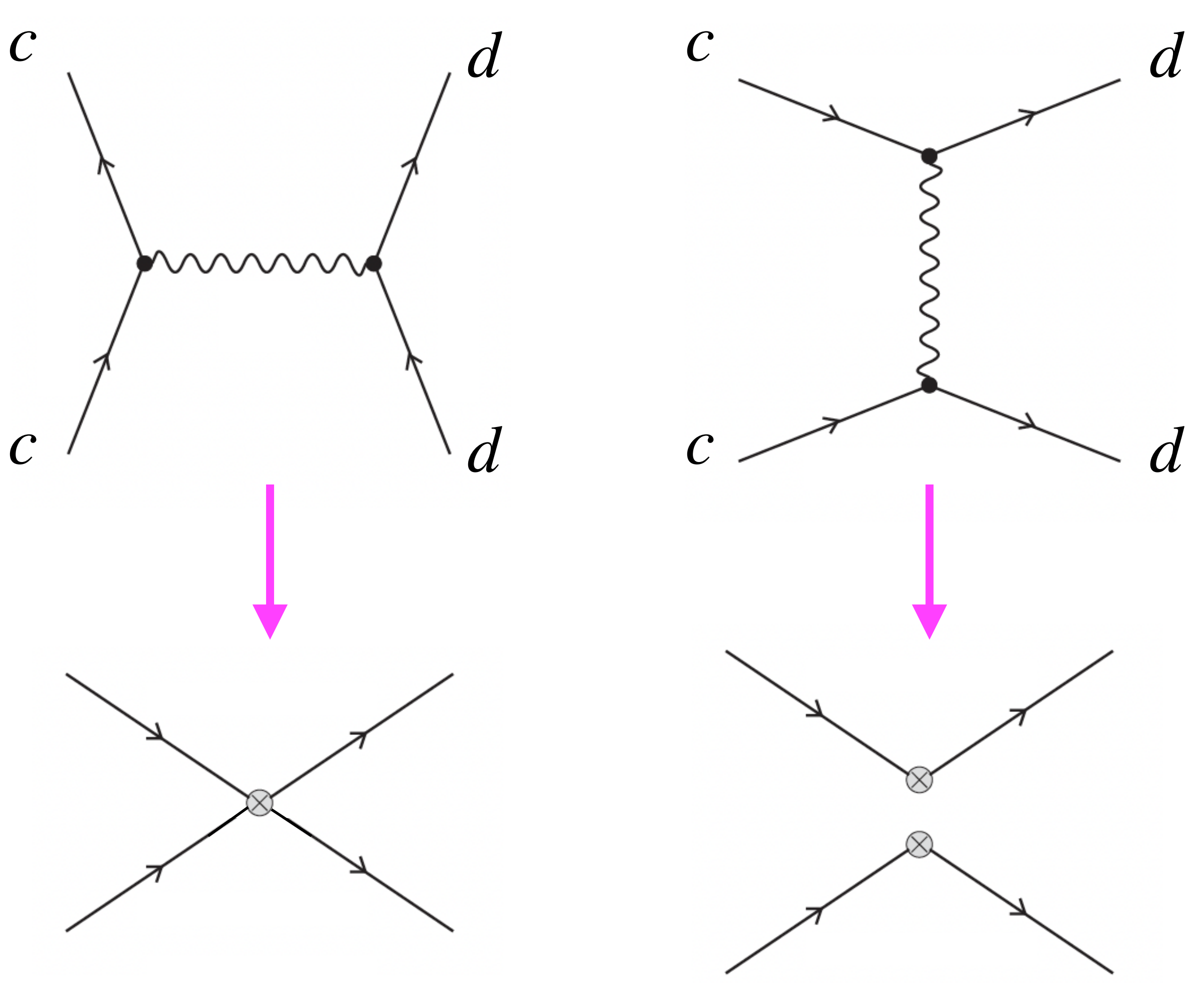
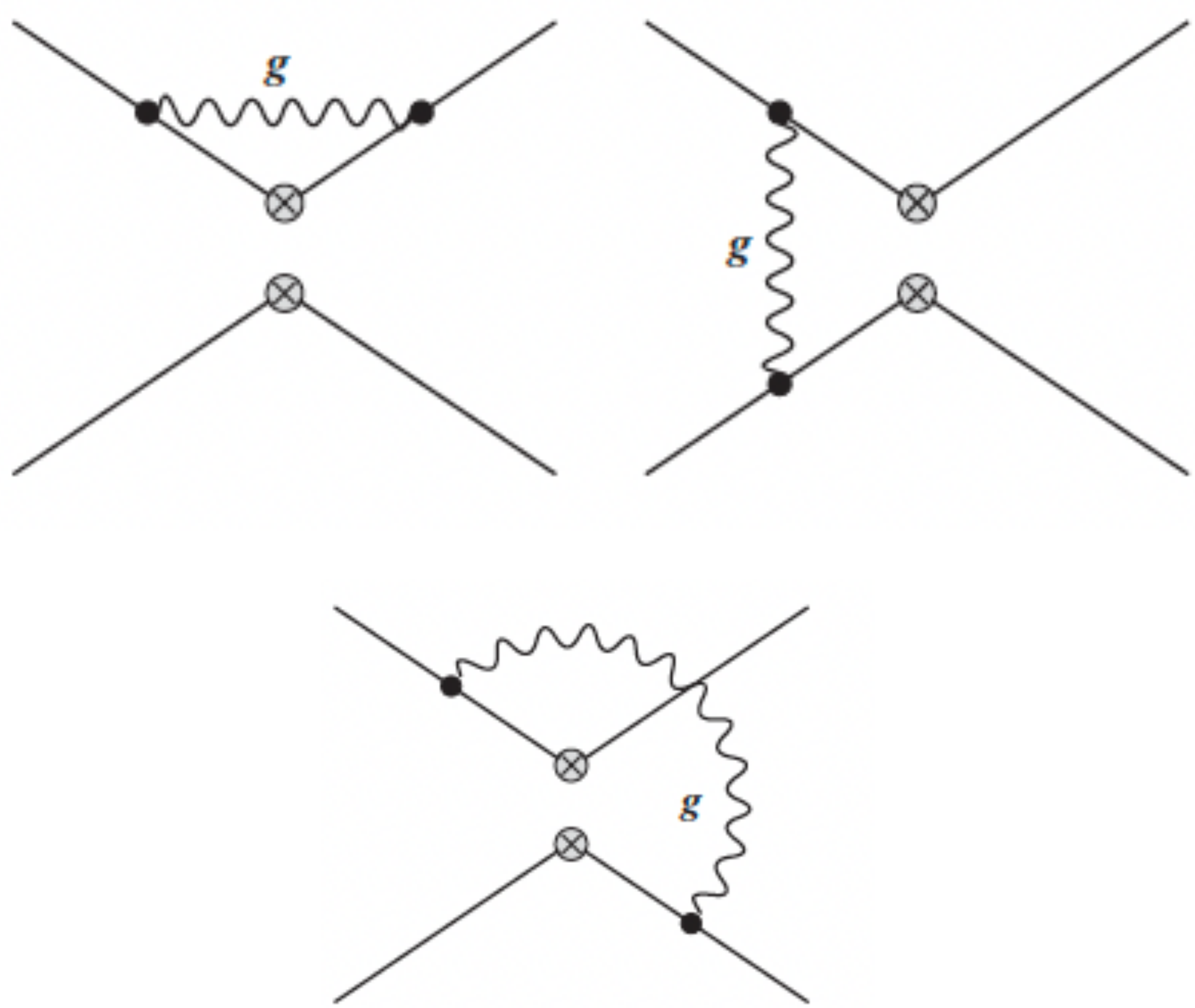
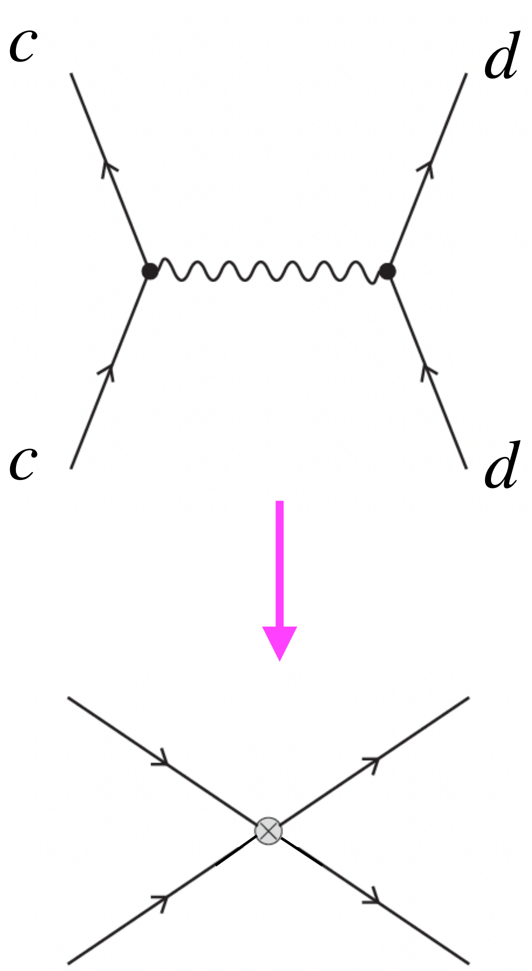




Form factors

F_A determination:

Z as an example:



$$\mathscr{L}_Z \supset -4\sqrt{2}G_F \cdot \sum_{q=u,d,s}\left[g^q_{V-A}g^c_{V+A}c_1\left(\bar{q}_R\gamma_\mu q_R\right)\left(\bar{c}_L\gamma_\mu c_L\right) + g^q_{V+A}g^c_{V-A}c_2\left(\bar{q}_L\gamma_\mu q_L\right)\left(\bar{c}_R\gamma_\mu c_R\right)\right]$$

$c_{1,2}(m_Z) = 1$, but its running will mix with the following two octet operators from the anomalous dimension even though they are absent at $\mu = m_Z$:

$$c_8\left(\bar{q}_R\gamma_\mu T^A q_R\right)\left(\bar{c}_L\gamma_\mu T^A c_L\right), \qquad c_8'\left(\bar{q}_L\gamma_\mu T^A q_L\right)\left(\bar{c}_R\gamma_\mu T^A c_R\right)$$

$$16\pi^2\frac{d}{d\ln\mu}\begin{pmatrix} c_1 \\ c_8 \end{pmatrix} = \begin{pmatrix} 0 & -\frac{6g_s^2 C_F}{N_c} \\ -12g_s^2 & -6g_s^2 N_c + \frac{12g_s^2}{N_c} \end{pmatrix}\begin{pmatrix} c_1 \\ c_8 \end{pmatrix}$$

Form factors

F_A determination:

Choose a basis to diagonalize the anomalous dimension and to disentangle the octet contribution:

$$\mathcal{O}^{LR}_{ud+} = \frac{1}{N_c}\left(\bar{d}_R\gamma_\mu d_R\right)\left(\bar{c}_L\gamma_\mu c_L\right) + 2\left(\bar{d}_R\gamma_\mu T^A d_R\right)\left(\bar{c}_L\gamma_\mu T^A c_L\right) \qquad \mathcal{O}^{LR}_{ud-} = -\frac{4C_F}{N_c}\left(\bar{d}_R\gamma_\mu d_R\right)\left(\bar{c}_L\gamma_\mu c_L\right) + \frac{4}{N_c}\left(\bar{d}_R\gamma_\mu T^A d_R\right)\left(\bar{c}_L\gamma_\mu T^A c_L\right)$$

$$\mathcal{L}_Z \supset -4\sqrt{2}G_F \cdot \sum_{q=d,s}\left[\frac{g^q_{V-A}g^c_{V+A}}{N_c}C^{LR}_{ud+}\mathcal{O}^{LR}_{ud+} - \frac{g^q_{V-A}g^c_{V+A}}{2}C^{LR}_{ud-}\mathcal{O}^{LR}_{ud-}\right]$$

the anomalous dimension is then simple to solve

$$16\pi^2\frac{d}{d\ln\mu}\begin{pmatrix} C^{LR}_{ud+} \\ C^{LR}_{ud-}\end{pmatrix} = 16\pi^2\frac{d}{d\ln\mu}\begin{pmatrix} \frac{6C_F}{b}\alpha_s & 0 \\ 0 & -\frac{3}{bN_c}\alpha_s\end{pmatrix}$$

Form factors

F_A determination:

For example, for Σ^0

$$F_A^{\Sigma^0} = \left(\frac{G_F g_V}{2\sqrt{2}}\right) \cdot D \cdot \left\{ \frac{1}{3} s_w^2 \left(\mathscr{R}_Z - \tilde{\mathscr{R}}_Z\right) - \left|V_{cd}\right|^2 \mathscr{R}_W \right\}$$

without running, $\mathscr{R}_Z = \tilde{\mathscr{R}}_Z = 1$ and $\mathscr{R}_W = 1/N_c \approx 0.33$.

with running, $\mathscr{R}_Z \approx 1.07$, $\tilde{\mathscr{R}}_Z \approx 1.09$ and $\mathscr{R}_W \approx -0.03$.

Form factors

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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^{Λ} ($\times 10^{-7}$)
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

Form factors

F_A determination:

For example, for Σ^0

Weak mixing angle determination

$$F_A^{\Sigma^0} = \left(\frac{G_F g_V}{2\sqrt{2}}\right) \cdot D \cdot \left\{ \frac{1}{3} s_w^2 \left(\mathscr{R}_Z - \tilde{\mathscr{R}}_Z\right) - \left|V_{cd}\right|^2 \mathscr{R}_W \right\}$$

2nd row CKM unitary test

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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

Form factors

$G_{1,2}$ determination:

$$\mathcal{M} = \epsilon_\mu^{J/\psi}(q)\bar{u}\,(k_1)\left[\gamma^\mu F_V + \gamma^\mu\gamma_5 F_A + \frac{i}{2m_B}\sigma^{\mu\nu}q_\nu H_\sigma + \sigma^{\mu\nu}q_\nu\gamma_5 H_T\right] v\,(k_2)$$

Small P violating

Small CP violating

Form factors

$G_{1,2}$ determination:

$$\mathcal{M} = \epsilon_\mu^{J/\psi}(q)\bar{u}(k_1)\left[\gamma^\mu F_V + \cancel{\gamma^\mu\gamma_5 F_A} + \frac{i}{2m_B}\sigma^{\mu\nu}q_\nu H_\sigma + \cancel{\sigma^{\mu\nu}q_\nu\gamma_5 H_T}\right]v(k_2)$$

Small P violating

Small CP violating

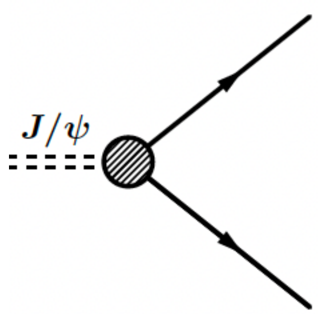
Form factors

$G_{1,2}$ determination:

$$\mathcal{M} = \epsilon_\mu^{J/\psi}(q)\bar{u}(k_1)\left[\gamma^\mu F_V + \cancel{\gamma^\mu\gamma_5 F_A} + \frac{i}{2m_B}\sigma^{\mu\nu}q_\nu H_\sigma + \cancel{\sigma^{\mu\nu}q_\nu\gamma_5 H_T}\right]v(k_2)$$

Small P violating

Small CP violating



$$\Gamma_{J/\psi\to B\bar{B}} = \frac{|G_1|^2 m_{J/\psi}}{12\pi}\sqrt{1-\frac{4m_B^2}{m_{J/\psi}^2}}\left(1+\frac{2m_B^2}{m_{J/\psi}^2}\left|\frac{G_2}{G_1}\right|^2\right)$$

Recall $|G_E/G_M| = |G_2/G_1|$, G_1 can be determined from the branching ratios.

Form factors

H_T determination:

$$\mathcal{M}=\epsilon_\mu^{J/\psi}(q)\bar{u}\left(k_1\right)\left[\gamma^\mu F_V+\gamma^\mu\gamma_5 F_A+\frac{i}{2m_B}\sigma^{\mu\nu}q_\nu H_\sigma+\sigma^{\mu\nu}q_\nu\gamma_5 H_T\right]v\left(k_2\right)$$

To this end, we assume this is dominated by the EDM of B, whose Lagrangian is given by

$$\mathscr{L}_{B_{\mathrm{EDM}}}=-i\frac{d_B}{2}\bar{B}\sigma_{\mu\nu}\gamma_5 BF^{\mu\nu}$$

Matching the amplitudes leads to

$$H_T=\frac{e\cdot Q_C\cdot g_V\cdot d_B}{m_{J/\psi^2}}$$

Q: How to calculate?

A: Quark model + NR QCD

Form factors

H_T determination:

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

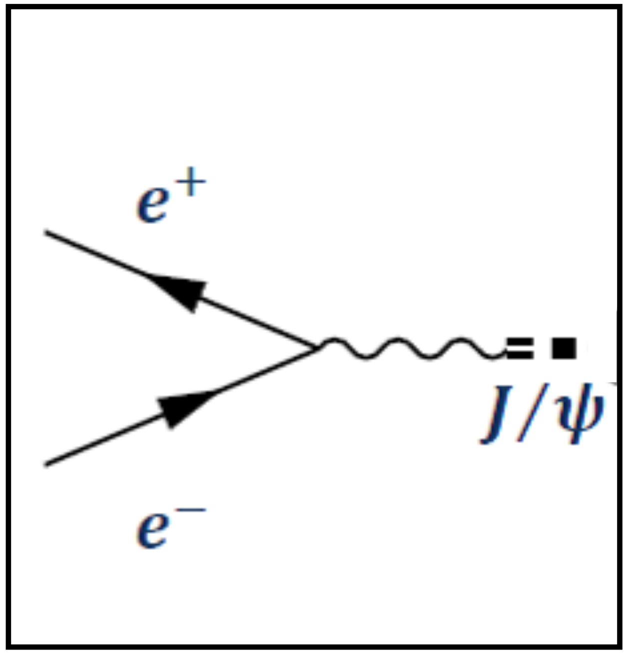
e.g., d_q as sourced from the dim-6 SMEFT dipole operators (cutoff scale around 1TeV at BESIII)

$$\boxed{\begin{array}{ll} Q_{fW} = \begin{cases} (\bar{\mathrm{F}}\sigma^{\mu\nu} f_R)\tau^I \varphi W^I_{\mu\nu}, & T_3^{\mathrm{F}} = -\frac{1}{2} \\ (\bar{\mathrm{F}}\sigma^{\mu\nu} f_R)\tau^I \widetilde{\varphi} W^I_{\mu\nu}, & T_3^{\mathrm{F}} = \frac{1}{2} \end{cases}, & Q_{fB} = \begin{cases} (\bar{\mathrm{F}}\sigma^{\mu\nu} f_R)\varphi B_{\mu\nu}, & T_3^{\mathrm{F}} = -\frac{1}{2} \\ (\bar{\mathrm{F}}\sigma^{\mu\nu} f_R)\widetilde{\varphi} B_{\mu\nu}, & T_3^{\mathrm{F}} = \frac{1}{2} \end{cases} \\ Q_{uG} = (\bar{Q}\sigma^{\mu\nu} T^A u_R)\widetilde{\varphi} G^A_{\mu\nu}, & Q_{dG} = (\bar{Q}\sigma^{\mu\nu} T^A d_R)\varphi G^A_{\mu\nu}, \end{array}}$$

Form factors

d_J determination:

Recall it is related to the production of J/ψ only, and is thus the simplest one to compute from Z exchange to violate parity



$$d_J = \frac{\sqrt{2}sG_F}{32\pi\alpha_{\rm EM}} \cdot (3 - 8s_w^2)$$

Another weak mixing angle determination with a precision $A_{\rm PV}^{(1)}$

RGE improvement negligible at leading order due to $\alpha_{\rm EM}$ suppression.

Experimental inputs

Experimental input

Parameters	$\Sigma^+\bar{\Sigma}^-$ [72]	$\Sigma^-\bar{\Sigma}^+$	$\Sigma^0\bar{\Sigma}^0$ [73]	$\Lambda\bar{\Lambda}$ [42]	$p\bar{p}$ [74]	$\Xi^0\bar{\Xi}^0$ [75, 76]	$\Xi^-\bar{\Xi}^+$ [40]
$\sqrt{s}$ (GeV)	2.9000	—	$m_{J/\psi}$	$m_{J/\psi}$	3.0800	$m_{J/\psi}$	$m_{J/\psi}$
$\alpha^B_{J/\psi}$	0.35 ± 0.23	—	-0.449 ± 0.022	0.4748 ± 0.0038	—	0.514 ± 0.016	0.586 ± 0.016
α_B	-0.982 ± 0.14	-0.068 ± 0.008	0.22 ± 0.31	0.7519 ± 0.0043	0.62 ± 0.11	-0.3750 ± 0.0038	-0.376 ± 0.008
$\bar{\alpha}_B$	-0.99 ± 0.04	—	—	0.7559 ± 0.0078	—	-0.3790 ± 0.0040	-0.371 ± 0.007
$\Delta\Phi$ (rad.)	1.3614 ± 0.4149	—	—	0.7521 ± 0.0066	—	1.168 ± 0.026	1.213 ± 0.049
$\|G_E/G_M\| \equiv \mathrm{R}$	0.8459 ± 0.2217	—	1.04 ± 0.37	0.8282 ± 0.0041	0.80 ± 0.15	0.6672 ± 0.0145	0.5986 ± 0.0146
$\|G_M\|$ ($\times 10^{-2}$)	(derived)	—	0.71 ± 0.09	(derived)	3.47 ± 0.18	(derived)	(derived)

P and CP asymmetries at BESIII and STCF

P/CP violation	$A^{(1)}_{\rm PV}$ ($\times 10^{-4}$)	$A^{(2)}_{\rm PV}$ ($\times 10^{-4}$)	$\sqrt{\epsilon \cdot t} \cdot d^{(1)}_B$ ($\times 10^{-18}\, e\,$cm)		$\sqrt{\epsilon \cdot t} \cdot d^{(2)}_B$ ($\times 10^{-18}\, e\,$cm)		$\sqrt{\epsilon \cdot t} \cdot \delta$ ($\times 10^{-4}$)	
			BESIII	STCF	BESIII	STCF	BESIII	STCF
Λ ($\epsilon = 0.4$)	2.88	5.49	2.62	0.14	8.64	0.47	2.30	0.13
Σ^+ ($\epsilon = 0.2$)	-2.49	7.78	1.47	0.08	18.4	1.00	3.06	0.17
Ξ^0 ($\epsilon = 0.2$)	-1.13	-3.45	6.12	0.33	82.6	4.41	2.92	0.16
Ξ^- ($\epsilon = 0.2$)	-1.08	-2.75	6.79	0.37	95.9	5.20	3.21	0.17

Results

Alternatively using the LR asymmetry

Jinlin Fu, Hai-Bo Li, Jian-Peng Wang, Fu-Sheng Yu, Jianyu Zhang, 2307.04346 (PRD)

Precision measurement of the weak mixing angle using, for example, $A_{\rm PV}^{(1)}$

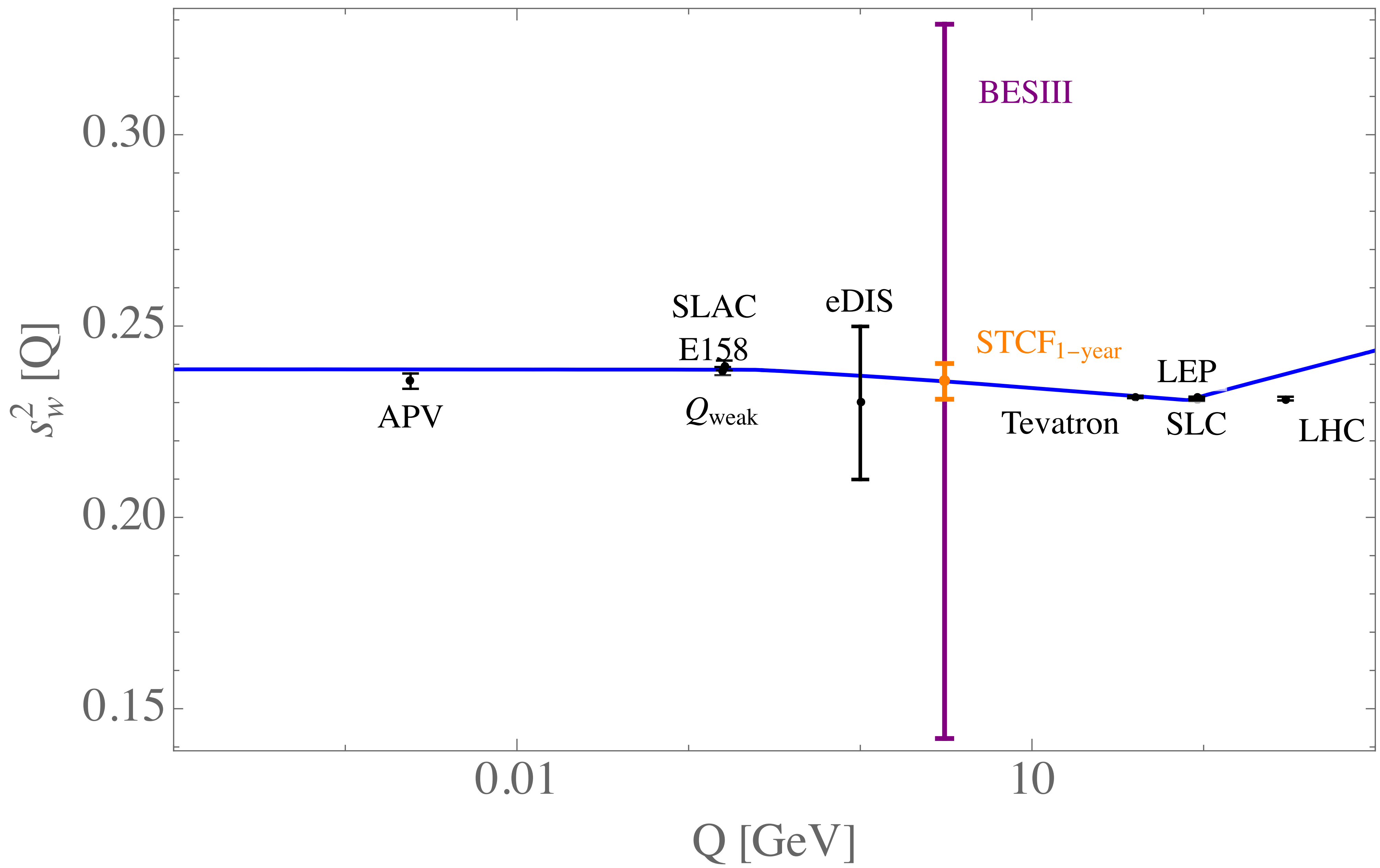
$$\frac{\delta s_w^2}{s_w^2} = \mathrm{a}_0 \frac{\delta m_B}{m_B} \oplus \mathrm{a}_1 \frac{\delta m_{J/\psi}}{m_{J/\psi}} \oplus \mathrm{a}_2 \frac{\delta \mathrm{R}}{\mathrm{R}} \oplus \mathrm{a}_3 \frac{\delta\alpha}{\alpha} \oplus \mathrm{a}_4 \frac{\delta\Delta\Phi}{\Delta\Phi} \oplus \mathrm{a}_5 \frac{\delta A_{\rm PV}^{(1)}}{A_{\rm PV}^{(1)}}$$

Baryons	a_0 $(\times 10^{-2})$	$\frac{\delta m_B}{m_B}$ $(\times 10^{-6})$	a_1	$\frac{\delta m_{J/\psi}}{m_{J/\psi}}$ $(\times 10^{-6})$	a_2 $(\times 10^{-2})$	$\frac{\delta \mathrm{R}}{\mathrm{R}}$	a_3	$\frac{\delta\alpha}{\alpha}$ $(\times 10^{-2})$
Λ	9.67	5.38	1.09	1.94	9.67	0.005	0.59	0.34
Σ^+	8.16	58.9	1.27	1.94	8.16	0.262	0.59	14.3
Ξ^0	1.83	152	1.17	1.94	1.83	0.022	0.59	1.46
Ξ^-	1.93	53.0	1.16	1.94	1.93	0.024	0.59	2.85

(continued)	a_4	$\frac{\delta\Delta\Phi}{\Delta\Phi}$ $(\times 10^{-2})$	a_5	$\frac{\sqrt{\epsilon}\delta A_{\rm PV}^{(1)}}{A_{\rm PV}^{(1)}}$	$(s_w^2 \pm \delta s_w^2)_{\rm BESIII}$
Λ	0.19	0.88	0.59	0.52	0.2355 ± 0.1760
Σ^+	0.81	30.5	0.59	1.01	0.2355 ± 0.3884
Ξ^0	0.50	2.23	0.59	1.88	0.2355 ± 0.8077
Ξ^-	0.51	4.04	0.59	2.22	0.2355 ± 0.9277

Results

First determination of $\sin\theta_W$ at the J/ψ threshold



Polarized beams?

Bondar, Grabovsky, Reznichenko, Rudenko, Vorbyev, 1912.09760 (JHEP)

Jinlin Fu, Hai-Bo Li, Jian-Peng Wang, Fu-Sheng Yu, Jianyu Zhang, 2307.04346 (PRD)

Xu Cao, Yu-Tie Liang, Rong-Gang Ping, 2404.00298

Summary

- We briefly present the formalism for extracting P and CP violation through J/ψ production and decay.

- The form factors for J/ψ production and decay are derived, with the large logs resummed using the RGE. Corrections to the axial-vector form factors are large (even differ by a factor of 10), which in turn affect both the magnitudes and the signs of the predicted parity-violating asymmetry.

- P-violating asymmetries are predicted to be of $\mathcal{O}(10^{-4})$, about to be measurable at BESIII. Baryon EDMs are found to be of $\mathcal{O}(10^{-18})\, e \cdot \mathrm{cm}$ using BESIII data, 100~1000 times better than current the only upper bound on d_Λ.

- A measurement of the weak mixing angle is feasible and the current relative precision is about 40%, limited by statistics. STCF can improve the precision by about a factor of 20 with one-year data taken.