MONASH University

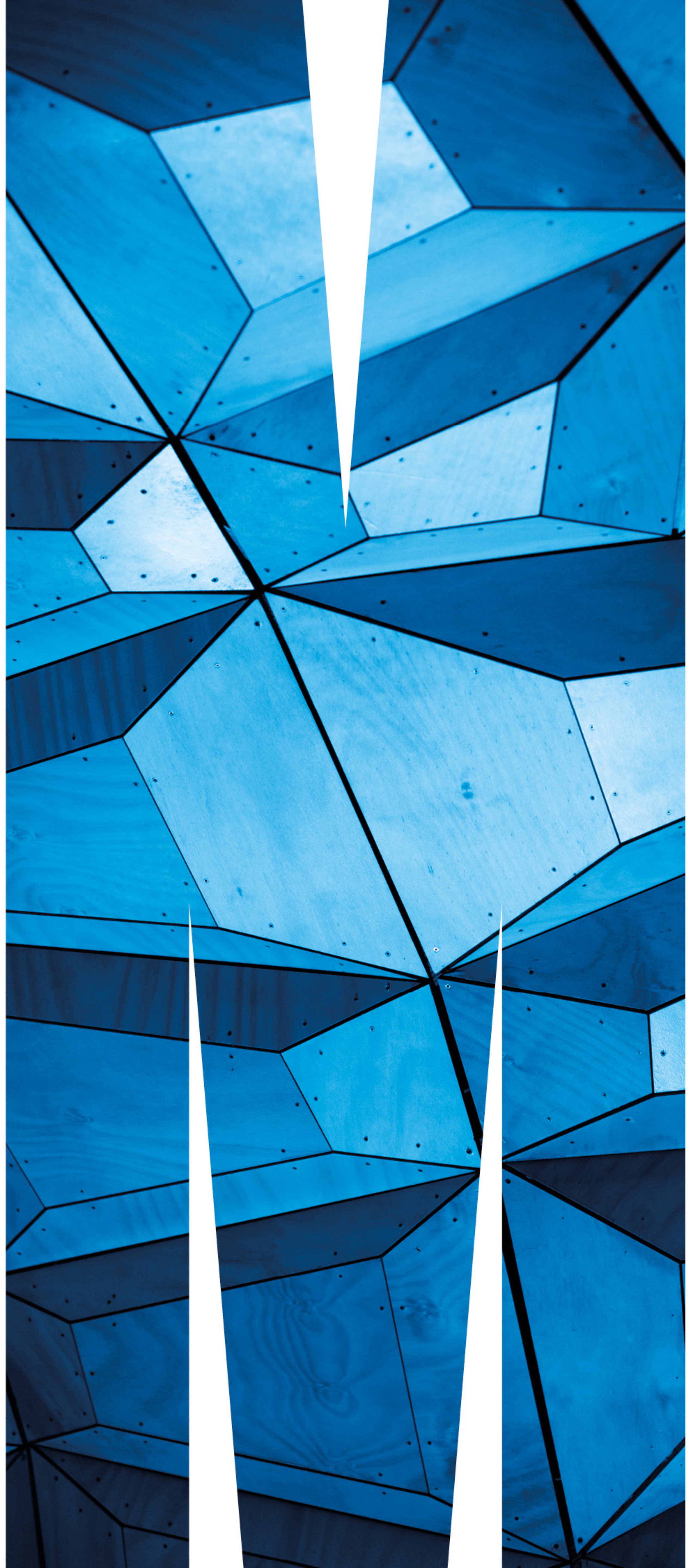
Pursuit of CP violation in hyperon decay

The 2024 International Workshop on Future Tau Charm Facilities

German Valencia

based on work with Xiao-Gang He and Jusak Tandean

GROUP OF EIGHT AUSTRALIA

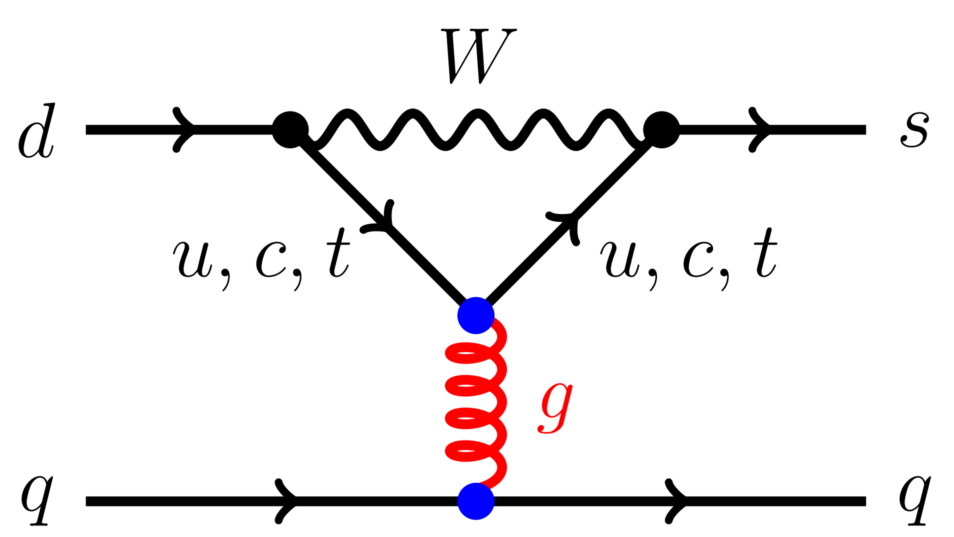


CP violation in s-quark decay

- CP violation in kaon decay has a long history, starting with the first observation of $K_L \to \pi\pi$ in 1964 (J. Christenson, J. Cronin, V. Fitch and R. Turlay)
- The first evidence for direct CP violation, ϵ'/ϵ, by NA31 came in 1988 and was later confirmed by NA48 and KTEV in the early 2000s.
- Calculations have been carried out since at least the early 80s
- The calculations are notoriously difficult and even after 40 years, large uncertainties remain.
- CP violation in hyperon decay is probably harder to estimate and has received much less attention than its kaon counterparts.
- Observation of CP violation in hyperons would help us complete this picture.

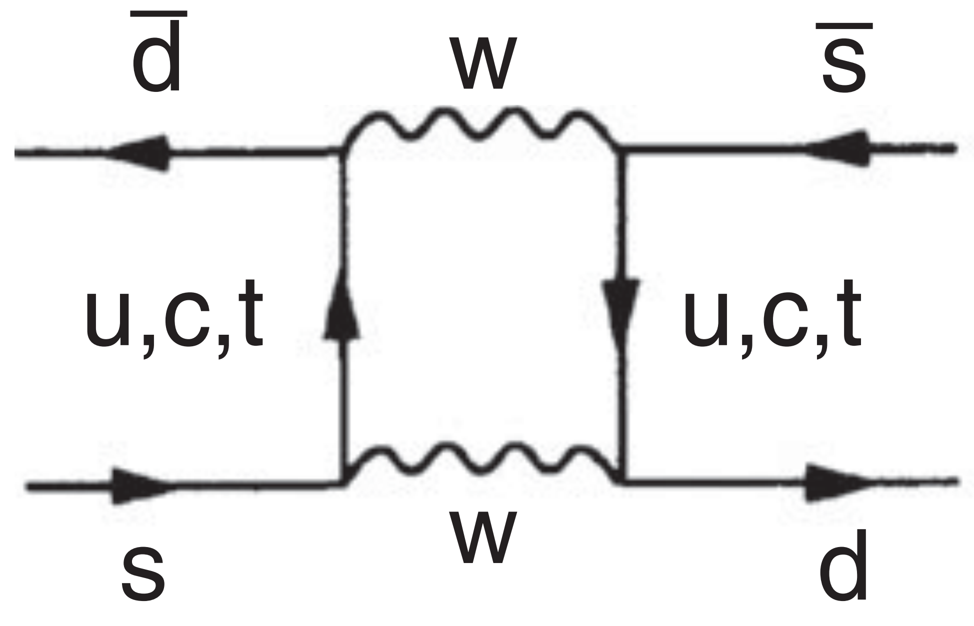
CP violation in $|\Delta S| = 1{,}2$ processes

$|\Delta S| = 1$

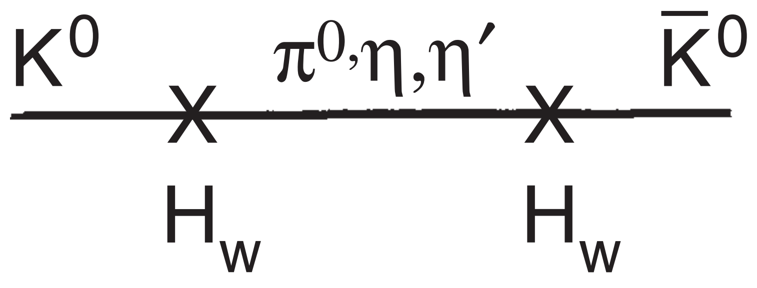


$K \to \pi\pi$ $\quad \Lambda \to p\pi^-$ $\quad \Xi^- \to \Lambda\pi^-$

$|\Delta S| = 2$



$K^0 - \bar{K}^0$



Long-distance

- Within the SM they all probe the same quantity $\sim \mathrm{Im} V_{td} V_{ts}^* = A^2 \lambda^5 \eta$
- the kaon observables have established CP violation but the uncertainty in their calculation still allows for relatively large contributions beyond the SM
- Beyond the SM, all these modes are complementary and observing CP violation in hyperon decay would add valuable information to the picture

CP violation in $K \to \pi\pi$

- **Recall for $K \to \pi\pi$ (PDG values)**
- $\eta^{+-} = \dfrac{A(K_L \to \pi^+\pi^-)}{A(K_S \to \pi^+\pi^-)} = \epsilon + \epsilon', \quad \eta^{00} = \dfrac{A(K_L \to \pi^0\pi^0)}{A(K_S \to \pi^0\pi^0)} = \epsilon - 2\epsilon'$

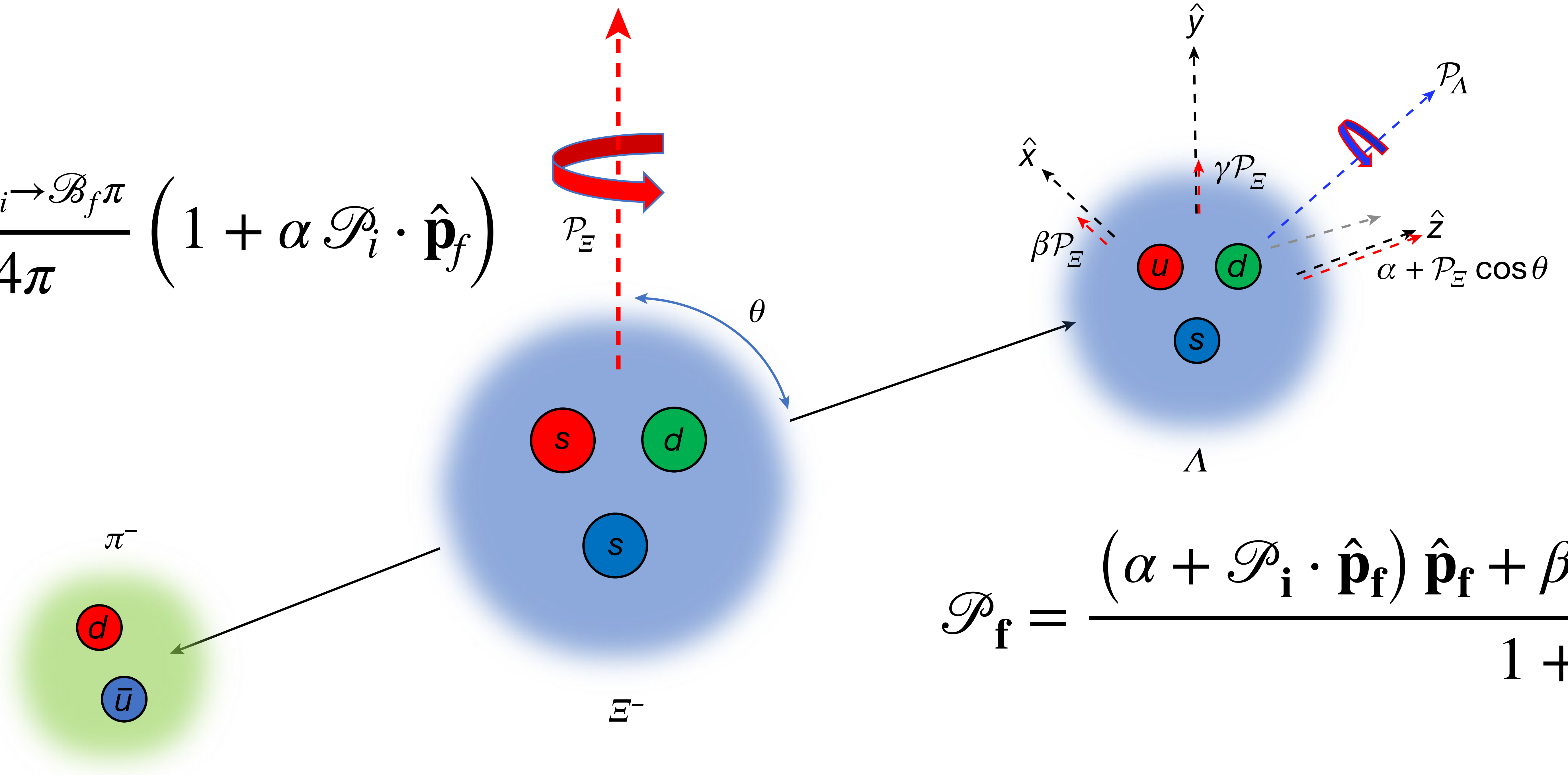
- Indirect CP violation: $|\epsilon| = (2.228 \pm 0.011) \times 10^{-3}$
- Direct CP violation: $\mathrm{Re}(\epsilon'/\epsilon) = (1.66 \pm 0.23) \times 10^{-3}$

- **Recent detailed theory calculations give for the SM**

- From 2019: $|\epsilon| = (2.16 \pm 0.18) \times 10^{-3}$ (Brod et. al. PRL 125.171803)
- From 2019: $\mathrm{Re}(\epsilon'/\epsilon) = (1.3^{+0.6}_{-0.7}) \times 10^{-3}$ (Cirigliano et. al. JHEP02(2020)032)

Hyperon non-leptonic decay - observables

$$\frac{d\Gamma_{\mathscr{B}_i \to \mathscr{B}_f \pi}}{d\Omega_f} = \frac{\Gamma_{\mathscr{B}_i \to \mathscr{B}_f \pi}}{4\pi}\left(1 + \alpha\, \mathscr{P}_i \cdot \hat{\mathbf{p}}_f\right)$$



$$\mathscr{P}_\mathbf{f} = \frac{\left(\alpha + \mathscr{P}_\mathbf{i} \cdot \hat{\mathbf{p}}_\mathbf{f}\right)\hat{\mathbf{p}}_\mathbf{f} + \beta \mathscr{P}_\mathbf{i} \times \hat{\mathbf{p}}_\mathbf{f} + \gamma \hat{\mathbf{p}}_\mathbf{f} \times \left(\mathscr{P}_\mathbf{i} \times \hat{\mathbf{p}}_\mathbf{f}\right)}{1 + \alpha \mathscr{P}_\mathbf{i} \cdot \hat{\mathbf{p}}_\mathbf{f}}$$

$$|\alpha|^2 + |\beta|^2 + |\gamma|^2 = 1$$

$$\beta = \sqrt{1-\alpha^2}\sin\phi$$

$$\gamma = \sqrt{1-\alpha^2}\cos\phi$$

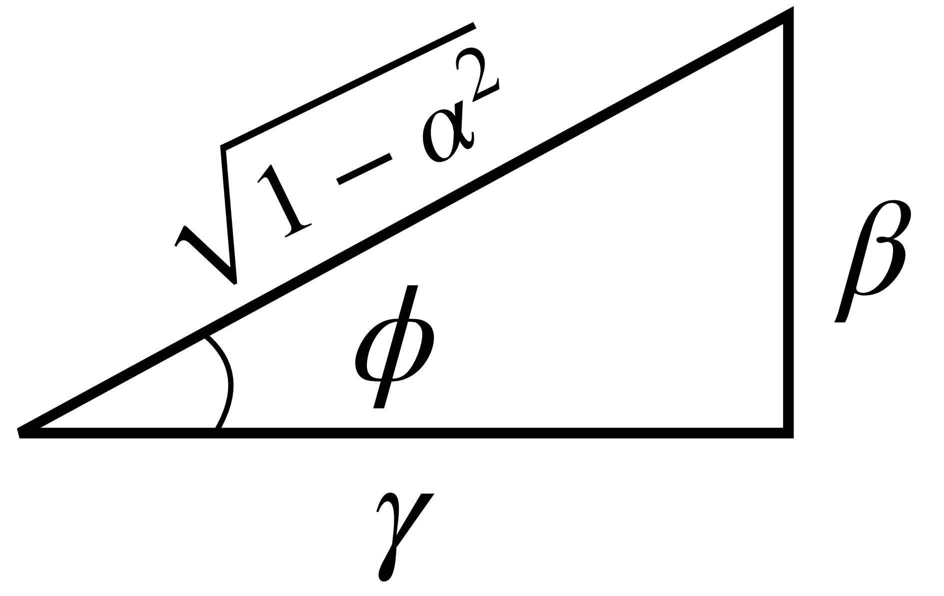
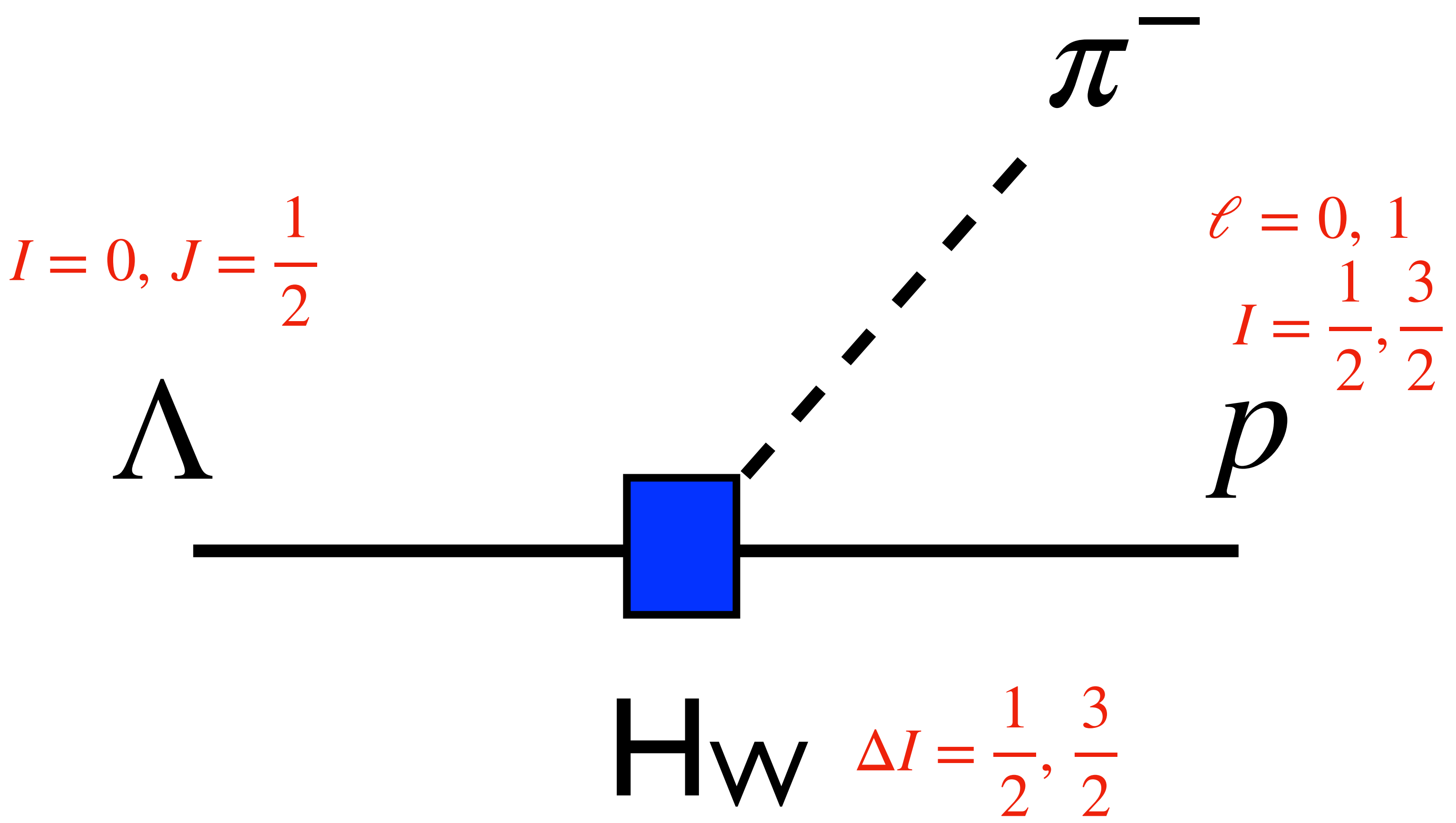
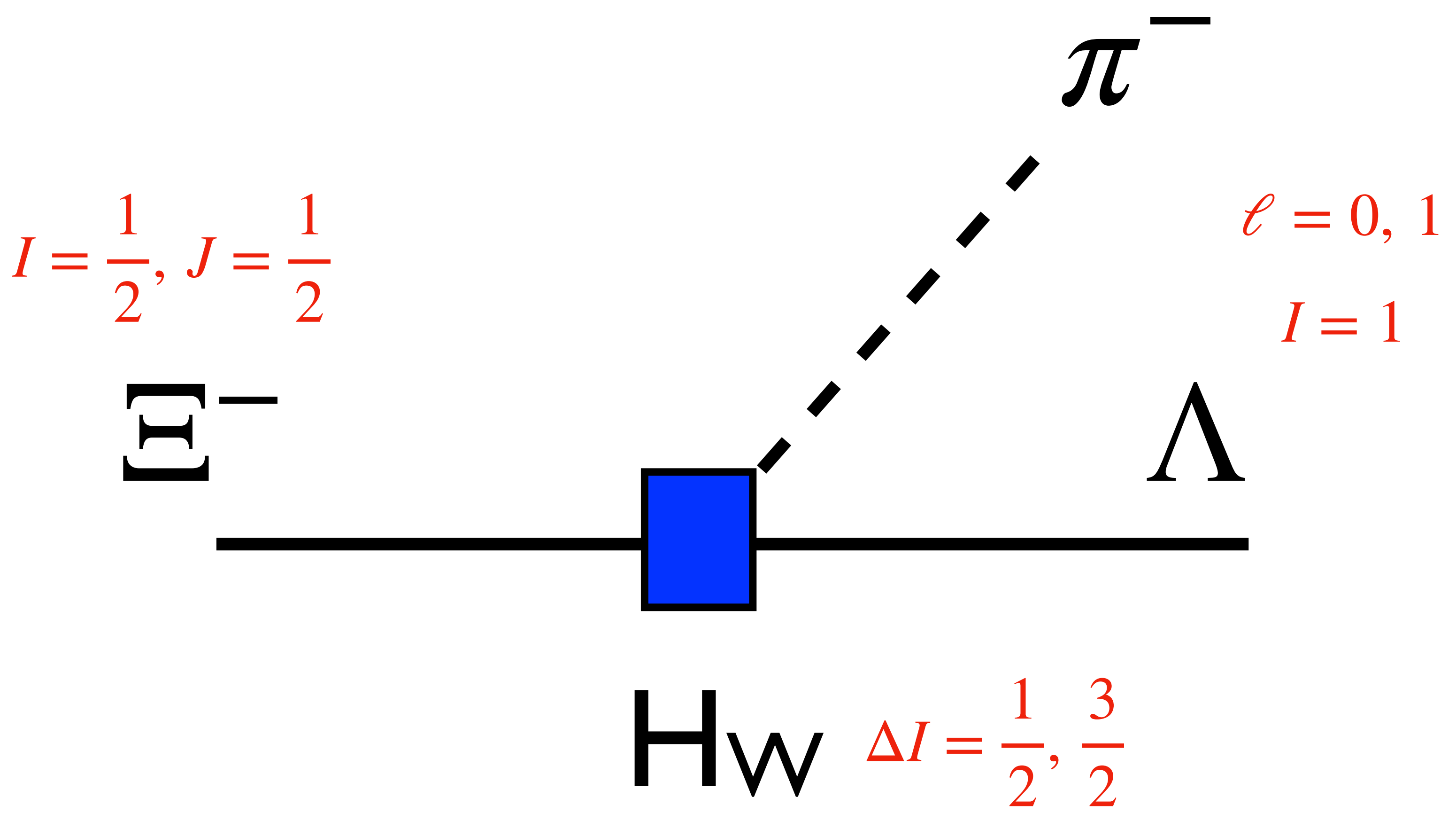


Figure from BESIII collaboration:: Ablikim, M., Achasov, M. N., Adlarson, P., Cetin, H. O., Kolcu, O. B. (2022). Probing CP symmetry and weak phases with entangled double-strange baryons. Nature, 606(7912), 64. And fron https://doi.org/10.1007/s00601-022-01762-0

Theory - notation





- contributions from different isospin and different parity amplitudes

$$\mathcal{M} = \chi_f^\dagger \left(S + \sigma \cdot \hat{\mathbf{p}}_f \ P \right) \chi_i$$

$$S = S_1 e^{i(\delta_1^S + \xi_1^S)} + S_3 e^{i(\delta_3^S + \xi_3^S)}$$

$$P = P_1 e^{i(\delta_1^P + \xi_1^P)} + P_3 e^{i(\delta_3^P + \xi_3^P)}$$

The amplitudes/phases have been measured

mode	S	P	S_3/S_1	P_3/P_1	strong phases
$\Lambda \to p\pi^-$	1.382 ± 0.008	0.624 ± 0.005	0.03 ± 0.01	-0.04 ± 0.02	$\delta_1^S - \delta_1^P = 7.31° \pm 0.12°$
$\Xi^- \to \Lambda\pi^-$	-1.994 ± 0.009	0.392 ± 0.004	0.04 ± 0.01	0.01 ± 0.02	$\delta_2^P - \delta_2^S = 4.6° \pm 1.8°$

- Amplitudes from a fit to PDB data on BR and decay parameters α
- Λ decay phases are extracted from pion-nucleon scattering data M. Hoferichter,et al Phys. Rep. 625, 1 (2016)
- Ξ phases measured by HyperCP M. Huang et al. (HyperCP Collaboration) PRL 93, 011802
  - BESIII also has a measurement, so far with large uncertainty
- Theory calculations of these strong phases also exist, for Ξ decays a recent χPT calculation gives $\delta_P - \delta_S = (8.78^{+0.19}_{-0.22})^\circ$ B-L. Huang et.al. Phys. Rev. D 96, 016021 (2017)

Tests of CP invariance

- Compare a decay to the corresponding antiparticle decay,

$$\Lambda \to p\pi^- \text{ vs } \bar{\Lambda} \to \bar{p}\pi^+$$

- If CP invariance holds, $\Gamma = \bar{\Gamma}, \quad \alpha = -\bar{\alpha}, \quad \beta = -\bar{\beta}$
- Test for CP invariance by comparing the corresponding observables:

$$\Delta_{CP} = \frac{\Gamma - \overline{\Gamma}}{\Gamma + \overline{\Gamma}} \qquad A_{CP} = \frac{\alpha + \overline{\alpha}}{\alpha - \overline{\alpha}} \qquad B_{CP} = \frac{\beta + \overline{\beta}}{\alpha - \overline{\alpha}}$$

- with

$$\Delta_{CP} \simeq \sqrt{2} \underbrace{\frac{S_3}{S_1}}_{\Delta I = 1/2 \text{ rule}} \underbrace{\sin(\delta_3^S - \delta_1^S)}_{\text{strong phases}} \underbrace{\sin(\xi_3^S - \xi_1^S)}_{\text{weak phases}}$$

$$A_{CP} \simeq -\tan(\delta_P - \delta_S)\tan(\xi_P - \xi_S)$$

$$B_{CP} \simeq \tan(\xi_P - \xi_S)$$

$$B_{CP} > A_{CP} > \Delta_{CP}$$

BES, BESIII, STCF

- the hyperons are produced in pairs in e^+e^- collisions, in reactions with sequential decays such as

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

- The weak decay analyses the decaying baryon polarisation
- the combined angular distribution for this example allows BESIII to extract simultaneously the parameters $\alpha_\Xi, \bar{\alpha}_\Xi, \alpha_\Lambda, \bar{\alpha}_\Lambda, \phi_\Xi, \bar{\phi}_\Xi$

TABLE I. Illustration of the expected statistical uncertainty for the CPV observables $A_{\rm CP}^{[\Lambda p]}$, $A_{\rm CP}^{[\Xi-]}$, and $B_{\rm CP}^{[\Xi-]}$ at BESIII and the proposed SCTF electron-positron collider. The results of the published BESIII measurements are given in the first row [31,32]. The uncertainties given in the two remaining rows are straightforward rescaling based on the expected number of events. The SM prediction for $A_{\rm CP}^{[\Lambda p]}$ is $\sim(1\text{–}5)\times 10^{-5}$, while for $B_{\rm CP}^{[\Xi-]}$, it amounts to $\mathcal{O}(10^{-4})$ [26]. from N. Salone et. al.PRD 105, 116022 (2022)

	$\sigma(A_{\rm CP}^{[\Lambda p]})$	$\sigma(A_{\rm CP}^{[\Xi-]})$	$\sigma(B_{\rm CP}^{[\Xi-]})$	Comment
BESIII	1.0×10^{-2}[a]	1.3×10^{-2}	3.5×10^{-2}	1.3×10^{9} J/ψ [31,32]
BESIII	3.6×10^{-3}	4.8×10^{-3}	1.3×10^{-2}	1.0×10^{10} J/ψ (projection)
SCTF	2.0×10^{-4}	2.6×10^{-4}	6.8×10^{-4}	3.4×10^{12} J/ψ (projection)

[a]This result is a combination of the two BESIII measurements.

Existing measurements

		process	Experiment
A_{CP}^{Λ}	$-0.004 \pm 0.012 \pm 0.009$	$J/\Psi \to \Xi\bar{\Xi} \to \Lambda\bar{\Lambda}\pi\pi$	BESIII (2022)
A_{CP}^{Λ}	$-0.0025 \pm 0.0046 \pm 0.0012$	$J/\Psi \to \Lambda\bar{\Lambda}$	BESIII (2022)
A_{CP}^{Λ}	$-0.081 \pm 0.055 \pm 0.059$	$J/\Psi \to \Lambda\bar{\Lambda}$	BES (2010)
A_{CP}^{Λ}	0.013 ± 0.022	$p\bar{p} \to \Lambda\bar{\Lambda}$	LEAR (1996)
A_{CP}^{Λ}	0.01 ± 0.10	$J/\Psi \to \Lambda\bar{\Lambda}$	DM2 (1988)
A_{CP}^{Λ}	-0.002 ± 0.004		PDG average

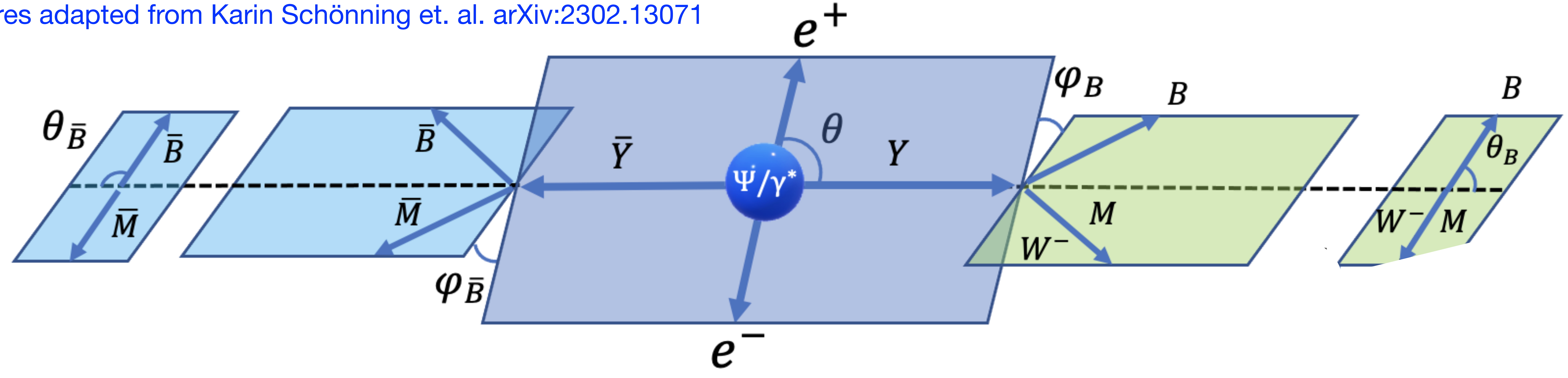
$\Lambda \to p\pi^-$

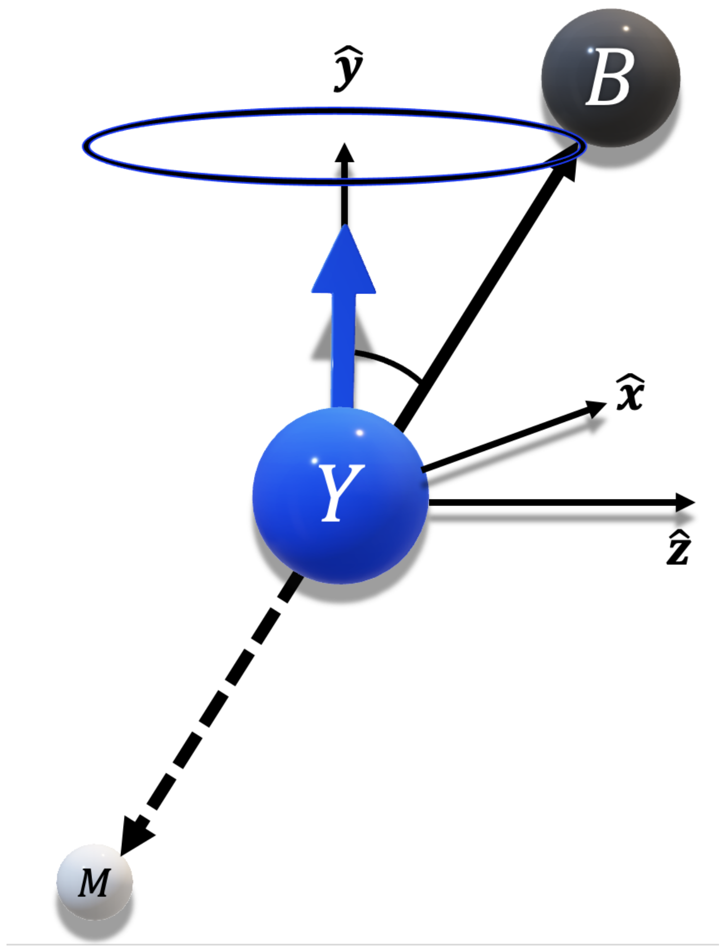
Other modes

		process	Experiment
$B_{CP}^{\Xi} \approx (\xi_P - \xi_S)^{\Xi}$	$(1.2 \pm 3.4 \pm 0.8) \times 10^{-2}$ rad	$J/\Psi \to \Xi\bar{\Xi} \to \Lambda\bar{\Lambda}\pi\pi$	BESIII (2022)
A_{CP}^{Ξ}	$(0.6 \pm 1.3 \pm 0.6) \times 10^{-2}$	$J/\Psi \to \Xi\bar{\Xi} \to \Lambda\bar{\Lambda}\pi\pi$	BESIII (2022)
A_{CP}^{Ξ}	$(-1.5 \pm 5.1 \pm 1.0) \times 10^{-2}$	$\Psi(3686) \to \Xi\bar{\Xi} \to \Lambda\bar{\Lambda}\pi\pi$	BESIII (2022)
$A_{CP}^{\Xi^0}$	$(-0.7 \pm 8.2 \pm 2.5) \times 10^{-2}$	$\Psi(3686) \to \Xi\bar{\Xi} \to \Lambda\bar{\Lambda}\pi\pi$	BESIII (2023)
$A_{CP}^{\Lambda} + A_{CP}^{\Xi}$	$(0.0 \pm 5.1 \pm 4.4) \times 10^{-4}$	$\Xi \to \Lambda\pi \to p\pi\pi$	HyperCP (2004)
$A_{CP}^{\Omega\to\Lambda K}$	$-0.016 \pm 0.092 \pm 0.089$	$\bar{\Omega}^+ \to \bar{\Lambda}K^+ \to \bar{p}\pi^+K^+$	HyperCP (2006)
$A_{CP}^{\Sigma^+}$	$0.004 \pm 0.037 \pm 0.010$	$J/\Psi/\Psi(2S) \to \Sigma^+\bar{\Sigma}^- \to p\bar{p}\pi^0\pi^0$	BESIII (2020)
$A_{CP}^{\Sigma^+}$	$-0.080 \pm 0.052 \pm 0.028$	$J/\Psi/\Psi(2S) \to \Sigma^+\bar{\Sigma}^- \to n\bar{n}\pi^+\pi^-$	BESIII (2023)

triple product correlations

figures adapted from Karin Schönning et. al. arXiv:2302.13071



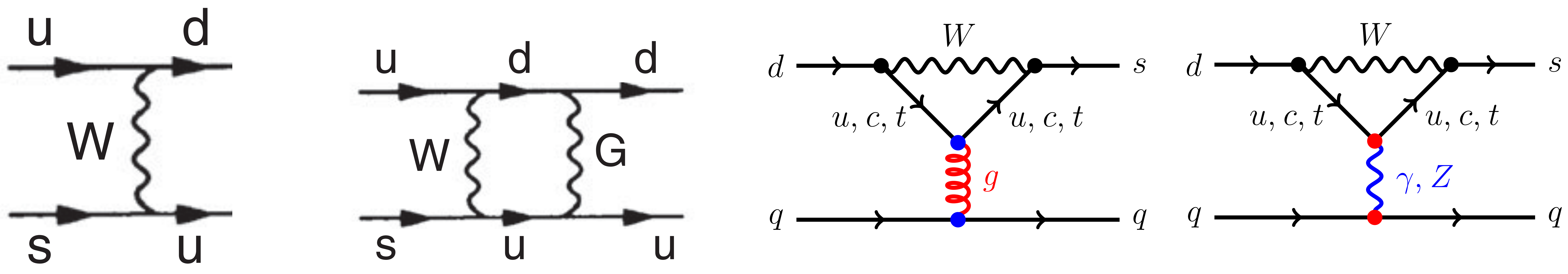


$W(\cos\theta_B) \sim (1 + \alpha_Y P_y \cos\theta_B)$

- in the e^+e^- CM frame $\vec{p}_{\bar{Y}} = -\vec{p}_Y$
- the polarisation of Y is in the direction of $\vec{p}_e \times \vec{p}_Y$ (parity and unpolarised electrons)
- the parameter α_Y measures the correlation between the polarisation of Y and the momentum of B
- the $T-$odd correlation $\mathcal{O} \equiv \vec{p}_e \times \vec{p}_Y \cdot (\vec{p}_B + \vec{p}_{\bar{B}}) \propto (\alpha_Y + \alpha_{\bar{Y}}) \sim A_{CP}^Y$
- can be extracted from a counting asymmetry $\dfrac{N_{\rm ev}(\mathcal{O} > 0) - N_{\rm ev}(\mathcal{O} < 0)}{N_{\rm ev}(\mathcal{O} > 0) + N_{\rm ev}(\mathcal{O} < 0)}$

hyperon amplitudes in the SM

- In principle, the calculation starts from the diagrams like these:



- which result in an effective weak Hamiltonian with WC and four-quark operators

- $$\mathscr{L}_{\text{eff}}^{\Delta S=1} = -\frac{G_F}{\sqrt{2}} V_{ud} V_{us}^* \sum_{i=1}^{10} \left(z_i - \frac{V_{td} V_{ts}^*}{V_{ud} V_{us}^*} y_i \right) Q_i$$

- $$Q_2 = (\bar{s}u)_{V-A} (\bar{u}d)_{V-A}, \quad Q_6 = (\bar{s}_i d_j)_{V-A} \sum_q (\bar{q}_j q_i)_{V+A}, \quad Q_8 = \frac{3}{2} (\bar{s}_i d_j)_{V-A} \sum_q e_q (\bar{q}_j q_i)_{V+A}, \quad \cdots$$

- Then we need to compute the matrix elements of the four-quark operators $\left\langle p\pi^- \left| Q_i \right| \Lambda \right\rangle$

- But this does not quite match the known amplitudes, long-distance effects get in the way…

From χPT ?

- Write an effective interaction in terms of the physical fields

$$\pi = \frac{1}{\sqrt{2}}\begin{pmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta_8 & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta_8 & K^0 \\ K^- & \overline{K}^0 & -\frac{2}{\sqrt{6}}\eta_8 \end{pmatrix} \quad B = \begin{pmatrix} \frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & \Sigma^+ & p \\ \Sigma^- & -\frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & n \\ \Xi^- & \Xi^0 & -\frac{2\Lambda}{\sqrt{6}} \end{pmatrix}$$

$$T_{111} = \Delta^{++}, \quad T_{112} = \frac{1}{\sqrt{3}}\Delta^+, \quad T_{122} = \frac{1}{\sqrt{3}}\Delta^0, \quad T_{222} = \Delta^-$$
$$T_{113} = \frac{1}{\sqrt{3}}\Sigma^{*+}, \quad T_{123} = \frac{1}{\sqrt{6}}\Sigma^{*0}, \quad T_{223} = \frac{1}{\sqrt{3}}\Sigma^{*-},$$
$$T_{133} = \frac{1}{\sqrt{3}}\Xi^{*0}, \quad T_{233} = \frac{1}{\sqrt{3}}\Xi^{*-}, \quad T_{333} = \Omega^- .$$

- Strong interactions in low energy expansion:

$$\mathscr{L}_s = \frac{f_\pi^2}{4}\mathrm{Tr}\left(\partial_\mu U \partial^\mu U^\dagger\right) + \mathrm{Tr}\overline{B}(i\not\partial - M)B + i\mathrm{Tr}\overline{B}\gamma^\mu\left[V_\mu, B\right] + \mathrm{Tr}\left(D\overline{B}\gamma^\alpha\gamma_5\{\mathscr{A}_\alpha, B\} + F\overline{B}\gamma^\alpha\gamma_5[\mathscr{A}_\alpha, B]\right)$$
$$+\epsilon_{kln}\mathscr{C}\left[\left(\overline{T}_{nvw}\right)^\alpha(\mathscr{A}_{wl})_\alpha B_{vk} + \overline{B}_{kv}(\mathscr{A}_{lw})_\alpha(T_{nvw})^\alpha\right],$$

$$\xi = e^{i\pi/f},\ U = \xi^2$$
$$A_\mu = i(\xi\partial_\mu\xi^\dagger - \xi^\dagger\partial_\mu\xi)$$
$$\hat{\kappa} = (\lambda_6 + i\lambda_7)/2$$

- D, F from semileptonic hyperon decay and $\mathscr{C}$ from strong $TB\phi$ decay
  - corrections $\sim 30\,\%$ if decuplet is included

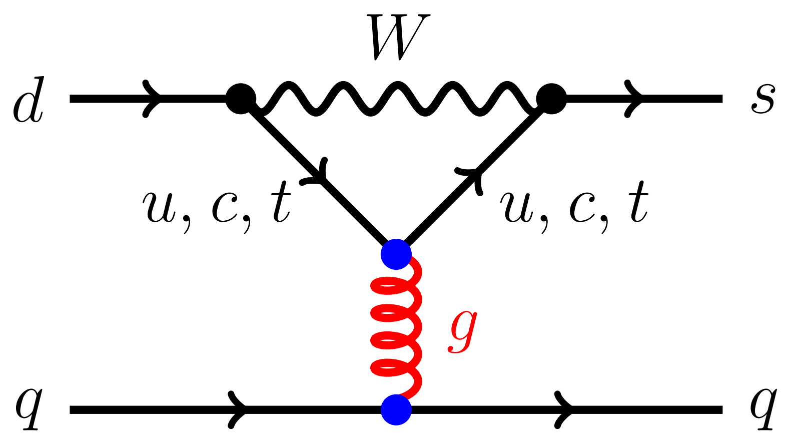
From χPT ?

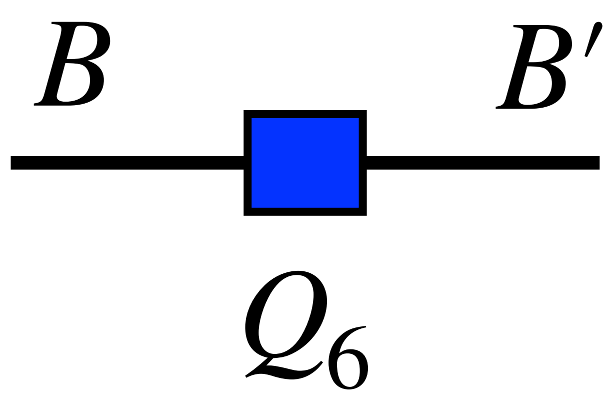
- Non-leptonic weak interactions

$$\mathscr{L}^{SM}_{\Delta S=1} \supset \mathrm{Tr}\left(h_D \bar{B}\{\xi^\dagger \hat{\kappa}\xi, B\} + h_F \bar{B}\left[\xi^\dagger \hat{\kappa}\xi, B\right] \right) + h_C \left(\bar{T}_{kln}\right)^\eta \left(\xi^\dagger \hat{\kappa}\xi\right)_{no} (T_{klo})_\eta$$

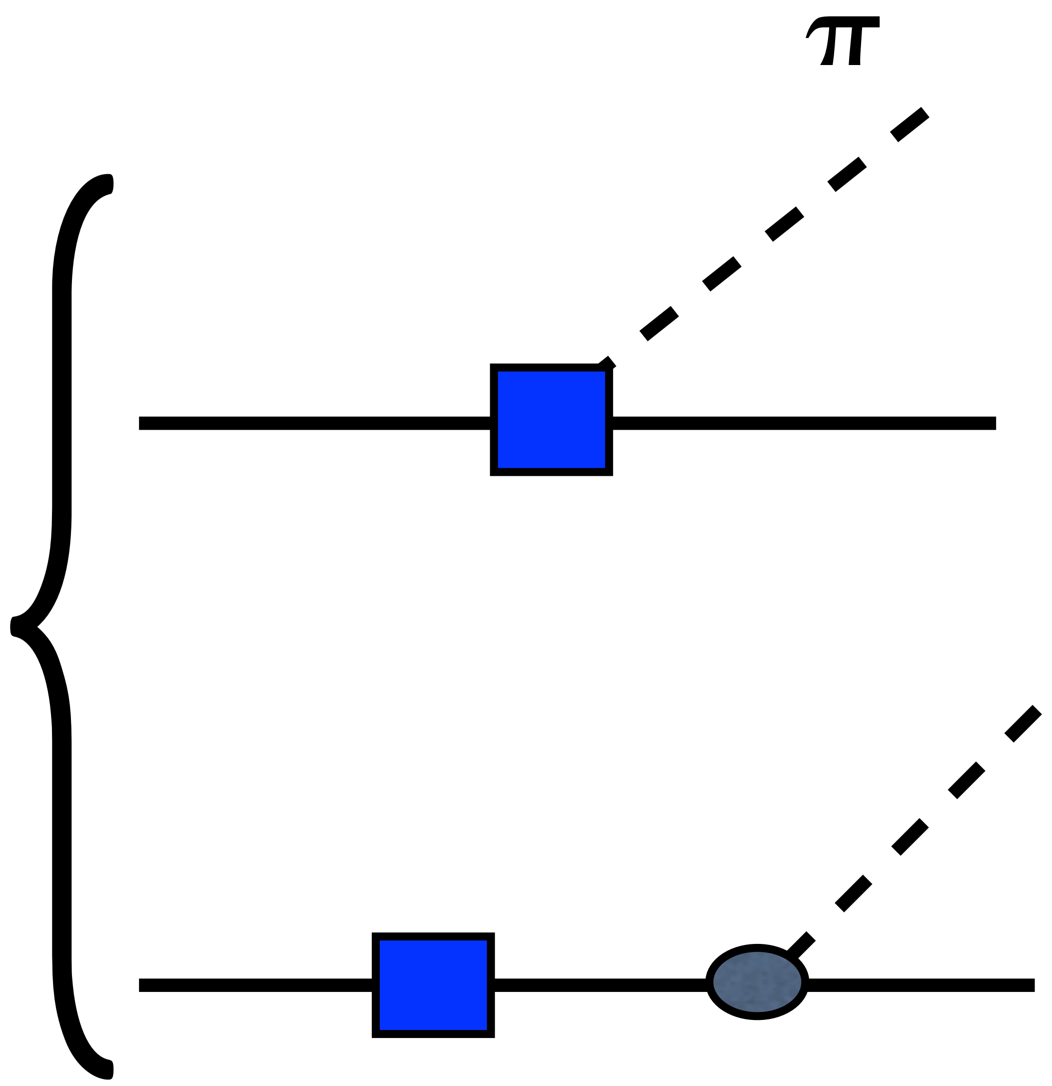
- $h_D,\ h_F,\ h_C$ from fits to weak non-leptonic hyperon decay (S or P waves) and P waves of $\Omega \to B\phi$ decay:
  – fit the S-waves $(h_D, h_F) \ = \ (-0.81,\ 1.89)\ G_F m^2_{\pi^+} f_\pi$
  – fit the P-waves $(h_D, h_F) \ = \ (-2.07,\ 2.71)\ G_F m^2_{\pi^+} f_\pi$
  – One-loop corrections are large and the discrepancy with experiment is consistent with the size of these corrections. At NLO there are too many parameters that need to be determined from experiment.
- estimate from SD $(h_D, h_F) \ \sim \ (-0.87,\ 0.85)\ G_F m^2_{\pi^+} f_\pi$

sketch of the calculation of weak phases





contribution from
$\mathrm{Im}(C_6)$ to h_D, h_F, h_C



mode	$\xi_1^S - \xi_1^P$
$\Lambda \to p\pi^-$	$(-0.1 \pm 1)\ A^2\lambda^5\eta$
$\Xi^- \to \Lambda\pi^-$	$(1.5 \pm 1.1)\ A^2\lambda^5\eta$

J.Tandean and G.V, PRD67, 056001 (2003), hep-ph/0211165

$A^2\lambda^5\bar{\eta} \approx 1.4 \times 10^{-4}$

- The imaginary part is short distance: in the SM mostly Q_6
- compute $\langle B' | \mathcal{O} | B \rangle$ in the bag model, lattice could improve these numbers
- Use leading order χPT to compute S and P waves, large uncertainties
- Estimate of errors from one-loop terms in χPT, captures the range of early estimates that used simple hadronic models
- $A_{CP}^{\Lambda} \sim (-3 \text{ to } 3) \times 10^{-5}, \quad A_{CP}^{\Xi} \sim (0.5 \text{ to } 6) \times 10^{-5}, \quad B_{CP}^{\Xi} \sim (-3.8 \text{ to } -0.3) \times 10^{-4}$

weak phases beyond the SM

- model dependent
- large uncertainty (same calculation as SM)
- Assume the real part of the amplitudes is still SM and include NP only as possible contributions to the imaginary parts
- since the NP introduces new phases into the non-leptonic $\Delta S = 1$ effective interaction at low-energy
  - –the interaction contributes to kaon decay as well
  - –the phases are constrained by the measurements of ϵ and ϵ'
- From the current uncertainty in the calculations of these two quantities, we estimate the window for NP contributions

Beyond SM SMEFT

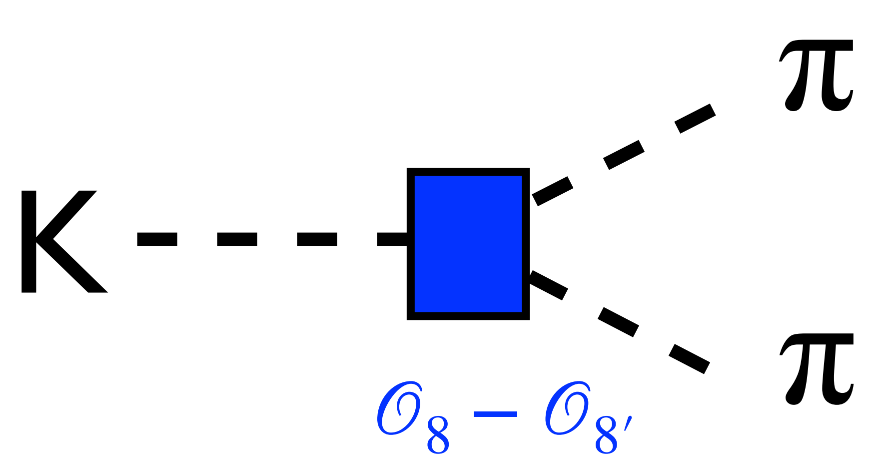
- Consider all dimension six $|\Delta S| = 1$ operators Buchmuller and Wyler, NPB 268 (1986) 621
- estimate all phases in vacuum saturation (very rough)
  - consider only long-distance contributions to ϵ
- Two operators are singled out as possibilities for enhanced CP violation in hyperon non-leptonic decay, $\Lambda \to p\pi^-$, specifically:
  1. $\bar{d}_R s_L \bar{u}_R u_L + \mathrm{h.c.}$
  2. $\bar{d}_{L(R)} \sigma^{\mu\nu} T^a s_{R(L)} G^a_{\mu\nu} + \mathrm{h.c.}$
- The second one appears in many models, it was used in the first estimates by Donoghue, He, Pakvasa as the “Weinberg model” with a more detailed study in a SUSY model by He, Murayama, Pakvasa, G.V. which emphasized the complementarity of the hyperon modes and the kaon modes

CP violation beyond SM - illustrative example

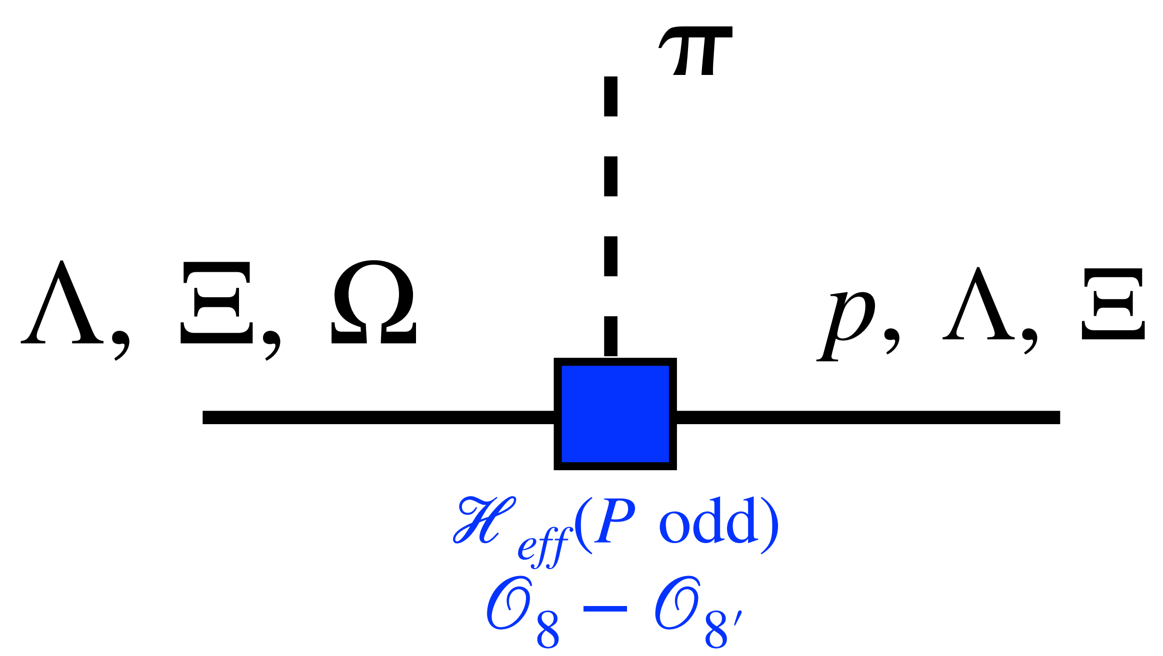
Complex coefficients

$$\mathscr{L}_{NP} \supset C_8 \mathcal{O}_8 + C_{8'} \mathcal{O}_{8'}, \qquad \mathcal{O}_{8(8')} = \frac{4G_F}{\sqrt{2}} V_{ts} V^*_{td} \frac{g_s}{16\pi^2} m_s \bar{d}_{L(R)} \sigma^{\mu\nu} T^a s_{R(L)} G^a_{\mu\nu}$$

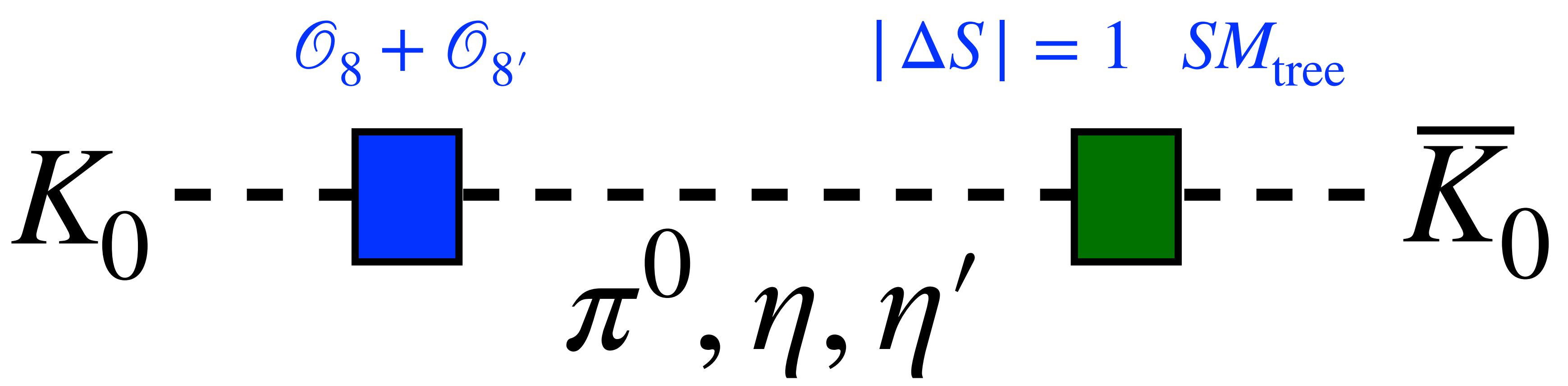
constraint from ε′



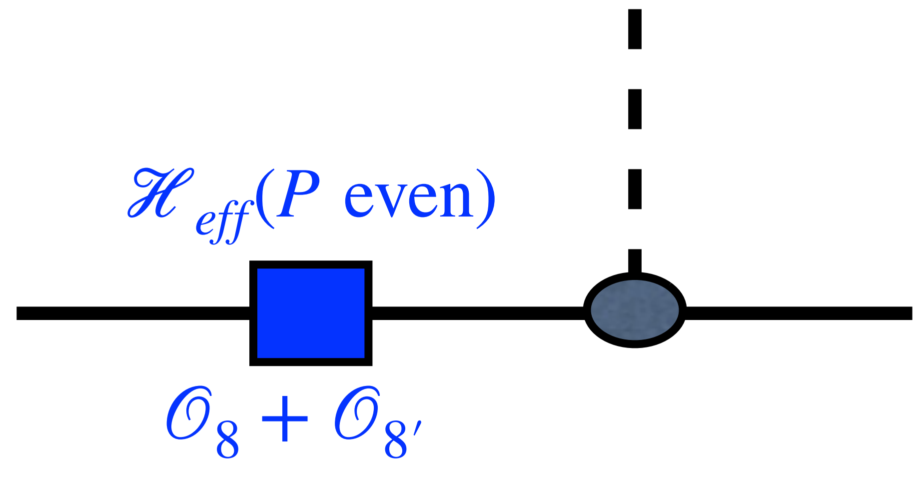
$\rightarrow (C_8 - C_{8'}) \rightarrow$ S (or D) waves



constraint from ε



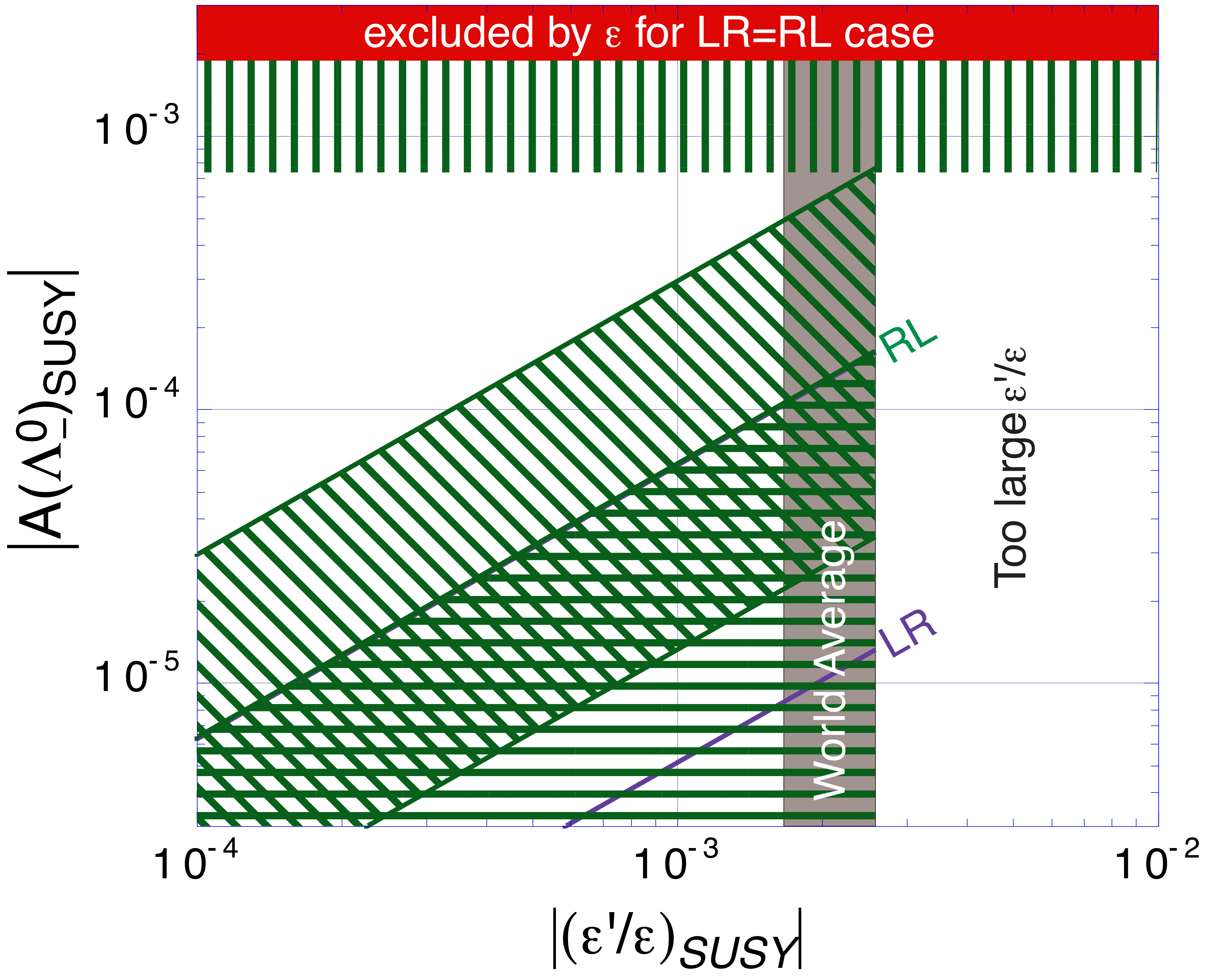
$\rightarrow (C_8 + C_{8'}) \rightarrow$ P waves



Old susy result (1999)

- Back then $\mathrm{Re}(\epsilon'/\epsilon) = (2.12 \pm 0.46) \times 10^{-3}$ and ``not inconsistent with SM”
- $|\epsilon| = (2.263 \pm 0.023) \times 10^{-3}$ the SM depends on B_K and poorly known long-distance contributions
- Conservatively allowing the LD pole contribution in SUSY to reach 2.3×10^{-3} we found
- $A^{\Lambda}_{CP} \lesssim 10^{-3}$
- the current estimates are similar even though the status of ϵ and ϵ' has changed

$$\left|\frac{\epsilon'}{\epsilon}\right|_{BSM} \leq 1 \times 10^{-3}, \ \ |\epsilon|_{BSM} \leq 2 \times 10^{-4}$$



From He, Murayama, Pakvasa, GV *Phys.Rev.D* 61 (2000) 071701

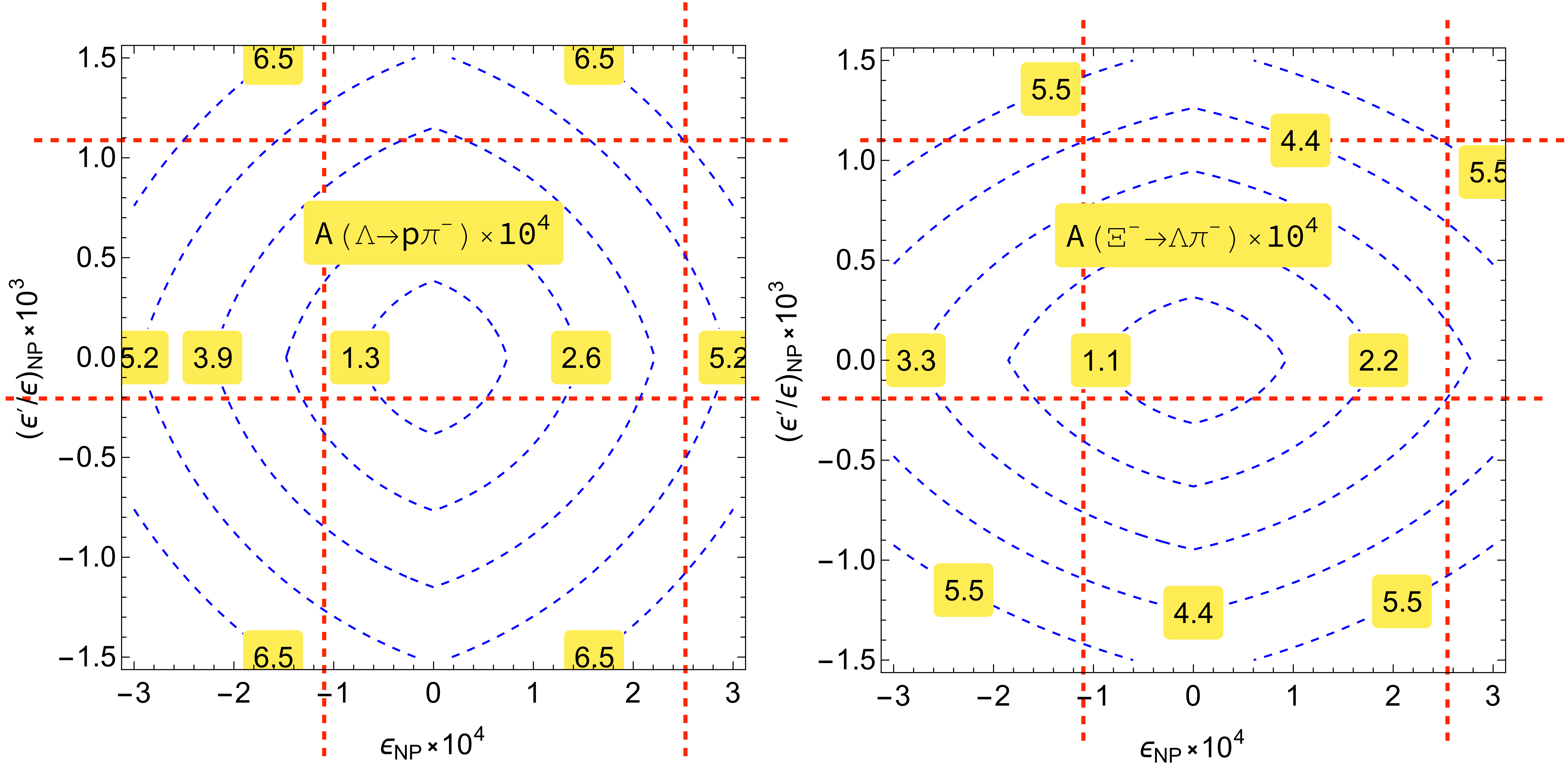
From 2019: $|\epsilon| = (2.16 \pm 0.18) \times 10^{-3}$ (Brod et. al. PRL 125.171803)

From 2019: $\mathrm{Re}(\epsilon'/\epsilon) = (1.3^{+0.6}_{-0.7}) \times 10^{-3}$ (Cirigliano et. al. JHEP02(2020)032)

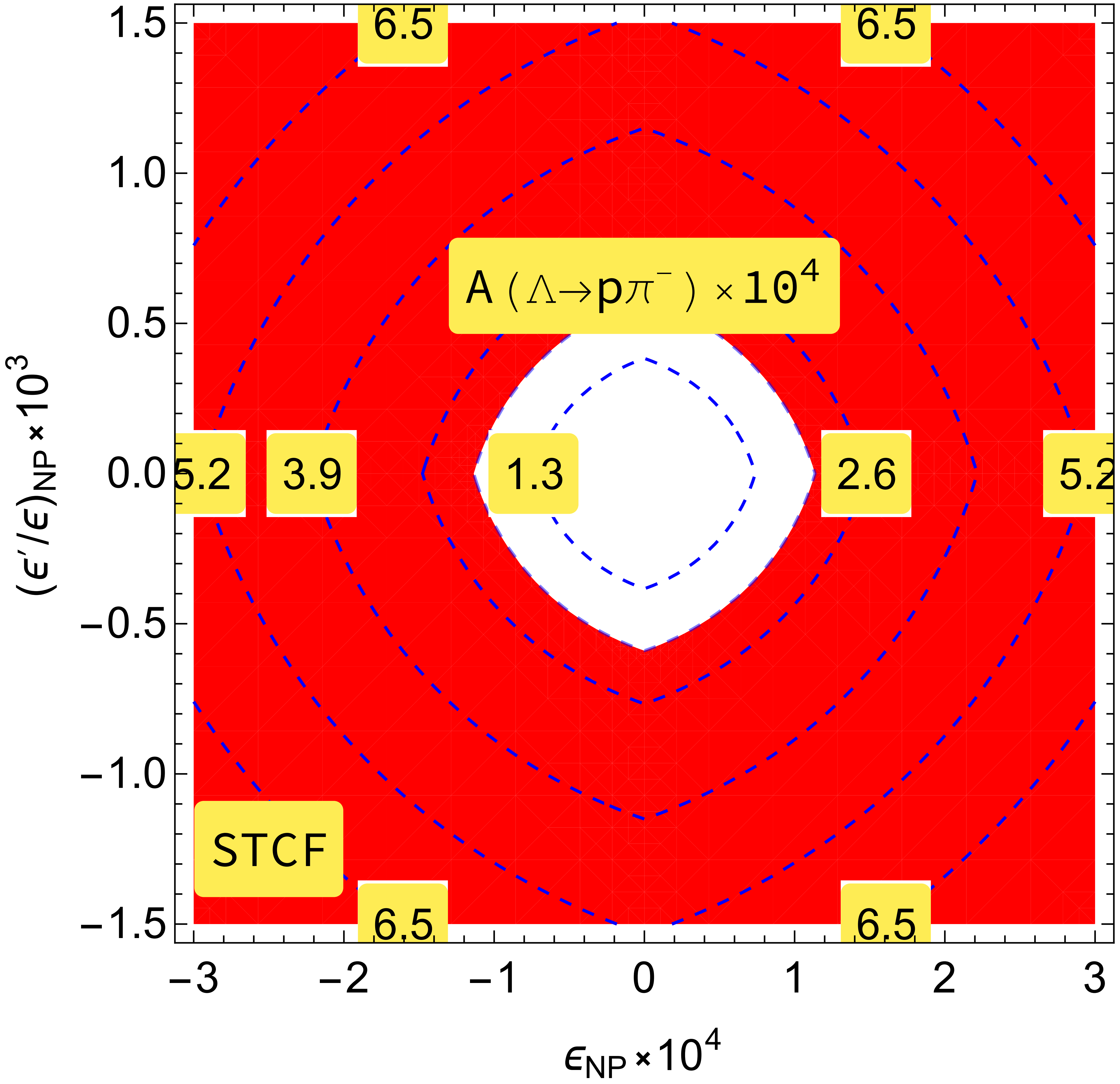
how large can the asymmetries be BSM?

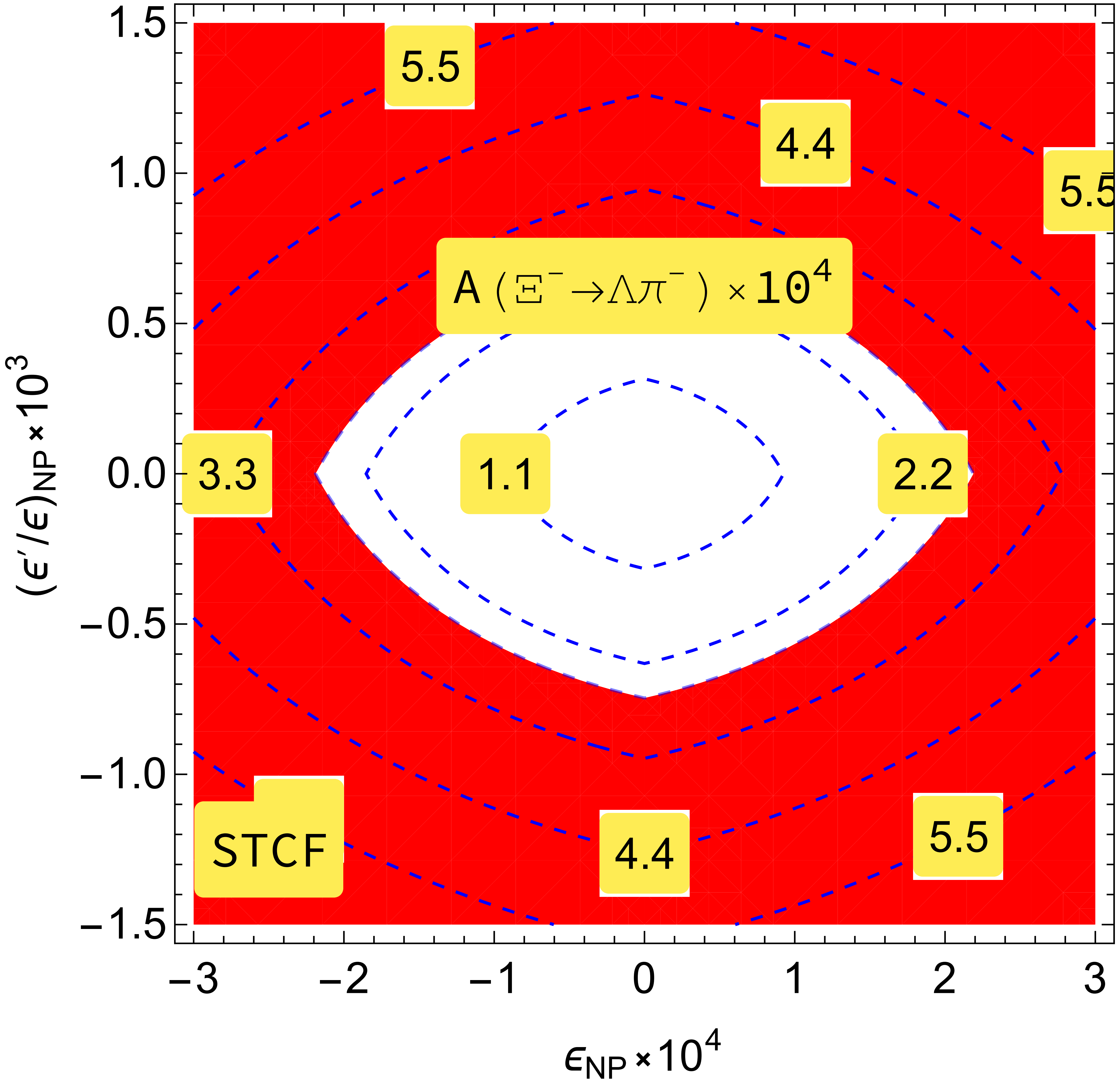
Largest asymmetries (absolute value) from gluon dipole operators constrained by $\epsilon,\ \epsilon'$

$$\left(\frac{\epsilon'}{\epsilon}\right)_{\rm exp} - \left(\frac{\epsilon'}{\epsilon}\right)_{\rm SM} = (.4^{+.7}_{-.6}) \times 10^{-3}, \quad \left|\epsilon_{\rm exp} - \epsilon_{\rm SM}\right| = (0.7 \pm 1.8) \times 10^{-4}$$



BSM asymmetries vs STCF





- STCF projected sensitivity with 3.4×10^{12} J/ψ: A_Λ $(A_\Xi) \sim 2$ $(2.6) \times 10^{-4}$

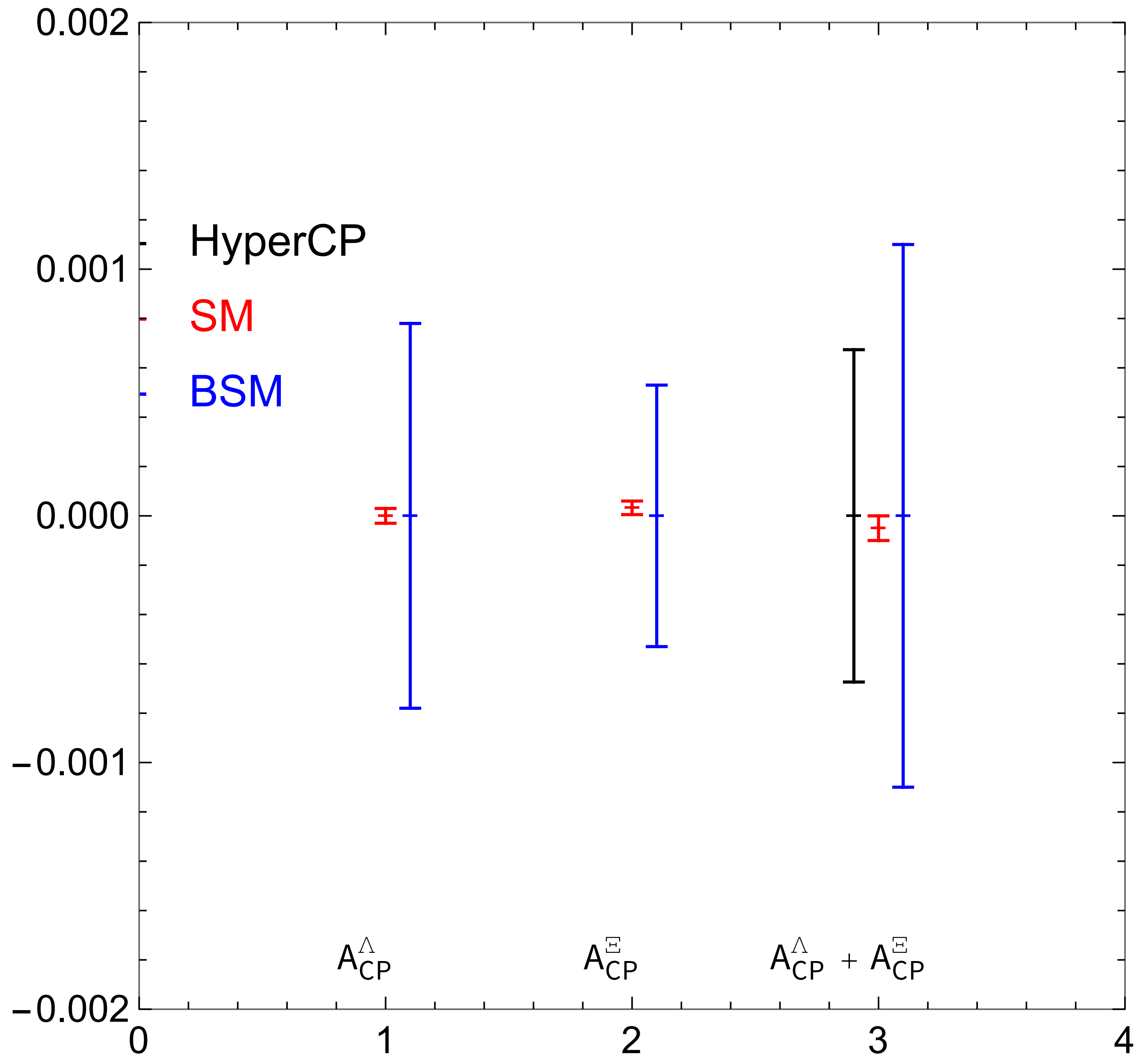
SM vs BSM possible ranges

- use as an example

$$\mathcal{L}_{NP} \supset C_8 \mathcal{O}_8 + C_{8'} \mathcal{O}_{8'}, \quad \mathcal{O}_{8(8')} = \frac{4G_F}{\sqrt{2}} V_{ts} V_{td}^* \frac{g_s}{16\pi^2} m_s \bar{d}_{L(R)} \sigma^{\mu\nu} T^a s_{R(L)} G^a_{\mu\nu}$$

then $$(\xi_P - \xi_S) \sim \left(C' \left(\frac{\epsilon'}{\epsilon}\right)_{BSM} + C\, \epsilon_{BSM} \right)$$

J. Tandean PRD **69**, 076008, (2004), N Salone et.al. PRD 105, 116022 (2022)



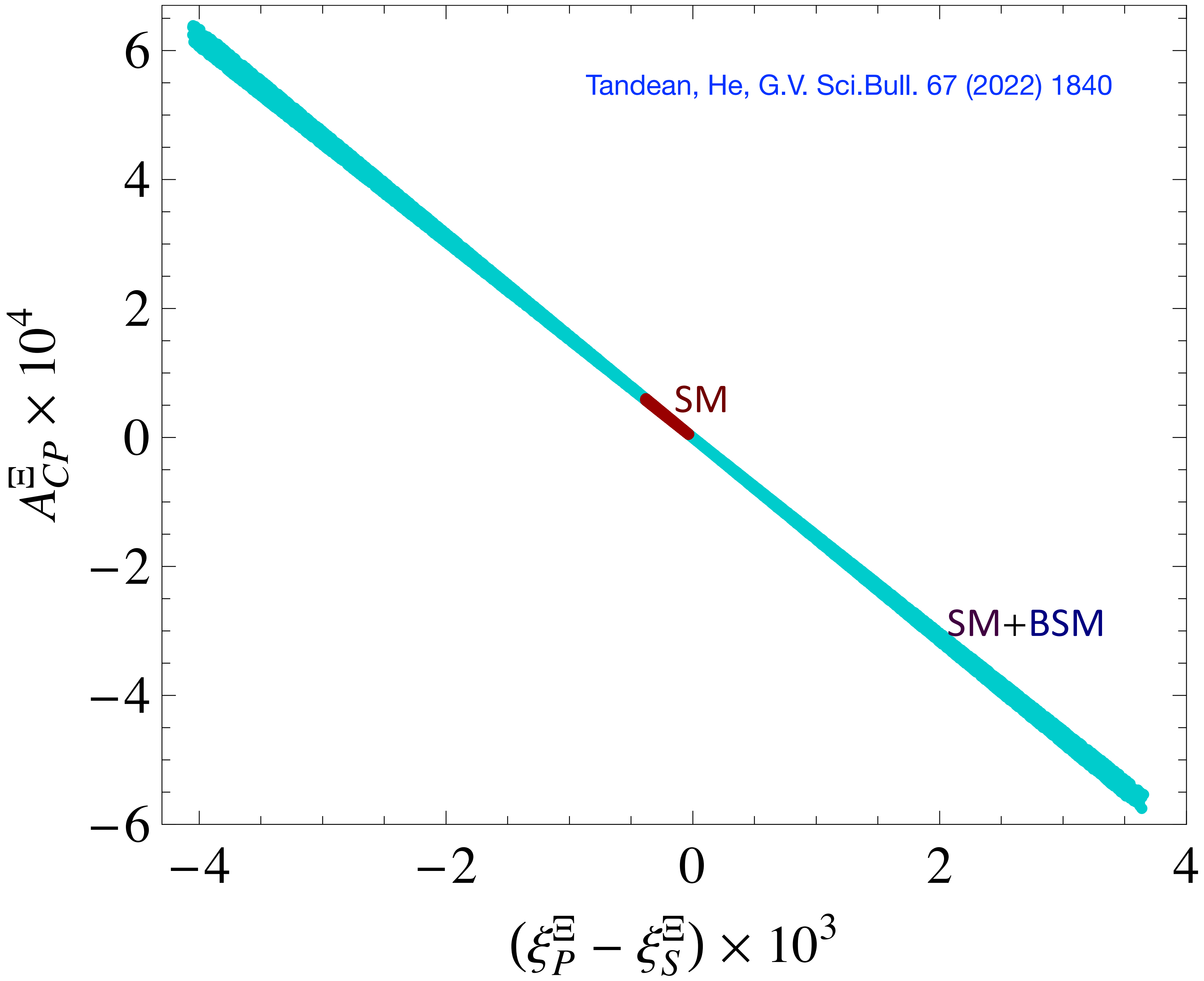
- Combined with $\left|\frac{\epsilon'}{\epsilon}\right|_{BSM} \lesssim 1 \times 10^{-3}, \ |\epsilon|_{BSM} \lesssim 2 \times 10^{-4}$
- Results in
- $|A^{\Lambda}_{CP}| \lesssim 7 \times 10^{-4}, \quad |A^{\Xi}_{CP}| \lesssim 5.9 \times 10^{-4}, \quad |B^{\Xi}_{CP}| \lesssim 3.7 \times 10^{-3}$
- theoretical uncertainty in SM, the largest values are shown

HyperCP result

$$\boxed{A_{\Xi\Lambda} = [0.0 \pm 5.1(\mathrm{stat}) \pm 4.4(\mathrm{syst})] \times 10^{-4}}$$

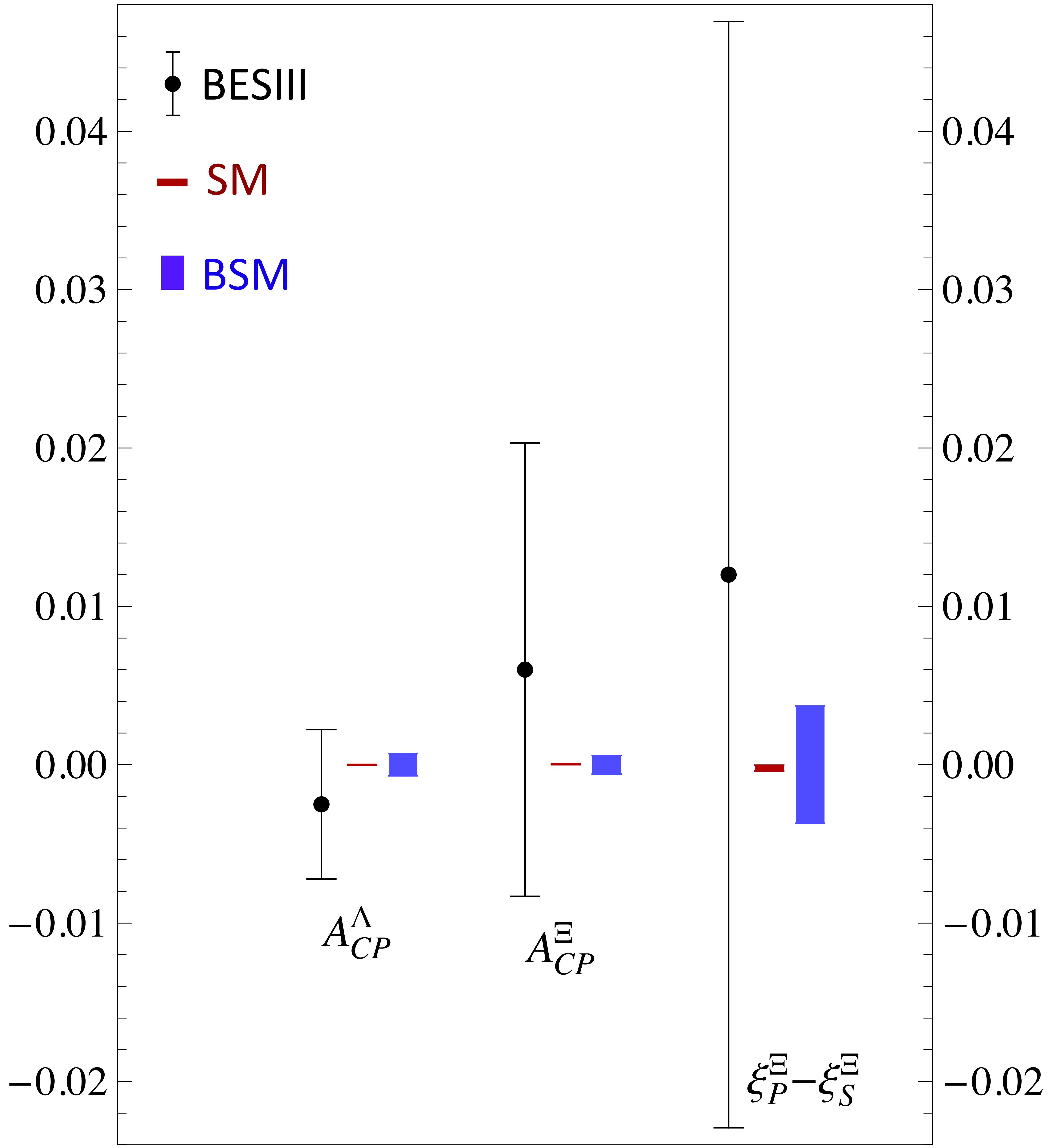
Phys.Rev.Lett.93:262001,2004.

BES III results vs BSM scenarios

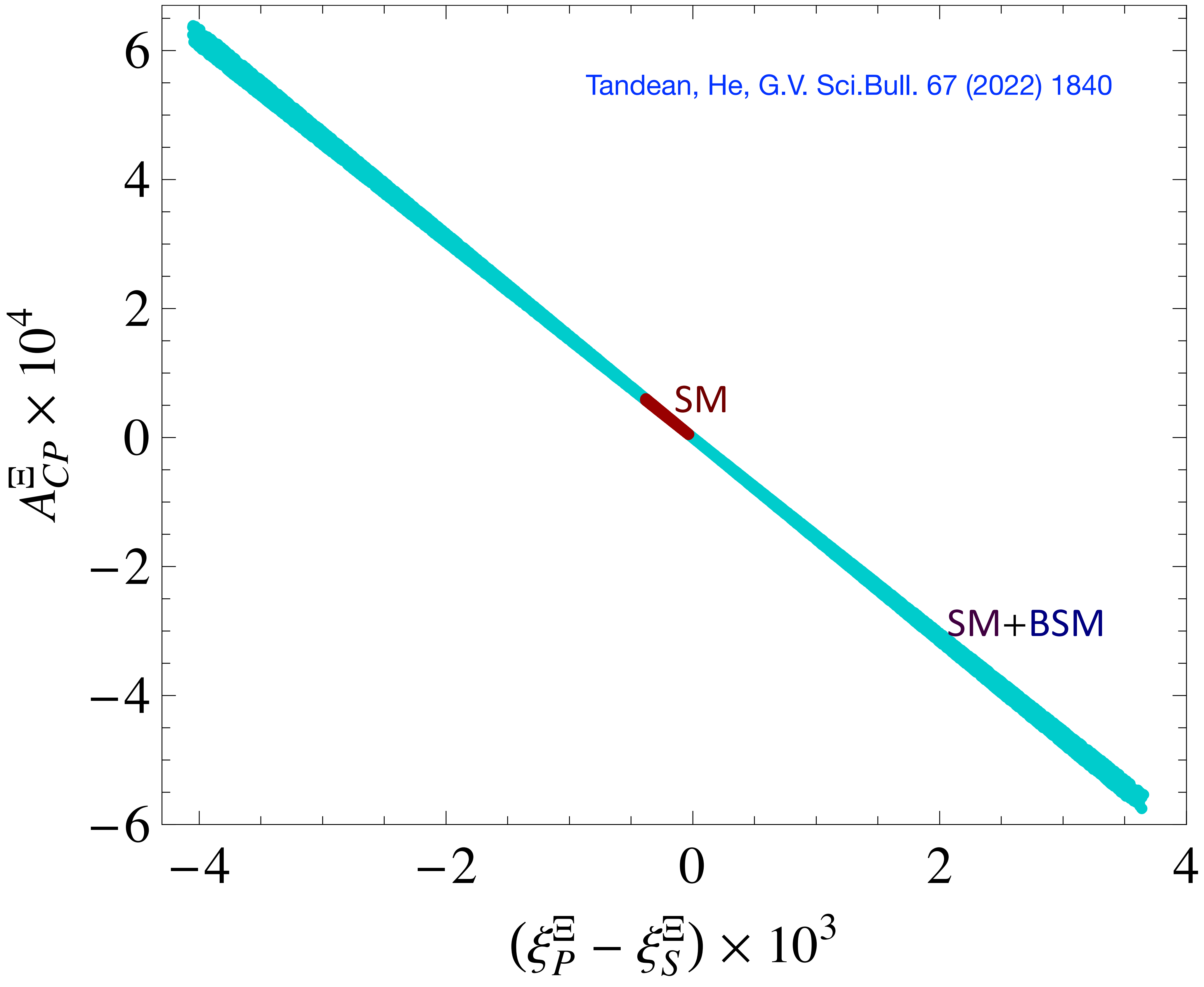


	Number of J/ψ	sensitivity to A^{Ξ}_{CP}
BESIII (current)	1.3×10^9	1.3×10^{-2}
BESIII (future)	1×10^{10}	4.8×10^{-3}
tau-charm factory	3.4×10^{12}	2.6×10^{-4}

Salone et. al., PHYSICAL REVIEW D 105, 116022 (2022)

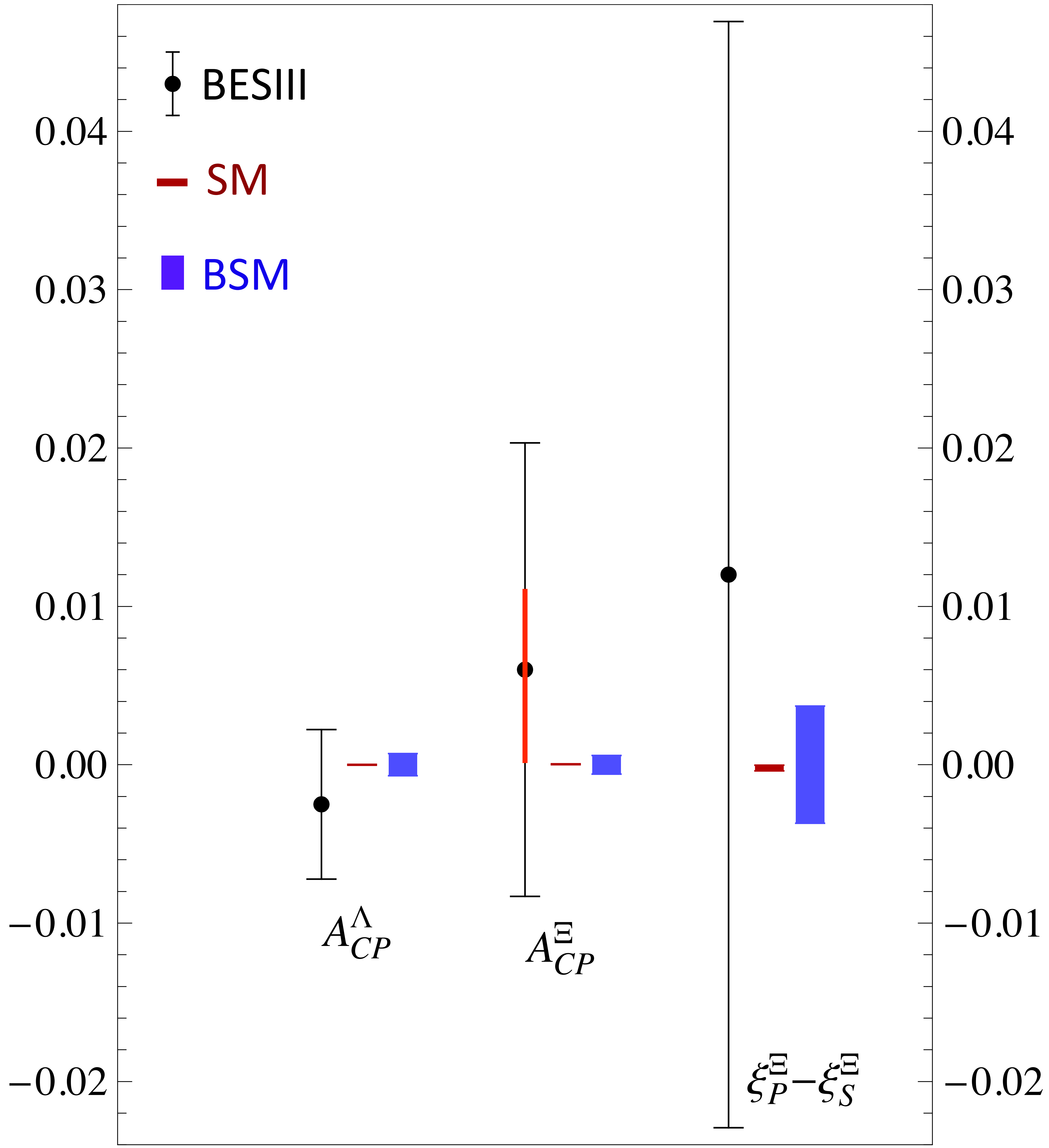


BES III results vs BSM scenarios

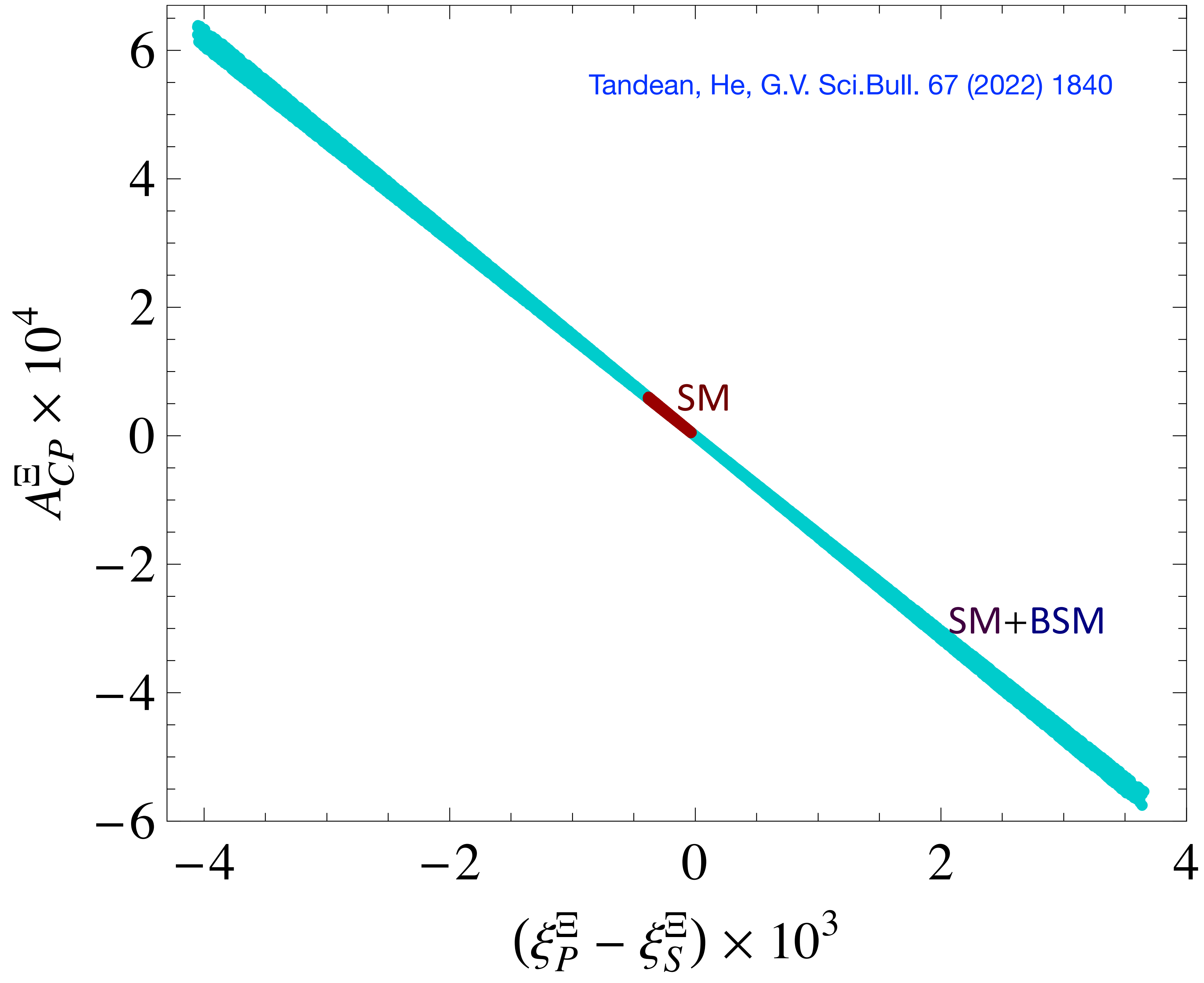


	Number of J/ψ	sensitivity to A_{CP}^{Ξ}
BESIII (current)	1.3×10^9	1.3×10^{-2}
BESIII (future)	1×10^{10}	4.8×10^{-3}
tau-charm factory	3.4×10^{12}	2.6×10^{-4}

Salone et. al., PHYSICAL REVIEW D 105, 116022 (2022)

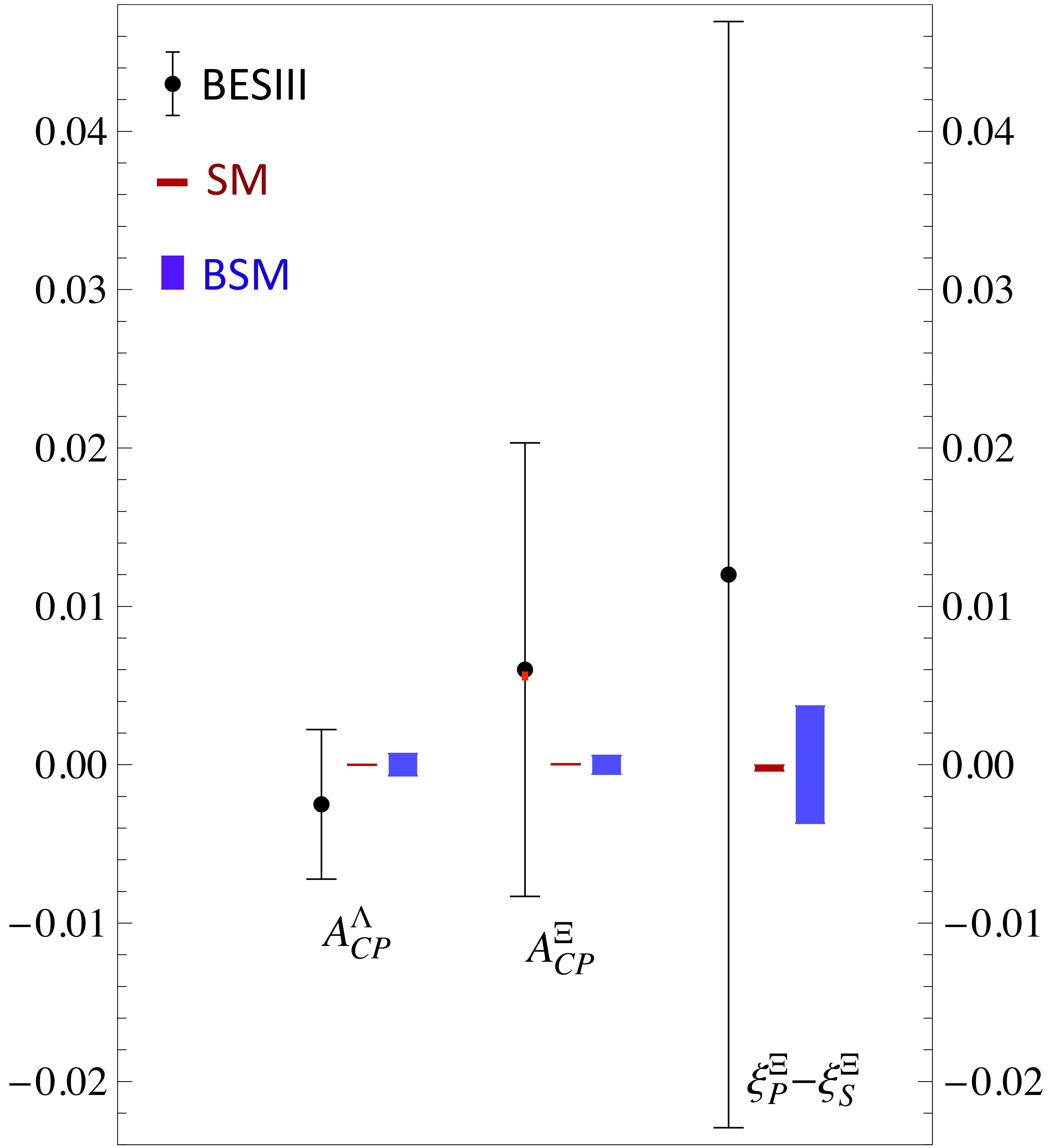


BES III results vs BSM scenarios



	Number of J/ψ	sensitivity to A_{CP}^{Ξ}
BESIII (current)	1.3×10^9	1.3×10^{-2}
BESIII (future)	1×10^{10}	4.8×10^{-3}
tau-charm factory	3.4×10^{12}	2.6×10^{-4}

Salone et. al., PHYSICAL REVIEW D 105, 116022 (2022)



Summary and conclusions

- Hyperon decays can play an important role in probing BSM physics in the $s \to d$ sector, complementing kaon decays, but need much higher sensitivity
- Hyperon decay modes allowed in the SM receive large long-distance contributions that are difficult to estimate reliably, the lattice community has started to look at some of the semileptonic modes but not yet at the non-leptonic decay modes
- Recent BESIII measurements have significantly increased our knowledge of CP violating observables in hyperon decay and we look forward to their future improvements
- A super tau-charm factory with $10^{12} - 10^{13}$ J/ψ leading to $10^{9} - 10^{10}$ reconstructed hyperon decays has the potential to test CP violation at levels near those estimated for the SM and to cover much of the BSM window