中國科学院 CHINESE ACADEMY OF SCIENCES

SCNT 南方核科学理论研究中心 Southern Center for Nuclear-Science Theory

IMP

# “2026年轻强子专题研讨会”

# 超子非轻衰变的理论研究进展

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**Based on arXiv: 2512.10346 and 2601.22670**

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**河南商丘**

# Outline

- □ **八重态超子Λ和$\Sigma^{\pm}$的两体非轻衰变的研究**

  arXiv: 2512.10346

- □ **十重态超子Ω的两体非轻衰变的研究**

  arXiv: 2601.22670

# 研究背景与意义：

□ 超子弱衰变是研究强相互作用和弱相互作用的重要工具。

（处于低能区，包含丰富的非微扰QCD效应）

□ 超子弱衰变是探索CP破坏的重要场所。

□ 近年来BESIII收集了超过10亿的J/psi事例，它们衰变产生了大量超子对，这为研究超子物理提供了实验支持（尤其是对不对称参数$\alpha$的测量）。

# 对超子$\Lambda$和$\Sigma^{\pm}$的两体强子弱衰变的研究

**$\Lambda/\Sigma^{\pm} \to N\pi$ 已经积累了丰富的实验数据。**

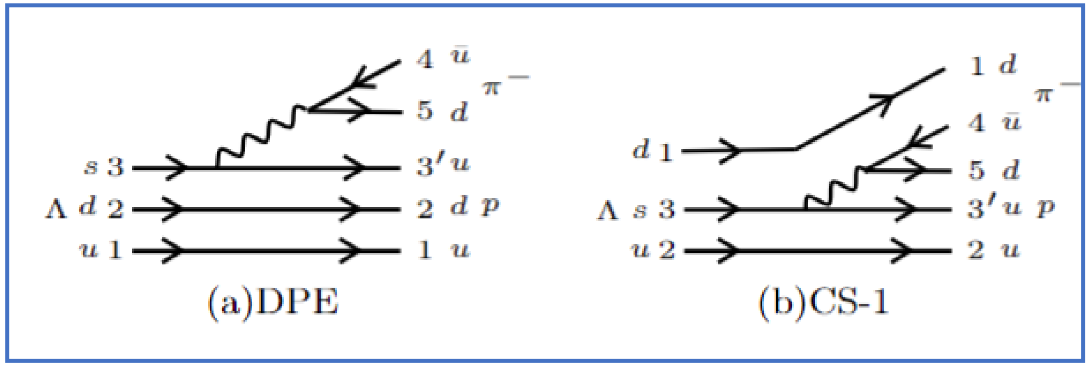
**$\Lambda \to p\pi^{-}/n\pi^{0}$:**

- ‘50s $R_{\Lambda} = \frac{\Gamma(\Lambda\to p\pi^{-})}{\Gamma(\Lambda\to p\pi^{-})+\Gamma(\Lambda\to n\pi^{0})} = 0.624 \pm 0.03$[1]
- ‘60s $R'_{\Lambda} = \frac{\Gamma(\Lambda\to n\pi^{0})}{\Gamma(\Lambda\to p\pi^{-})+\Gamma(\Lambda\to n\pi^{0})} = 0.35 \pm 0.05$[2]; $0.291 \pm 0.034$[3]
- ‘70s $R_{\Lambda} = \frac{\Gamma(\Lambda\to p\pi^{-})}{\Gamma(\Lambda\to p\pi^{-})+\Gamma(\Lambda\to n\pi^{0})} = 0.646 \pm 0.008$[4]

Puzzling relation in $\Lambda$ decay!

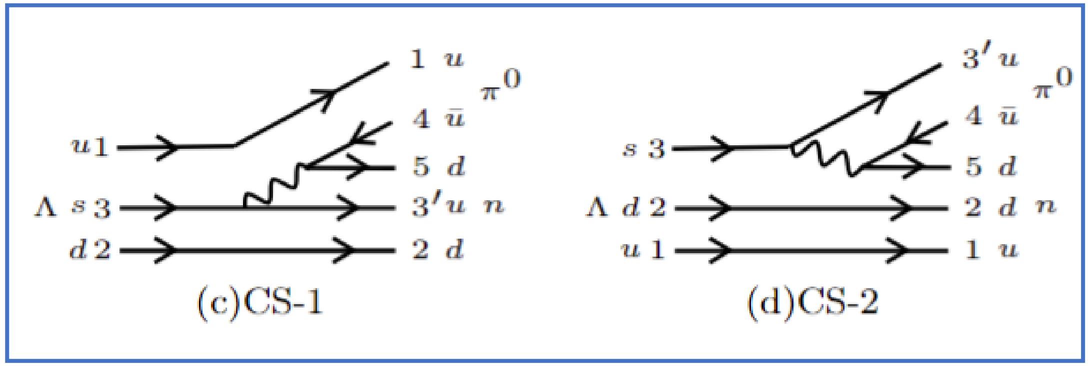
$$\frac{Br^{exp}(\Lambda \to p\pi^{-})}{Br^{exp}(\Lambda \to n\pi^{0})} \approx 2$$

**$\Lambda \to p\pi^{-}$**



(a)DPE (b)CS-1

**$\Lambda \to n\pi^{0}$**



(c)CS-1 (d)CS-2

**dominant**

$$\frac{Br^{\text{DPE+CS}}(\Lambda \to p\pi^{-})}{Br^{\text{CS}}(\Lambda \to n\pi^{0})} \gg 2$$

**to find new Mechanism!**

# 对超子Λ和$\Sigma^{\pm}$的两体强子弱衰变的研究

**$\Sigma^{\pm} \to n\pi^{\pm}$ and $\Sigma^{+} \to p\pi^{0}$:**

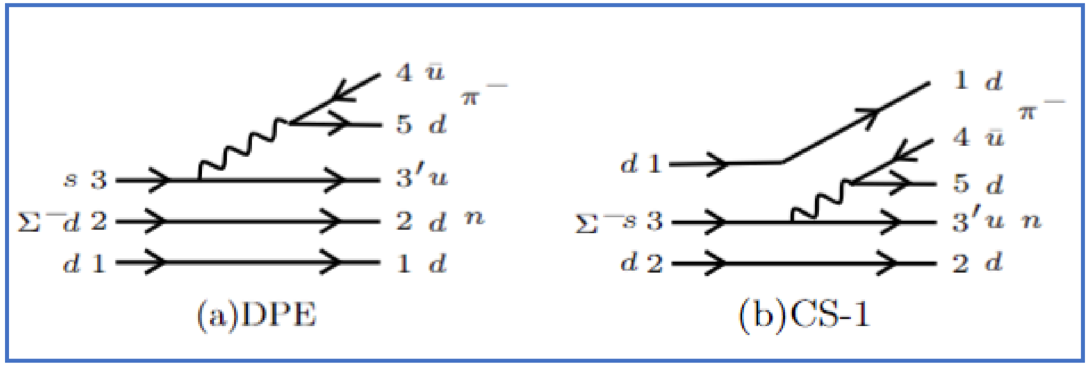
BESIII, arXiv: 2512. 09628

- '70s $R_{\Sigma^+} = \frac{\Gamma(\Sigma^+\to n\pi^+)}{\Gamma(\Sigma^+\to n\pi^+)+\Gamma(\Sigma^+\to p\pi^0)} = 0.488 \pm 0.008$[5]
- '80s $\mathrm{BR}(\Sigma^+ \to p\pi^0) = 0.5172 \pm 0.0036$[6]

DPE/CS ✗

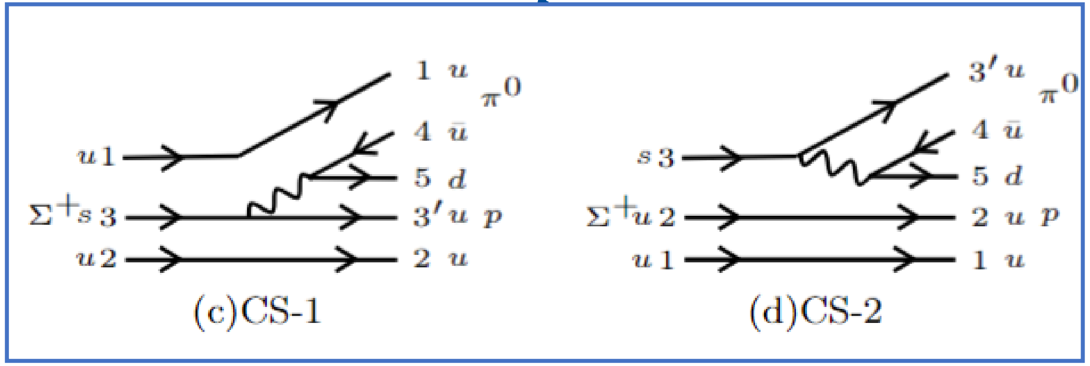
$$\frac{Br^{exp}\boxed{(\Sigma^+ \to n\pi^+)}}{Br^{exp}(\Sigma^+ \to p\pi^0)} \approx 1$$

**$\Sigma^{-} \to n\pi^{-}$**



(a)DPE (b)CS-1

**$\Sigma^{+} \to p\pi^{0}$**



(c)CS-1 (d)CS-2

**DPE和CS过程对$\Sigma^+ \to n\pi^+$没有贡献，那么为什么**

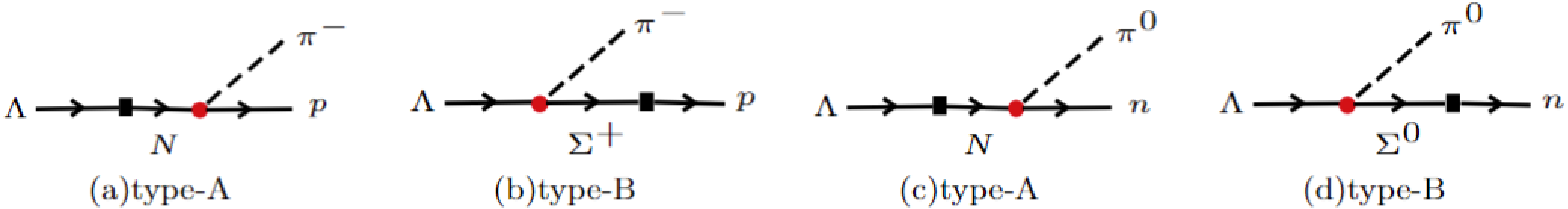
$Br(\Sigma^+ \to n\pi^+) : Br(\Sigma^+ \to p\pi^0) \approx 1:1$ ?

**to find new Mechanism!**

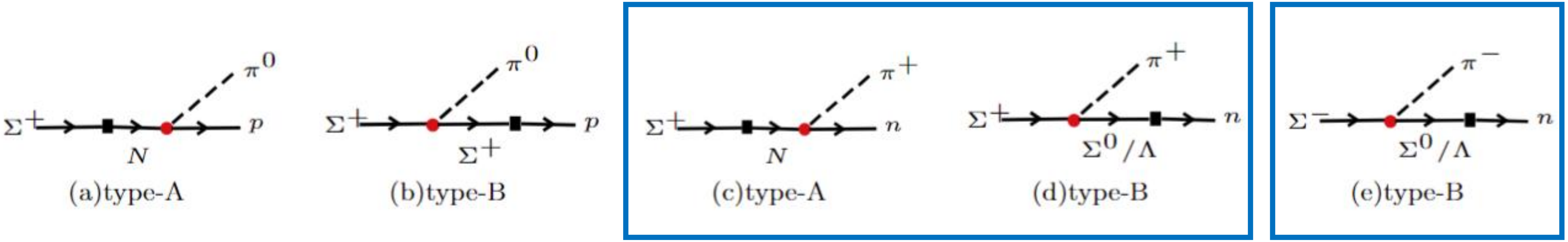
**超子衰变中尚未解决的问题与强相互作用的非微扰动力学密切相关！**

# 对超子$\Lambda$和$\Sigma^{\pm}$的两体强子弱衰变的研究

## 极点项



(a)type-A (b)type-B (c)type-A (d)type-B



(a)type-A (b)type-B (c)type-A (d)type-B (e)type-B

$\Sigma^+ \to n\pi^+$ 的极点项

$\Sigma^- \to n\pi^-$ 只有type-B

极点项是一个两步过程，根据强弱相互作用发生的先后顺序将其分为**type-A**和**type-B**两种类型。

极点项是涉及**长程效应**的非局域跃迁过程。

# 对超子Λ和Σ±的两体强子弱衰变的研究

## The weak “2 → 2” internal conversion (PC) process

宇称守恒:

$\frac{1}{2}^+ \to \frac{1}{2}^+$

$$\hat{O}^{(\mathrm{PC})}_{f-s} = \alpha_i^{(+)}\beta_j^{(-)}(1-\boldsymbol{\sigma}_i\cdot\boldsymbol{\sigma}_j)$$

$$|56,{}^2 8,0,0^+,\frac{1}{2}^+\rangle = \frac{1}{\sqrt{2}}(\phi^\rho\chi^\rho+\phi^\lambda\chi^\lambda)\psi^s_{000}(\boldsymbol{p}_\rho,\boldsymbol{p}_\lambda)$$

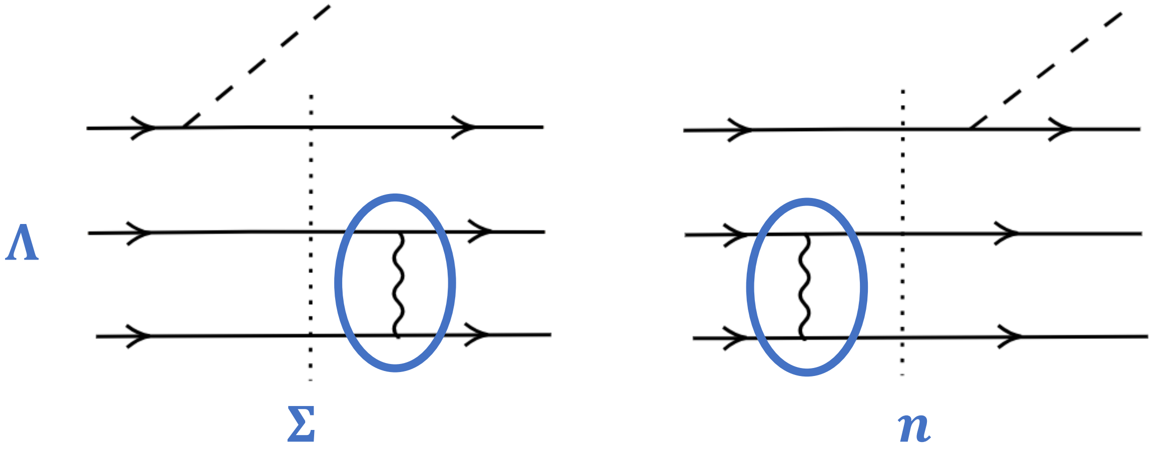


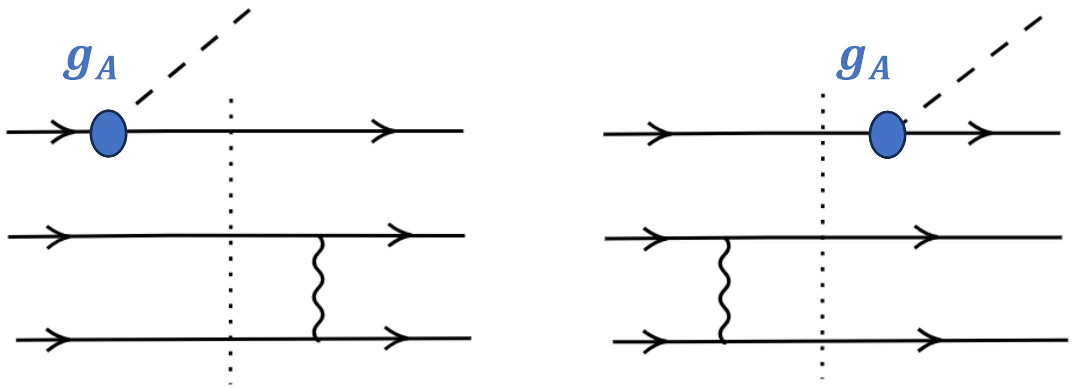
TABLE X: The flavor-spin matrix elements $C^{f-s(\mathrm{PC})}_{(\mathbb{B}_i\to\mathbb{B}_f)}$ for the ground-state baryon conversions.

| $\langle n\|\hat{O}^{(\mathrm{PC})}_{f-s}\|\Lambda\rangle$ | $\langle p\|\hat{O}^{(\mathrm{PC})}_{f-s}\|\Sigma^+\rangle$ | $\langle n\|\hat{O}^{(\mathrm{PC})}_{f-s}\|\Sigma^0\rangle$ |
|---|---|---|
| $-1/\sqrt{6}$ | 1 | $1/\sqrt{2}$ |

# 对超子$\Lambda$和$\Sigma^\pm$的两体强子弱衰变的研究

## Pion emission process in the chiral quark model (CQM)

- 赝标介子被视为基本粒子。
- 发生相互作用的夸克与赝标介子通过赝矢流耦合起来。



$$\hat{H}_m = \frac{1}{f_m}\sum_j \bar{\psi}_j \gamma_\mu \gamma_5 \partial^\mu \phi_m \hat{I}^m_j \psi_j,$$

$$\Downarrow$$

$$H_m^{NR} = \frac{1}{f_m\sqrt{(2\pi)^3 2\omega_m}}\sum_j \left[\frac{\omega_m}{2m_j}\boldsymbol{\sigma}_j\cdot\boldsymbol{p}_j + \frac{\omega_m}{2m'_j}\boldsymbol{\sigma}_j\cdot\boldsymbol{p}'_j - \boldsymbol{\sigma}_j\cdot\boldsymbol{k}\right]\hat{I}^m_j \delta^3(\boldsymbol{p}_j - \boldsymbol{p}'_j - \boldsymbol{k}),$$

$$|56,{}^2 8,0,0^+,\frac{1}{2}^+\rangle = \frac{1}{\sqrt{2}}(\phi^\rho\chi^\rho + \phi^\lambda\chi^\lambda)\psi^s_{000}(\boldsymbol{p}_\rho,\boldsymbol{p}_\lambda)$$

TABLE XIII: Axial-vector couplings for the pion emission.

| Processes | $g_A$ | Processes | $g_A$ | Processes | $g_A$ | Processes | $g_A$ |
|---|---|---|---|---|---|---|---|
| $n\to p\pi^-$ | $-5/3$ | $\Sigma^+\to\Sigma^+\pi^0$ | $-4/(3\sqrt{2})$ | $\Sigma^-\to\Sigma^-\pi^0$ | $4/(3\sqrt{2})$ | $\Lambda_8\to\Sigma^+\pi^-$ | $2/\sqrt{6}$ |
| $n\to n\pi^0$ | $5/(3\sqrt{2})$ | $\Sigma^+\to\Sigma^0\pi^+$ | $4/(3\sqrt{2})$ | $\Sigma^-\to\Sigma^0\pi^-$ | $-4/(3\sqrt{2})$ | $\Lambda_8\to\Sigma^0\pi^0$ | $-2/\sqrt{6}$ |
| $p\to n\pi^+$ | $5/3$ | $\Sigma^+\to\Lambda_8\pi^+$ | $-2/\sqrt{6}$ | $\Sigma^-\to\Lambda_8\pi^-$ | $-2/\sqrt{6}$ | $\Lambda_8\to\Sigma^-\pi^+$ | $2/\sqrt{6}$ |
| $p\to p\pi^0$ | $-5/(3\sqrt{2})$ | | | | | | |

对于衰变 $\boxed{\mathbb{B}_i(\frac{1}{2}^+)\to\mathbb{B}_f(\frac{1}{2}^+)+\pi}$ :

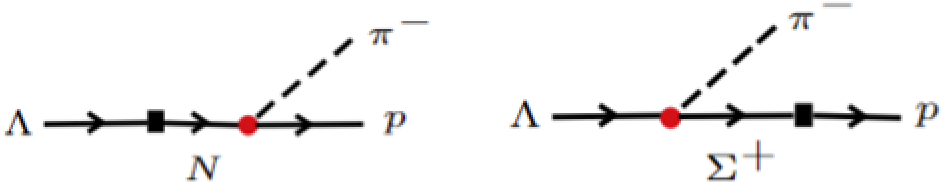
$$g_A(\mathbb{B}_i\mathbb{B}_f\pi) \equiv \frac{\langle\mathbb{B}_f|\sum_j \hat{I}^\pi_j\sigma_{jz}|\mathbb{B}_i\rangle}{\langle\mathbb{B}_f|\sigma_z^{tot}|\mathbb{B}_i\rangle}$$

# 对超子$\Lambda$和$\Sigma^{\pm}$的两体强子弱衰变的研究

## Amplitude of pole terms (PT)

$$\mathcal{M}^{(\mathrm{PC})}_{\mathrm{Pole,A}} = \mathcal{F}^{(\mathrm{PC})}_{A}(\boldsymbol{k}) \times \mathcal{G}^{(\mathrm{PC})}_{A},$$
$$\mathcal{M}^{(\mathrm{PC})}_{\mathrm{Pole,B}} = \mathcal{F}^{(\mathrm{PC})}_{B}(\boldsymbol{k}) \times \mathcal{G}^{(\mathrm{PC})}_{B},$$

以$\Lambda \to p\pi^-$为例,



(a)type-Λ (b)type-B

$$\mathcal{F}^{(\mathrm{PC})}_{A}(\boldsymbol{k}) = \frac{G_F}{\sqrt{2}} V_{ud}V_{us} 48 \left(\frac{\alpha^2\alpha_\rho\alpha_\lambda}{\sqrt{\pi}(4\alpha^2+\alpha_\lambda^2+3\alpha_\rho^2)}\right)^{3/2} \times \frac{1}{f_\pi\sqrt{(2\pi)^3 2\omega_0}}|\boldsymbol{k}|\left(-1-\frac{\omega_0}{6m_q}\right)\exp\left[-\frac{\boldsymbol{k}^2}{6\alpha^2}\right],$$

$$\mathcal{F}^{(\mathrm{PC})}_{B}(\boldsymbol{k}) = \frac{G_F}{\sqrt{2}} V_{ud}V_{us} 48 \left(\frac{\alpha^2\alpha_\rho\alpha_\lambda}{\sqrt{\pi}(4\alpha^2+\alpha_\lambda^2+3\alpha_\rho^2)}\right)^{3/2} \times \frac{1}{f_\pi\sqrt{(2\pi)^3 2\omega_0}}|\boldsymbol{k}|\left(-1-\frac{\omega_0}{4m_q+2m_s}\right)\exp\left[-\frac{\boldsymbol{k}^2}{8}\left(\frac{3m_s^2}{(2m_q+m_s)^2\alpha_\lambda^2}+\frac{1}{\alpha_\rho^2}\right)\right],$$

反号

$$\mathcal{G}^{(\mathrm{PC})} = \mathcal{G}^{(\mathrm{PC})}_{A} + \mathcal{G}^{(\mathrm{PC})}_{B}$$

$$\mathcal{G}^{(\mathrm{PC})}(\Lambda \to p\pi^-) \equiv \left[\frac{(2M_n)\overset{-\frac{5}{3}}{\boxed{g_A^{np\pi^-}}}\overset{-\frac{1}{\sqrt{6}}}{\boxed{C^{f-s(\mathrm{PC})}_{(\Lambda\to n)}}}}{M_\Lambda^2-M_n^2} + \frac{(2M_\Sigma)\overset{\frac{2}{\sqrt{6}}}{\boxed{g_A^{\Lambda\Sigma^+\pi^-}}}\overset{1}{\boxed{C^{f-s(\mathrm{PC})}_{(\Sigma^+\to p)}}}}{M_p^2-M_\Sigma^2}\right]$$

# 对超子Λ和Σ$^{\pm}$的两体强子弱衰变的研究

$$\mathcal{G}^{(\mathrm{PC})}=\mathcal{G}_A^{(\mathrm{PC})}+\mathcal{G}_B^{(\mathrm{PC})}.$$

$$\mathcal{G}^{(\mathrm{PC})}(\Lambda\to p\pi^-)\equiv\left[\overset{\text{A}}{\frac{(2M_n)g_A^{np\pi^-}C^{f-s(\mathrm{PC})}_{(\Lambda\to n)}}{M_\Lambda^2-M_n^2}}+\overset{\text{B}}{\frac{(2M_\Sigma)g_A^{\Lambda\Sigma^+\pi^-}C^{f-s(\mathrm{PC})}_{(\Sigma^+\to p)}}{M_p^2-M_\Sigma^2}}\right],$$

反号

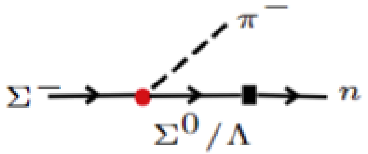
$$\mathcal{G}^{(\mathrm{PC})}(\Lambda\to n\pi^0)\equiv\left[\overset{\text{A}}{\frac{(2M_n)g_A^{nn\pi^0}C^{f-s(\mathrm{PC})}_{(\Lambda\to n)}}{M_\Lambda^2-M_n^2}}+\overset{\text{B}}{\frac{(2M_\Sigma)g_A^{\Lambda\Sigma^0\pi^0}C^{f-s(\mathrm{PC})}_{(\Sigma^0\to n)}}{M_n^2-M_\Sigma^2}}\right],$$

反号

$$\frac{\mathcal{G}^{(\mathrm{PC})}(\Lambda\to n\pi^0)}{\mathcal{G}^{(\mathrm{PC})}(\Lambda\to p\pi^-)}=-\frac{1}{\sqrt{2}}$$

$$\mathcal{G}^{(\mathrm{PC})}(\Sigma^-\to n\pi^-)=\mathcal{G}_B^{(\mathrm{PC})}(\Sigma^-\to n\pi^-)\equiv\left[\overset{B}{\frac{(2M_{\Sigma^0})g_A^{\Sigma^-\Sigma^0\pi^-}C^{f-s(\mathrm{PC})}_{(\Sigma^0\to n)}}{M_n^2-M_{\Sigma^0}^2}}+\overset{\text{B}}{\frac{(2M_\Lambda)g_A^{\Sigma^-\Lambda\pi^-}C^{f-s(\mathrm{PC})}_{(\Lambda\to n)}}{M_n^2-M_\Lambda^2}}\right],$$

反号



(e)type-B

$$\mathcal{G}^{(\mathrm{PC})}(\Sigma^+\to p\pi^0)\equiv\left[\overset{\text{A}}{\frac{(2M_p)g_A^{pp\pi^0}C^{f-s(\mathrm{PC})}_{(\Sigma^+\to p)}}{M_{\Sigma^+}^2-M_p^2}}+\overset{\text{B}}{\frac{(2M_{\Sigma^+})g_A^{\Sigma^+\Sigma^+\pi^0}C^{f-s(\mathrm{PC})}_{(\Sigma^+\to p)}}{M_p^2-M_{\Sigma^+}^2}}\right],$$

反号

$$\mathcal{G}^{(\mathrm{PC})}(\Sigma^+\to n\pi^+)\equiv\left[\overset{\text{A}}{\frac{(2M_p)g_A^{pn\pi^+}C^{f-s(\mathrm{PC})}_{(\Sigma^+\to p)}}{M_{\Sigma^+}^2-M_p^2}}+\boxed{\overset{\text{B}}{\frac{(2M_{\Sigma^0})g_A^{\Sigma^+\Sigma^0\pi^+}C^{f-s(\mathrm{PC})}_{(\Sigma^0\to n)}}{M_n^2-M_{\Sigma^0}^2}}+\overset{\text{B}}{\frac{(2M_\Lambda)g_A^{\Sigma^+\Lambda\pi^+}C^{f-s(\mathrm{PC})}_{(\Lambda\to n)}}{M_n^2-M_\Lambda^2}}}\right],$$

反号

同号

- 对于 $\Sigma^-\to n\pi^-$, 只有B-型极点项有贡献 。
- 极点项的贡献情况在不同的衰变道中是不同的。
- 这些极点项振幅之间总存在着某种形式的相消机制。

# 对超子$\Lambda$和$\Sigma^{\pm}$的两体强子弱衰变的研究

- 我们注意到$\Lambda$和$\Sigma^{\pm}$同属于奇异数为-1的基态重子八重态，预期它们应该有**相似的衰变机制。**
- 我们对$\Lambda$和$\Sigma^{\pm}$到$N\pi$的衰变做了一个**联合分析**，在组分夸克模型的框架下系统计算了每个道中所涉及的**外发射DPE过程、内发射CS过程和极点项的贡献。**
- 然而上述机制唯独对$\Lambda \to n\pi^0$描述不好。 ?

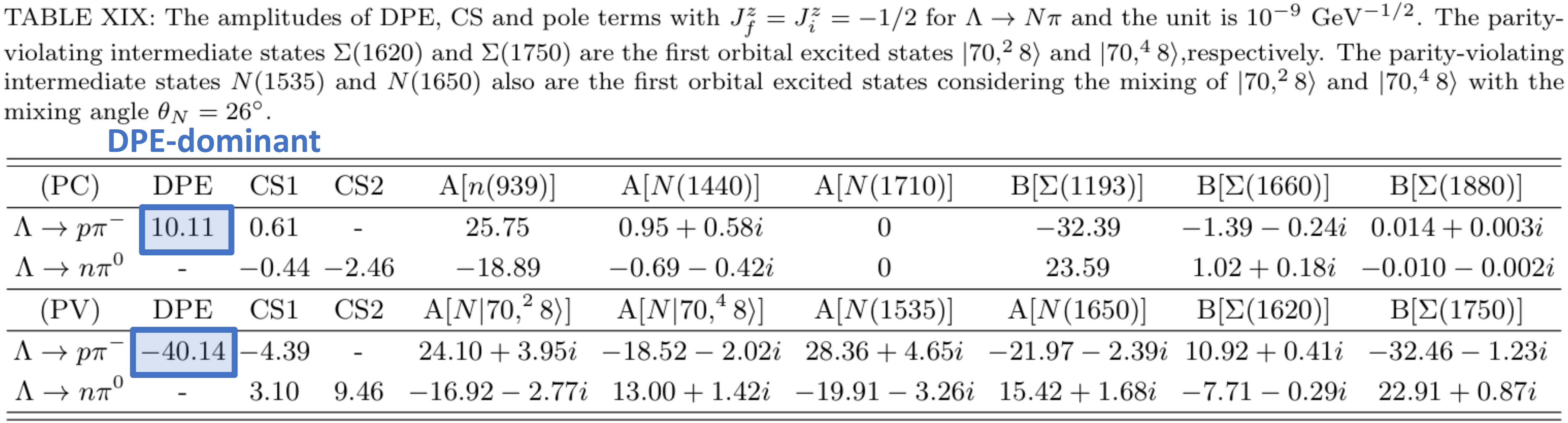


TABLE XIX: The amplitudes of DPE, CS and pole terms with $J_f^z = J_i^z = -1/2$ for $\Lambda \to N\pi$ and the unit is $10^{-9}$ GeV$^{-1/2}$. The parity-violating intermediate states $\Sigma(1620)$ and $\Sigma(1750)$ are the first orbital excited states $|70,^2 8\rangle$ and $|70,^4 8\rangle$,respectively. The parity-violating intermediate states $N(1535)$ and $N(1650)$ also are the first orbital excited states considering the mixing of $|70,^2 8\rangle$ and $|70,^4 8\rangle$ with the mixing angle $\theta_N = 26^\circ$.

DPE-dominant

PC:宇称守恒

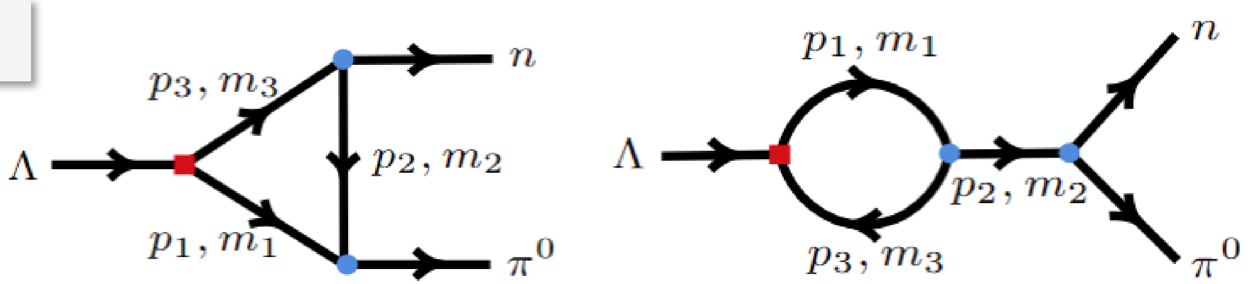
PV:宇称破坏

| (PC) | DPE | CS1 | CS2 | A[$n(939)$] | A[$N(1440)$] | A[$N(1710)$] | B[$\Sigma(1193)$] | B[$\Sigma(1660)$] | B[$\Sigma(1880)$] |
|---|---|---|---|---|---|---|---|---|---|
| $\Lambda \to p\pi^-$ | 10.11 | 0.61 | - | 25.75 | $0.95+0.58i$ | 0 | $-32.39$ | $-1.39-0.24i$ | $0.014+0.003i$ |
| $\Lambda \to n\pi^0$ | - | $-0.44$ | $-2.46$ | $-18.89$ | $-0.69-0.42i$ | 0 | 23.59 | $1.02+0.18i$ | $-0.010-0.002i$ |
| (PV) | DPE | CS1 | CS2 | A[$N\|70,^2 8\rangle$] | A[$N\|70,^4 8\rangle$] | A[$N(1535)$] | A[$N(1650)$] | B[$\Sigma(1620)$] | B[$\Sigma(1750)$] |
| $\Lambda \to p\pi^-$ | $-40.14$ | $-4.39$ | - | $24.10+3.95i$ | $-18.52-2.02i$ | $28.36+4.65i$ | $-21.97-2.39i$ | $10.92+0.41i$ | $-32.46-1.23i$ |
| $\Lambda \to n\pi^0$ | - | 3.10 | 9.46 | $-16.92-2.77i$ | $13.00+1.42i$ | $-19.91-3.26i$ | $15.42+1.68i$ | $-7.71-0.29i$ | $22.91+0.87i$ |

- 基于$\Lambda \to p\pi^-$有这么大的DPE贡献，我们便合理地考虑了从$p\pi^-$重散射到$n\pi^0$的FSIs机制。
- 在$\Sigma$衰变中不存在这种来自于主导的直接发射过程的FSIs贡献。

# 对超子Λ和Σ$^\pm$的两体强子弱衰变的研究

**圈过程**



(a)$t$-channel (b)$s$-channel

$[t, (P), M1, M3, (M2)]$

$[s, (P), M1, M3, (M2)]$

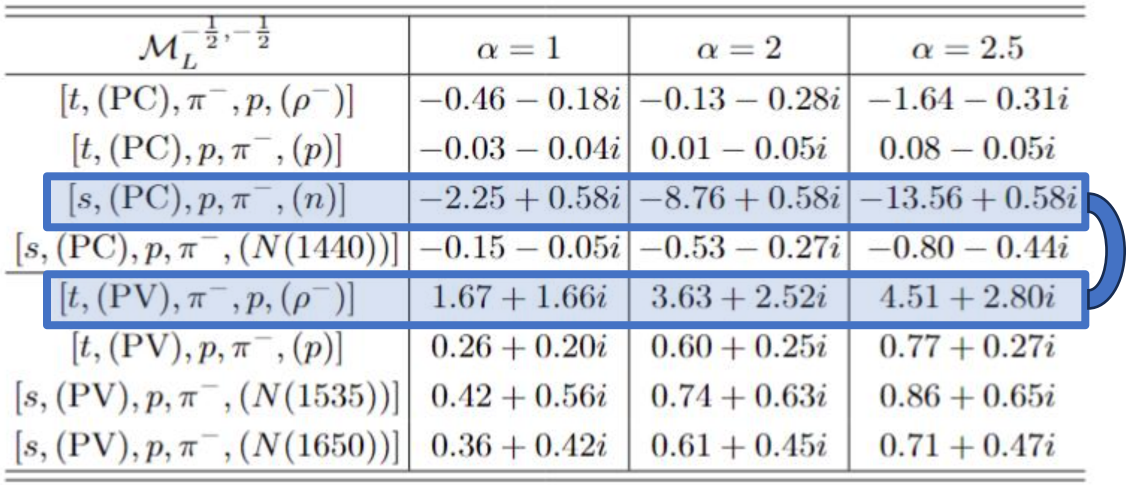
| | |
|---|---|
| $[t, (PC), \pi^-, p, (\rho^-)]$ | $[s, (PC), p, \pi^-, (n)]$ |
| $[t, (PC), p, \pi^-, (p)]$ | $[s, (PC), p, \pi^-, (N(1440))]$ |
| $[t, (PV), \pi^-, p, (\rho^-)]$ | $[s, (PV), p, \pi^-, (N(1535))]$ |
| $[t, (PV), p, \pi^-, (p)]$ | $[s, (PV), p, \pi^-, (N(1650))]$ |

$$i\mathcal{M} = g_1 g_2 g_3 \int \frac{d^4p_1}{(2\pi)^4} \frac{\bar{u}(p_n)\left(\gamma_\alpha - \frac{f_3}{2M_B g_3}\frac{[\gamma_\alpha,\gamma_\beta]}{2}p_2^\beta\right)(\not{p}_3 + m_3)\gamma_\mu\gamma_5 p_1^\mu u(p_\Lambda)(p_1+p_\pi)_\nu\left(g^{\alpha\nu} - \frac{p_2^\alpha p_2^\nu}{p_2^2}\right)}{(p_1^2 - m_1^2 + i\epsilon)(p_2^2 - m_2^2 + i\epsilon)(p_3^2 - m_3^2 + i\epsilon)}\mathcal{F}(p_i^2).$$

# 对基态超子Λ和$\Sigma^{\pm}$的两体强子弱衰变的研究

TABLE XIX: The loop amplitudes with $J_f^z = J_i^z = -1/2$ for $\Lambda \to n\pi^0$ and the unit is $10^{-9}$ GeV$^{-1/2}$.

$\Lambda \to N\pi$

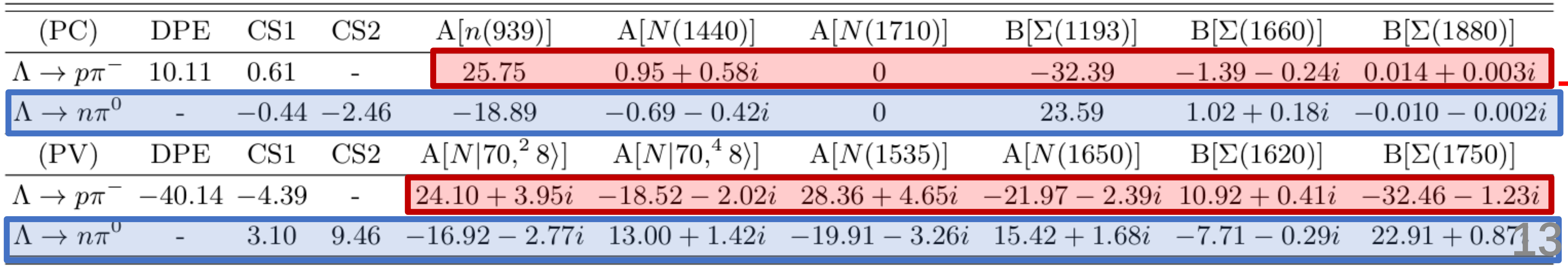


| $\mathcal{M}_L^{-\frac{1}{2},-\frac{1}{2}}$ | $\alpha = 1$ | $\alpha = 2$ | $\alpha = 2.5$ |
|---|---|---|---|
| $[t, (\mathrm{PC}), \pi^-, p, (\rho^-)]$ | $-0.46 - 0.18i$ | $-0.13 - 0.28i$ | $-1.64 - 0.31i$ |
| $[t, (\mathrm{PC}), p, \pi^-, (p)]$ | $-0.03 - 0.04i$ | $0.01 - 0.05i$ | $0.08 - 0.05i$ |
| $[s, (\mathrm{PC}), p, \pi^-, (n)]$ | $-2.25 + 0.58i$ | $-8.76 + 0.58i$ | $-13.56 + 0.58i$ |
| $[s, (\mathrm{PC}), p, \pi^-, (N(1440))]$ | $-0.15 - 0.05i$ | $-0.53 - 0.27i$ | $-0.80 - 0.44i$ |
| $[t, (\mathrm{PV}), \pi^-, p, (\rho^-)]$ | $1.67 + 1.66i$ | $3.63 + 2.52i$ | $4.51 + 2.80i$ |
| $[t, (\mathrm{PV}), p, \pi^-, (p)]$ | $0.26 + 0.20i$ | $0.60 + 0.25i$ | $0.77 + 0.27i$ |
| $[s, (\mathrm{PV}), p, \pi^-, (N(1535))]$ | $0.42 + 0.56i$ | $0.74 + 0.63i$ | $0.86 + 0.65i$ |
| $[s, (\mathrm{PV}), p, \pi^-, (N(1650))]$ | $0.36 + 0.42i$ | $0.61 + 0.45i$ | $0.71 + 0.47i$ |

more important

- 有些圈过程起到了重要作用。
- 在极点项之间存在着一种 **“fine-tuned”相消机制。**

TABLE XIX: The amplitudes of DPE, CS and pole terms with $J_f^z = J_i^z = -1/2$ for $\Lambda \to N\pi$ and the unit is $10^{-9}$ GeV$^{-1/2}$. The parity-violating intermediate states $\Sigma(1620)$ and $\Sigma(1750)$ are the first orbital excited states $|70,^2 8\rangle$ and $|70,^4 8\rangle$,respectively. The parity-violating intermediate states $N(1535)$ and $N(1650)$ also are the first orbital excited states considering the mixing of $|70,^2 8\rangle$ and $|70,^4 8\rangle$ with the mixing angle $\theta_N = 26°$.



| (PC) | DPE | CS1 | CS2 | A[$n(939)$] | A[$N(1440)$] | A[$N(1710)$] | B[$\Sigma(1193)$] | B[$\Sigma(1660)$] | B[$\Sigma(1880)$] |
|---|---|---|---|---|---|---|---|---|---|
| $\Lambda \to p\pi^-$ | 10.11 | 0.61 | - | 25.75 | $0.95 + 0.58i$ | 0 | $-32.39$ | $-1.39 - 0.24i$ | $0.014 + 0.003i$ |
| $\Lambda \to n\pi^0$ | - | $-0.44$ | $-2.46$ | $-18.89$ | $-0.69 - 0.42i$ | 0 | 23.59 | $1.02 + 0.18i$ | $-0.010 - 0.002i$ |
| **(PV)** | **DPE** | **CS1** | **CS2** | **A[$N\|70,^2 8\rangle$]** | **A[$N\|70,^4 8\rangle$]** | **A[$N(1535)$]** | **A[$N(1650)$]** | **B[$\Sigma(1620)$]** | **B[$\Sigma(1750)$]** |
| $\Lambda \to p\pi^-$ | $-40.14$ | $-4.39$ | - | $24.10 + 3.95i$ | $-18.52 - 2.02i$ | $28.36 + 4.65i$ | $-21.97 - 2.39i$ | $10.92 + 0.41i$ | $-32.46 - 1.23i$ |
| $\Lambda \to n\pi^0$ | - | 3.10 | 9.46 | $-16.92 - 2.77i$ | $13.00 + 1.42i$ | $-19.91 - 3.26i$ | $15.42 + 1.68i$ | $-7.71 - 0.29i$ | $22.91 + 0.87$ |

# 对超子$\Lambda$和$\Sigma^{\pm}$的两体强子弱衰变的研究

$\Lambda \to N\pi$

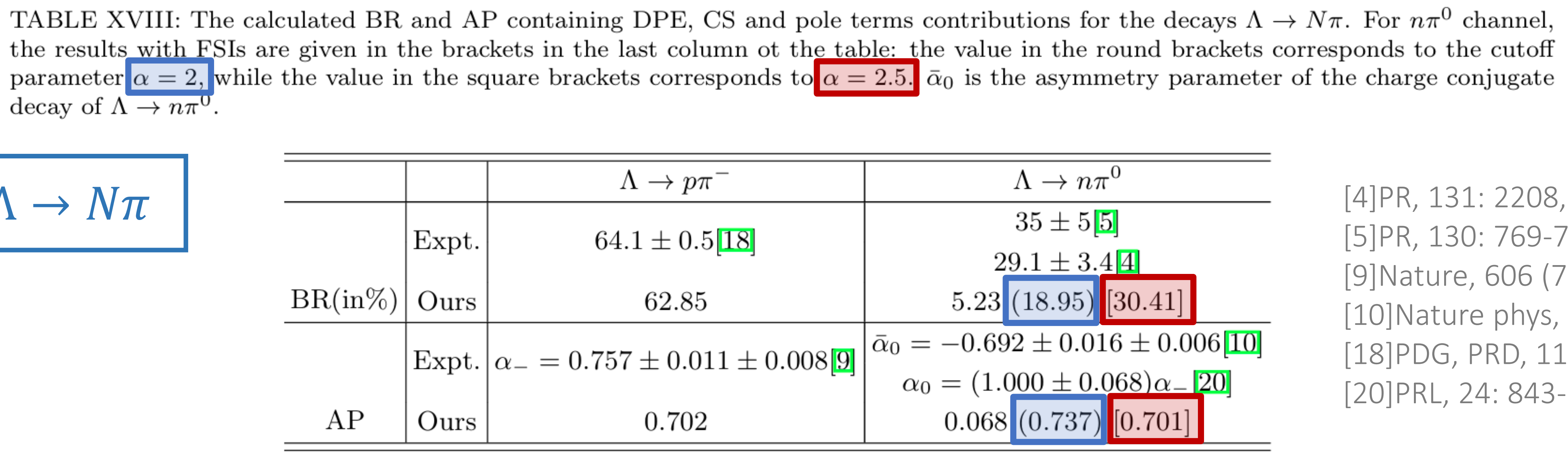


TABLE XVIII: The calculated BR and AP containing DPE, CS and pole terms contributions for the decays $\Lambda \to N\pi$. For $n\pi^0$ channel, the results with FSIs are given in the brackets in the last column ot the table: the value in the round brackets corresponds to the cutoff parameter $\alpha = 2$, while the value in the square brackets corresponds to $\alpha = 2.5$. $\bar{\alpha}_0$ is the asymmetry parameter of the charge conjugate decay of $\Lambda \to n\pi^0$.

| | | $\Lambda \to p\pi^-$ | $\Lambda \to n\pi^0$ |
|---|---|---|---|
| BR(in%) | Expt. | $64.1 \pm 0.5$[18] | $35 \pm 5$[5]<br>$29.1 \pm 3.4$[4] |
| | Ours | 62.85 | 5.23 (18.95) [30.41] |
| AP | Expt. | $\alpha_- = 0.757 \pm 0.011 \pm 0.008$[9] | $\bar{\alpha}_0 = -0.692 \pm 0.016 \pm 0.006$[10]<br>$\alpha_0 = (1.000 \pm 0.068)\alpha_-$[20] |
| | Ours | 0.702 | 0.068 (0.737) [0.701] |

[4]PR, 131: 2208, 1963
[5]PR, 130: 769-775, 1963
[9]Nature, 606 (7912): 64-69, 2022
[10]Nature phys, 15: 631-634, 2019
[18]PDG, PRD, 110 (3): 030001, 2024
[20]PRL, 24: 843-847, 1970

- 包含DPE, CS和极点项贡献的BR和AP与$\Lambda \to p\pi^-$的实验数据相一致，但对 $\Lambda \to n\pi^0$的描述是失败的。
- 来自$p\pi^-$ 的FSIs贡献对$\Lambda \to n\pi^0$的BR有一定的增强效果。
- 考虑FSIs后，我们发现在选取一个稍微比较大的截断参数后， $\Lambda \to n\pi^0$的BR和AP也将更加靠近实验值。

# 对超子$\Lambda$和$\Sigma^{\pm}$的两体强子弱衰变的研究

## $\Sigma^{\pm} \to N\pi$

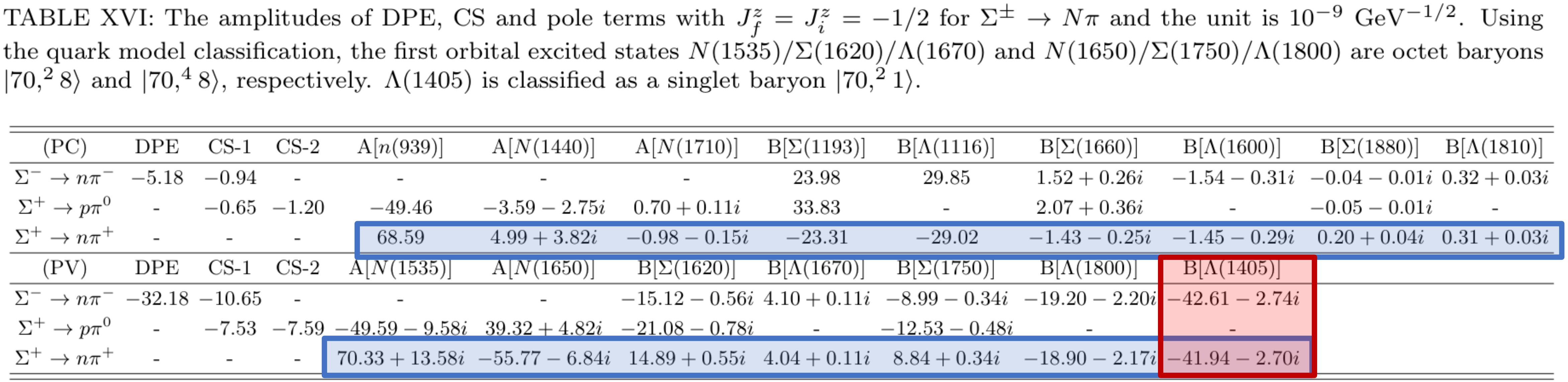


TABLE XVI: The amplitudes of DPE, CS and pole terms with $J_f^z = J_i^z = -1/2$ for $\Sigma^{\pm} \to N\pi$ and the unit is $10^{-9}$ GeV$^{-1/2}$. Using the quark model classification, the first orbital excited states $N(1535)/\Sigma(1620)/\Lambda(1670)$ and $N(1650)/\Sigma(1750)/\Lambda(1800)$ are octet baryons $|70,^2 8\rangle$ and $|70,^4 8\rangle$, respectively. $\Lambda(1405)$ is classified as a singlet baryon $|70,^2 1\rangle$.

| (PC) | DPE | CS-1 | CS-2 | A[$n(939)$] | A[$N(1440)$] | A[$N(1710)$] | B[$\Sigma(1193)$] | B[$\Lambda(1116)$] | B[$\Sigma(1660)$] | B[$\Lambda(1600)$] | B[$\Sigma(1880)$] | B[$\Lambda(1810)$] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\Sigma^- \to n\pi^-$ | $-5.18$ | $-0.94$ | - | - | - | - | 23.98 | 29.85 | $1.52 + 0.26i$ | $-1.54 - 0.31i$ | $-0.04 - 0.01i$ | $0.32 + 0.03i$ |
| $\Sigma^+ \to p\pi^0$ | - | $-0.65$ | $-1.20$ | $-49.46$ | $-3.59 - 2.75i$ | $0.70 + 0.11i$ | 33.83 | - | $2.07 + 0.36i$ | - | $-0.05 - 0.01i$ | - |
| $\Sigma^+ \to n\pi^+$ | - | - | - | 68.59 | $4.99 + 3.82i$ | $-0.98 - 0.15i$ | $-23.31$ | $-29.02$ | $-1.43 - 0.25i$ | $-1.45 - 0.29i$ | $0.20 + 0.04i$ | $0.31 + 0.03i$ |
| (PV) | DPE | CS-1 | CS-2 | A[$N(1535)$] | A[$N(1650)$] | B[$\Sigma(1620)$] | B[$\Lambda(1670)$] | B[$\Sigma(1750)$] | B[$\Lambda(1800)$] | B[$\Lambda(1405)$] | | |
| $\Sigma^- \to n\pi^-$ | $-32.18$ | $-10.65$ | - | - | - | $-15.12 - 0.56i$ | $4.10 + 0.11i$ | $-8.99 - 0.34i$ | $-19.20 - 2.20i$ | $-42.61 - 2.74i$ | | |
| $\Sigma^+ \to p\pi^0$ | - | $-7.53$ | $-7.59$ | $-49.59 - 9.58i$ | $39.32 + 4.82i$ | $-21.08 - 0.78i$ | - | $-12.53 - 0.48i$ | - | - | | |
| $\Sigma^+ \to n\pi^+$ | - | - | - | $70.33 + 13.58i$ | $-55.77 - 6.84i$ | $14.89 + 0.55i$ | $4.04 + 0.11i$ | $8.84 + 0.34i$ | $-18.90 - 2.17i$ | $-41.94 - 2.70i$ | | |

- 极点项的贡献情况是是依赖于衰变过程的，所以它们的抵消模式和抵消程度在各个道中也是不同的。
- 极点项的贡献是不可忽略的，尤其是对$\Sigma^+ \to n\pi^+$。
- 单态$\Lambda(1405)$对$\Sigma^{\pm} \to n\pi^{\pm}$这两个道具有不小的贡献。

# 对超子$\Lambda$和$\Sigma^{\pm}$的两体强子弱衰变的研究

## $\Sigma^{\pm} \to N\pi$

[12]BESIII, PRL, 125 (5): 052004, 2020
[13]BESIII, PRL, 131 (19): 191802, 2023
[18]PDG, PRD, 110 (3): 030001, 2024

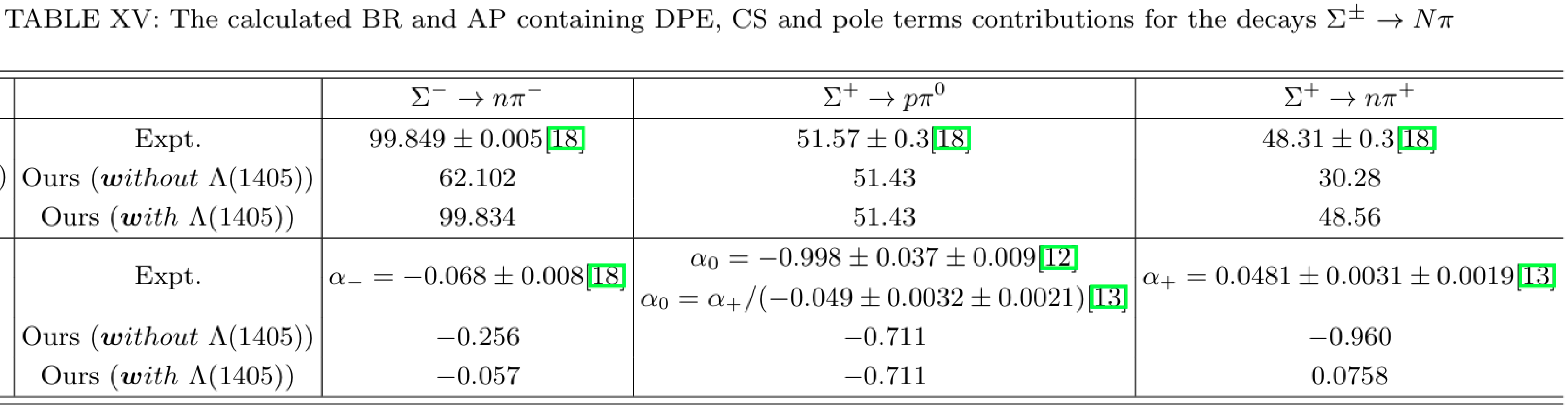


TABLE XV: The calculated BR and AP containing DPE, CS and pole terms contributions for the decays $\Sigma^{\pm} \to N\pi$

| | | $\Sigma^- \to n\pi^-$ | $\Sigma^+ \to p\pi^0$ | $\Sigma^+ \to n\pi^+$ |
|---|---|---|---|---|
| BR(in%) | Expt. | $99.849 \pm 0.005$[18] | $51.57 \pm 0.3$[18] | $48.31 \pm 0.3$[18] |
| | Ours (*without* $\Lambda(1405)$) | 62.102 | 51.43 | 30.28 |
| | Ours (*with* $\Lambda(1405)$) | 99.834 | 51.43 | 48.56 |
| AP | Expt. | $\alpha_- = -0.068 \pm 0.008$[18] | $\alpha_0 = -0.998 \pm 0.037 \pm 0.009$[12]<br>$\alpha_0 = \alpha_+/(-0.049 \pm 0.0032 \pm 0.0021)$[13] | $\alpha_+ = 0.0481 \pm 0.0031 \pm 0.0019$[13] |
| | Ours (*without* $\Lambda(1405)$) | $-0.256$ | $-0.711$ | $-0.960$ |
| | Ours (*with* $\Lambda(1405)$) | $-0.057$ | $-0.711$ | 0.0758 |

- 当将DPE、CS和极点项的贡献统一考虑在内后， 我们计算得到的分支比和不对称参数$\alpha$的符号与实验测量结果一致。
- $\alpha$的大小行为也与实验比较一致，即$n\pi^-$和$n\pi^+$趋于0，而$p\pi^0$更偏向于1。

# 对超子$\Lambda$和$\Sigma^{\pm}$的两体强子弱衰变的研究

## 小结

- 我们对超子$\Lambda$和$\Sigma^{\pm}$的两体强子弱衰变进行了综合的理论分析，并给出了BR和AP的定量计算结果。
- 我们发现在低能区，以极点项和重散射方式出现的长程机制在其中发挥着重要作用。

# 对十重态超子Ω的两体强子弱衰变的研究

$\Omega^-$是唯一通过弱相互作用进行衰变的十重态重子。

$$\mathrm{BR}[\Omega^- \to \Xi^0\pi^-] = (25.03 \pm 0.44 \pm 0.53)\%,$$

$$\mathrm{BR}[\Omega^- \to \Xi^-\pi^0] = (8.43 \pm 0.52 \pm 0.28)\%,$$

$$\mathrm{BR}[\Omega^- \to \Lambda K^-] = (66.3 \pm 0.8 \pm 2.0)\%,$$

BESIII, PRD, 108(9): L091101, 2023

$$\alpha[\Omega^- \to \Xi^0\pi^-] = 0.09 \pm 0.14,$$

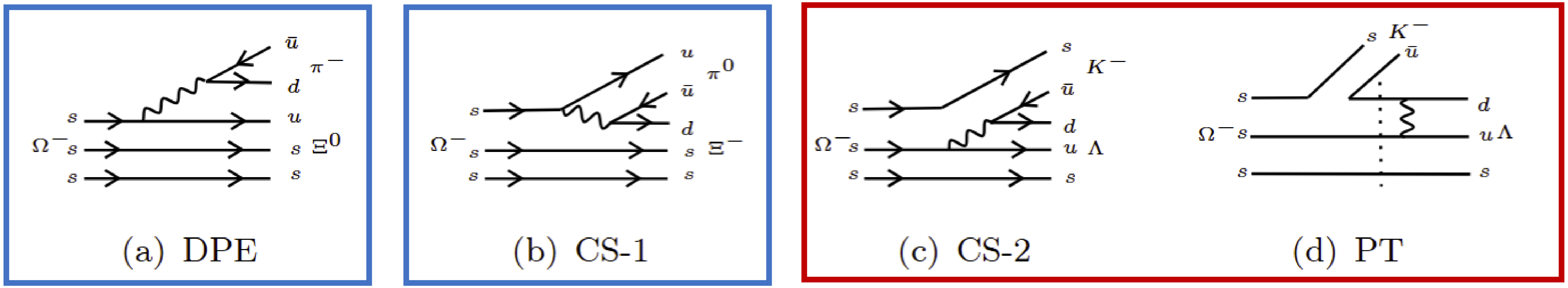
$$\alpha[\Omega^- \to \Xi^-\pi^0] = 0.05 \pm 0.21,$$

$$\alpha[\Omega^- \to \Lambda K^-] = 0.0154 \pm 0.0020.$$

$$\alpha = \frac{2\mathrm{Re}(P^* D)}{|P|^2 + |D|^2}$$

$\alpha$几乎为零，说明衰变由宇称守恒（$P$ wave）或宇称破坏（$D$ wave）主导。

# 对十重态超子Ω的两体强子弱衰变的研究



(a) DPE (b) CS-1 (c) CS-2 (d) PT

- $\frac{f_{color}(CS)}{f_{color}(DPE)} = \frac{1}{3}$
- $\langle \pi^- | d\bar{u} \rangle = 1$ and $\langle \pi^0 | u\bar{u} \rangle = \frac{1}{\sqrt{2}}$

$$\Rightarrow \left| \frac{\mathcal{M}_{\rm CS}(\Omega^- \to \Xi^- \pi^0)}{\mathcal{M}_{\rm DPE}(\Omega^- \to \Xi^0 \pi^-)} \right| = \frac{1}{3\sqrt{2}}$$

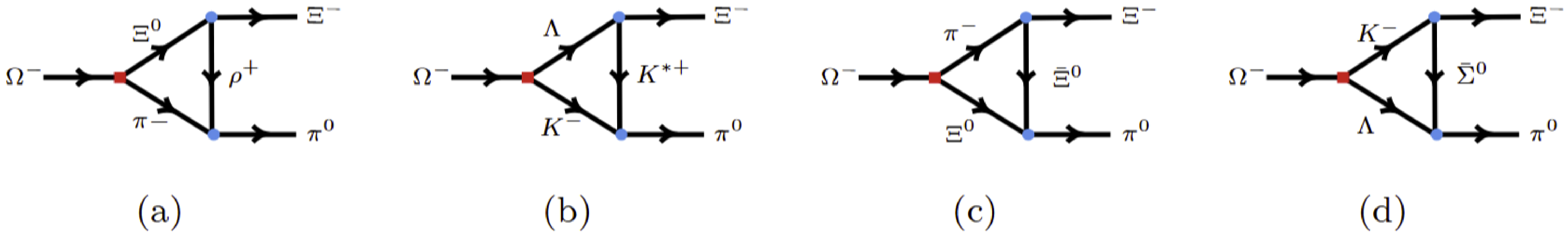
(单个)极点项在Ω非轻衰变中发挥重要作用。

$$\mathrm{BR}[\Omega^- \to \Xi^0 \pi^-] = (25.03 \pm 0.44 \pm 0.53)\%,$$

$$\mathrm{BR}[\Omega^- \to \Xi^- \pi^0] = (8.43 \pm 0.52 \pm 0.28)\%,$$

$$\mathrm{BR}[\Omega^- \to \Lambda K^-] = (66.3 \pm 0.8 \pm 2.0)\%,$$

# 对十重态超子Ω的两体强子弱衰变的研究



(a) (b) (c) (d)

对$\Omega^- \to \Xi^-\pi^0$：考虑来自于中间过程$\Xi^0\pi^-$和$\Lambda K^-$的末态相互作用（FSIs）贡献。

$$i\mathcal{M}_t = g_1 g_2 g_3 \int \frac{d^4p_1}{(2\pi)^4} \frac{p_{1\mu}(p_1+p_M)_\nu\left(g^{\alpha\nu} - \frac{p_2^\alpha p_2^\nu}{p_2^2}\right)\bar{u}(p_f,\lambda_f)\left(\gamma_\alpha - \frac{f_3}{2m_\Xi g_3}\frac{[\gamma_\alpha,\gamma_\beta]}{2}p_2^\beta\right)(\not{p}_3+m_3)u^\mu(p_i,\lambda_i)}{(p_1^2-m_1^2+i\epsilon)(p_2^2-m_2^2+i\epsilon)(p_3^2-m_3^2+i\epsilon)}\mathcal{F}(p_i^2)$$

计算结果表明：长程的FSIs扮演重要角色（低能区包含丰富的非微扰QCD效应）。

# 对十重态超子Ω的两体强子弱衰变的研究

**PC: 宇称守恒** **PV: 宇称破坏**

TABLE VII: The tree-level amplitudes with $J_f^z = J_i^z = -1/2$ for different channels and the unit is $10^{-7}$ GeV.

| $\mathcal{M}_T^{\frac{3}{2}-\frac{1}{2};\frac{1}{2}-\frac{1}{2}}$ | DPE(PC) | CS-1(PC) | CS-2(PC) | PT(PC) | PT(PV) |
|---|---|---|---|---|---|
| $\Omega^- \to \Xi^0\pi^-$ | 9.70 | - | - | - | - |
| $\Omega^- \to \Xi^-\pi^0$ | - | $-2.24$ | - | - | - |
| $\Omega^- \to \Lambda K^-$ | - | - | 1.43 | $-18.69$ | $-0.114 - 0.002i$ |

TABLE VIII: The loop amplitudes with $J_f^z = J_i^z = -1/2$ for $\Omega^- \to \Xi^0\pi^-$ at two different values of $\Lambda$ and the unit is $10^{-8}$ GeV.

| $\mathcal{M}_L^{\frac{3}{2}-\frac{1}{2};\frac{1}{2}-\frac{1}{2}}$ | $[\pi^-, \Xi^0, (\rho^+)]$ | $[K^-, \Lambda, (K^{*+})]$ | $[\Xi^0, \pi^-, (\bar{\Xi}^0)]$ | $[\Lambda, K^-, (\bar{\Sigma}^0)]$ |
|---|---|---|---|---|
| $\Lambda = 1.5$ GeV | $9.25 - 6.14i$ | $-5.32 - 11.89i$ | $0.008 - 0.03i$ | $0.026 - 0.38i$ |
| $\Lambda = 2.0$ GeV | $10.68 - 18.92i$ | $-6.74 - 16.84i$ | $0.006 - 0.14i$ | $0.020 - 1.00i$ |

$$\frac{\mathbf{3}}{\mathbf{2}}^{+} \to \frac{\mathbf{1}}{\mathbf{2}}^{+} + \mathbf{0}^{-}$$

DPE and CS $(s \to u d \bar{u})$

PT$(su \to ud)$

$$\frac{\mathbf{3}}{\mathbf{2}}^{+} \to \frac{\mathbf{3}}{\mathbf{2}}^{\pm} \to \frac{\mathbf{1}}{\mathbf{2}}^{+} + \mathbf{0}^{-}$$

- 我们考虑的NR极限下的$H_{W(s\to ud\bar{u})}$只包括$S$和$P$波算符
- 对$\Lambda K^-$，PT贡献不小
- 对$\Xi^0\pi^-$道，圈图贡献不小

# 对十重态超子Ω的两体强子弱衰变的研究

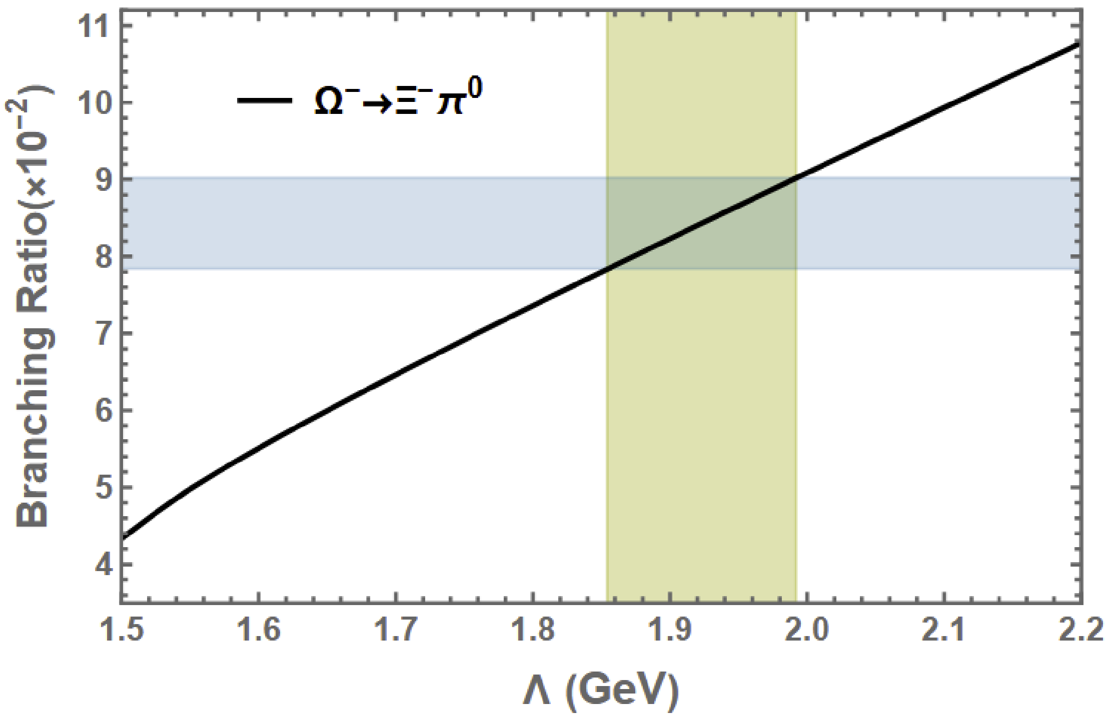


FIG. 3: The obtained branching ratio of $\Omega^- \to \Xi^- \pi^0$ as a function of the cut-off parameter $\Lambda$, comparing with the experimental data (horizontal blue bands). The vertical dark yellow band indicates the range where our results overlap with the experimental data.

$$\mathcal{F}(p_i^2) = \prod_i \left(\frac{\Lambda_i^2 - m_i^2}{\Lambda_i^2 - p_i^2}\right)$$

- 在$\Lambda = 1.9$ GeV附近时，$\Xi^0\pi^-$的分支比与实验范围保持一致
- FSIs对重现$\Xi^0\pi^-$的BR至关重要
- 长程机制在低能区的超子弱衰变不可忽视

# 对十重态超子Ω的两体强子弱衰变的研究

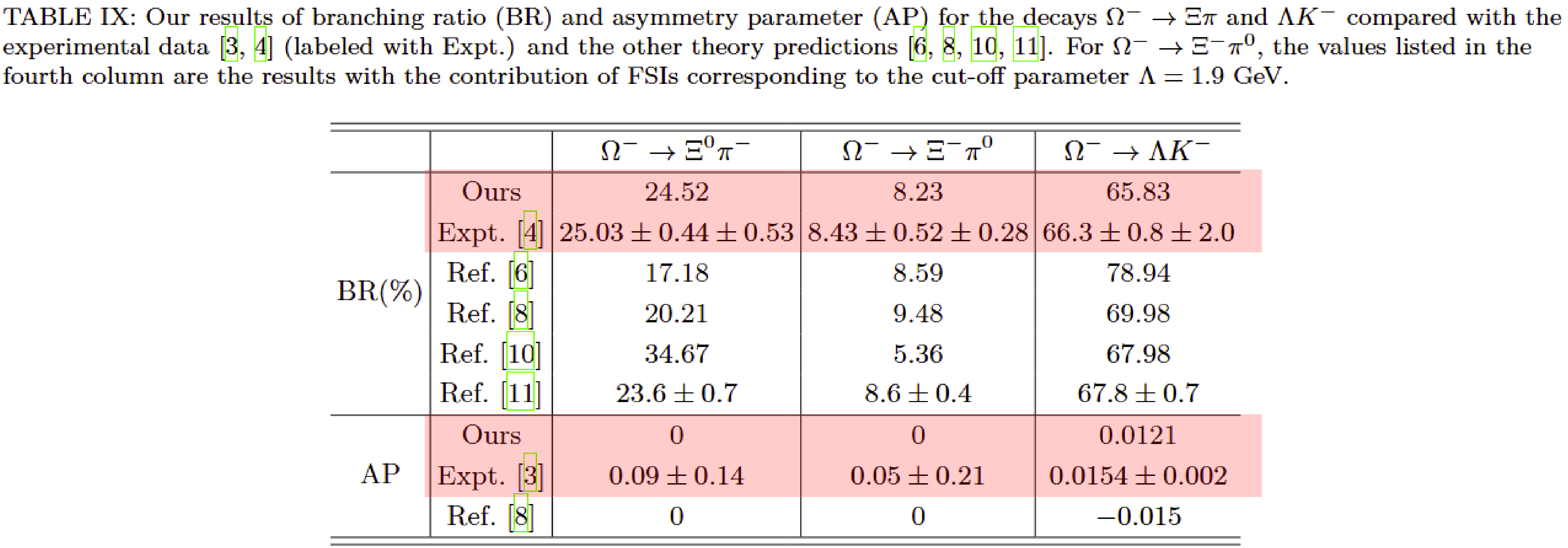


TABLE IX: Our results of branching ratio (BR) and asymmetry parameter (AP) for the decays $\Omega^- \to \Xi\pi$ and $\Lambda K^-$ compared with the experimental data [3, 4] (labeled with Expt.) and the other theory predictions [6, 8, 10, 11]. For $\Omega^- \to \Xi^-\pi^0$, the values listed in the fourth column are the results with the contribution of FSIs corresponding to the cut-off parameter $\Lambda = 1.9$ GeV.

| | | $\Omega^- \to \Xi^0\pi^-$ | $\Omega^- \to \Xi^-\pi^0$ | $\Omega^- \to \Lambda K^-$ |
|---|---|---|---|---|
| BR(%) | Ours | 24.52 | 8.23 | 65.83 |
| | Expt. [4] | $25.03 \pm 0.44 \pm 0.53$ | $8.43 \pm 0.52 \pm 0.28$ | $66.3 \pm 0.8 \pm 2.0$ |
| | Ref. [6] | 17.18 | 8.59 | 78.94 |
| | Ref. [8] | 20.21 | 9.48 | 69.98 |
| | Ref. [10] | 34.67 | 5.36 | 67.98 |
| | Ref. [11] | $23.6 \pm 0.7$ | $8.6 \pm 0.4$ | $67.8 \pm 0.7$ |
| AP | Ours | 0 | 0 | 0.0121 |
| | Expt. [3] | $0.09 \pm 0.14$ | $0.05 \pm 0.21$ | $0.0154 \pm 0.002$ |
| | Ref. [8] | 0 | 0 | $-0.015$ |

- 我们对Ω的三个衰变道的BR和AP的计算结果与实验范围相一致
- $\Xi^0\pi^-$和$\Lambda K^-$有较大的分支比是由于大的DPE和PT贡献
- $\Xi^-\pi^0$的分支比受到$\Xi^0\pi^-$和$\Lambda K^-$的重散射相互作用的增强

# 对十重态超子Ω的两体强子弱衰变的研究

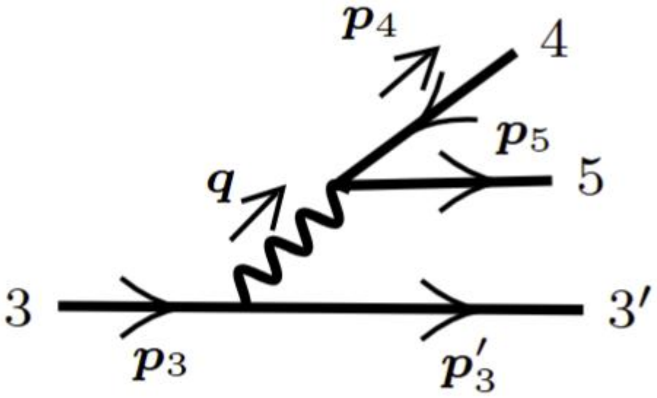
## 小结

- 这项工作表明，对Ω 强子弱衰变的统一描述需要夸克层次的弱跃迁顶点、极点结构以及长程FSIs动力学之间的相互作用。
- Ω的三个衰变道的各个衰变机制和BR的排序更直接说明超子衰变中长程动力学的存在，这是对八重态超子的弱衰变机制的补充。
- 在低能区，以极点项和重散射方式出现的长程机制在超子中发挥着重要作用。

# THANKS

恳请老师们批评与指正

# 对十重态超子Ω的两体强子弱衰变的研究



1 → 3

$$\frac{3}{2}^+ \rightarrow \underbrace{\frac{1}{2}^+ + 0^-}_{P/D\text{-wave}}$$

| “1 → 3” | $\bar{u}(\boldsymbol{p}'_3)\Gamma u(\boldsymbol{p}_3)$ | $\bar{u}(\boldsymbol{p}_5)\Gamma v(\boldsymbol{p}_4)$ |
|---|---|---|
| $J_V^0=\bar\psi\gamma^0\psi$ | $\phi_3'^\dagger\left[\boxed{1}+\frac{\boldsymbol{p}'_3\cdot\boldsymbol{p}_3+i\boldsymbol{\sigma}\cdot(\boldsymbol{p}'_3\times\boldsymbol{p}_3)}{(2m'_3)(2m_3)}\right]\phi_3$ | $\phi_5^\dagger\left[\frac{\boldsymbol{\tau}\cdot\boldsymbol{p}_4}{2m_4}+\frac{\boldsymbol{\tau}\cdot\boldsymbol{p}_5}{2m_5}\right]\phi_4$ |
| $\boldsymbol{J}_V=\bar\psi\boldsymbol{\gamma}\psi$ | $\phi_3'^\dagger\left[\frac{\boldsymbol{p}_3-i\boldsymbol{\sigma}\times\boldsymbol{p}_3}{2m_3}+\frac{\boldsymbol{p}'_3+i\boldsymbol{\sigma}\times\boldsymbol{p}'_3}{2m'_3}\right]\phi_3$ | $\phi_5^\dagger\left[\boxed{\boldsymbol{\tau}}+\frac{(\boldsymbol{\tau}\cdot\boldsymbol{p}_5)\boldsymbol{\tau}(\boldsymbol{\tau}\cdot\boldsymbol{p}_4)}{(2m_5)(2m_4)}\right]\phi_4$ |
| $J_A^0=\bar\psi\gamma^0\gamma_5\psi$ | $\phi_3'^\dagger\left[\frac{\boldsymbol{\sigma}\times\boldsymbol{p}_3}{2m_3}+\frac{\boldsymbol{\sigma}\times\boldsymbol{p}'_3}{2m'_3}\right]\phi_3$ | $\phi_5^\dagger\left[\boxed{1}+\frac{\boldsymbol{p}_5\cdot\boldsymbol{p}_4+i\boldsymbol{\tau}\cdot(\boldsymbol{p}_5\times\boldsymbol{p}_4)}{(2m_5)(2m_4)}\right]\phi_4$ |
| $\boldsymbol{J}_A=\bar\psi\boldsymbol{\gamma}\gamma_5\psi$ | $\phi_3'^\dagger\left[\boxed{\boldsymbol{\sigma}}-\frac{(\boldsymbol{\sigma}\cdot\boldsymbol{p}'_3)\boldsymbol{\sigma}(\boldsymbol{\sigma}\cdot\boldsymbol{p}_3)}{(2m'_3)(2m_3)}\right]\phi_3$ | $\phi_5^\dagger\left[\frac{\boldsymbol{p}_4-i\boldsymbol{\tau}\times\boldsymbol{p}_4}{2m_4}+\frac{\boldsymbol{p}_5+i\boldsymbol{\tau}\times\boldsymbol{p}_5}{2m_5}\right]\phi_4$ |

# 科研工作二：对十重态超子Ω的两体强子弱衰变的研究

$$\hat{H}^{(\mathrm{PC})(\mathrm{LO})}_{W,1\to3} = \frac{G_F}{\sqrt{2}} V_{ud} V_{us} \frac{\beta}{(2\pi)^3} \hat{\alpha}^{(+)}_3 \hat{I}_P \delta^3(\boldsymbol{p}_3 - \boldsymbol{p}'_3 - \boldsymbol{p}_4 - \boldsymbol{p}_5)$$
$$\times \Big\{ \Big[ \langle s'_3|I|s_3\rangle\langle s_5\bar{s}_4|\boldsymbol{\sigma}|0\rangle - \langle s'_3|\boldsymbol{\sigma}|s_3\rangle\langle s_5\bar{s}_4|I|0\rangle \Big] \cdot \Big[ \Big(\frac{\boldsymbol{p}_5}{2m_5} + \frac{\boldsymbol{p}_4}{2m_4}\Big) - \Big(\frac{\boldsymbol{p}'_3}{2m'_3} + \frac{\boldsymbol{p}_3}{2m_3}\Big) \Big]$$
$$+ i\langle s'_3|\boldsymbol{\sigma}|s_3\rangle \times \langle s_5\bar{s}_4|\boldsymbol{\sigma}|0\rangle \cdot \Big[ \Big(\frac{\boldsymbol{p}_4}{2m_4} - \frac{\boldsymbol{p}_5}{2m_5}\Big) - \Big(\frac{\boldsymbol{p}_3}{2m_3} - \frac{\boldsymbol{p}'_3}{2m'_3}\Big) \Big] \Big\},$$

$$\frac{3}{2}^+ \to \underbrace{\frac{1}{2}^+ + 0^-}_{P/D\text{-wave}}$$

直接泡利约化法

$$\hat{H}^{(\mathrm{PV})(\mathrm{LO})}_{W,1\to3} = \frac{G_F}{\sqrt{2}} V_{ud} V_{us} \frac{\beta}{(2\pi)^3} \hat{\alpha}^{(+)}_3 \hat{I}_P \delta^3(\boldsymbol{p}_3 - \boldsymbol{p}'_3 - \boldsymbol{p}_4 - \boldsymbol{p}_5)$$
$$\times \boxed{\Big( - \langle s'_3|I|s_3\rangle\langle s_5\bar{s}_4|I|0\rangle + \langle s'_3|\boldsymbol{\sigma}|s_3\rangle \cdot \langle s_5\bar{s}_4|\boldsymbol{\sigma}|0\rangle \Big)},$$

$S$-wave

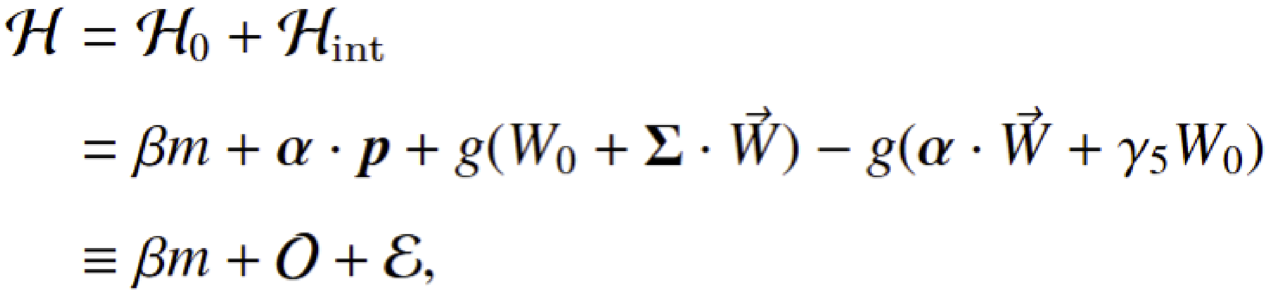
| “1 → 3” | $\bar{u}(\boldsymbol{p}'_3)\Gamma u(\boldsymbol{p}_3)$ | $\bar{u}(\boldsymbol{p}_5)\Gamma v(\boldsymbol{p}_4)$ |
|---|---|---|
| $J^0_V = \bar{\psi}\gamma^0\psi$ | $\phi'^{\dagger}_3\Big[1 + \boxed{\frac{p'_3\cdot p_3 + i\sigma\cdot(p'_3\times p_3)}{(2m'_3)(2m_3)}}\Big]\phi_3$ | $\phi^{\dagger}_5\Big[\frac{\tau\cdot p_4}{2m_4} + \frac{\tau\cdot p_5}{2m_5}\Big]\phi_4$ |
| $\boldsymbol{J}_V = \bar{\psi}\boldsymbol{\gamma}\psi$ | $\phi'^{\dagger}_3\Big[\frac{p_3 - i\sigma\times p_3}{2m_3} + \frac{p'_3 + i\sigma\times p'_3}{2m'_3}\Big]\phi_3$ | $\phi^{\dagger}_5\Big[\boldsymbol{\tau} + \frac{(\tau\cdot p_5)\tau(\tau\cdot p_4)}{(2m_5)(2m_4)}\Big]\phi_4$ |
| $J^0_A = \bar{\psi}\gamma^0\gamma_5\psi$ | $\phi'^{\dagger}_3\Big[\frac{\sigma\times p_3}{2m_3} + \frac{\sigma\times p'_3}{2m'_3}\Big]\phi_3$ | $\phi^{\dagger}_5\Big[1 + \boxed{\frac{p_5\cdot p_4 + i\tau\cdot(p_5\times p_4)}{(2m_5)(2m_4)}}\Big]\phi_4$ |
| $\boldsymbol{J}_A = \bar{\psi}\boldsymbol{\gamma}\gamma_5\psi$ | $\phi'^{\dagger}_3\Big[\boldsymbol{\sigma} - \frac{(\sigma\cdot p'_3)\sigma(\sigma\cdot p_3)}{(2m'_3)(2m_3)}\Big]\phi_3$ | $\phi^{\dagger}_5\Big[\frac{p_4 - i\tau\times p_4}{2m_4} + \frac{p_5 + i\tau\times p_5}{2m_5}\Big]\phi_4$ |

$$u(\boldsymbol{p}) \overset{\mathrm{NR}}{\approx} \begin{pmatrix} 1 \\ \frac{\boldsymbol{\sigma}\cdot\boldsymbol{p}}{2m} \end{pmatrix} \phi$$

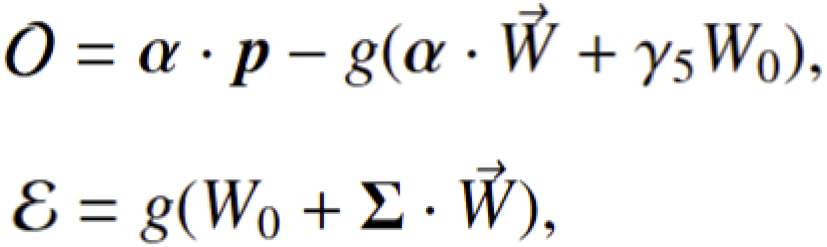
我们需要次领头阶的 $D$ -波算符！

# 对十重态超子Ω的两体强子弱衰变的研究

将描述费米子与W玻色子的相对论Dirac哈密顿量进行Foldy-Wouthuysen(FW)变换，逐阶对角化哈密顿量（消除连接大小分量的奇算符）。

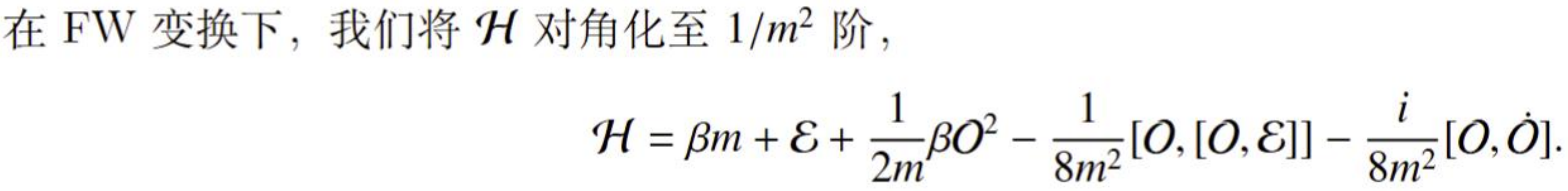


$$\begin{aligned}\mathcal{H} &= \mathcal{H}_0 + \mathcal{H}_{\rm int} \\ &= \beta m + \boldsymbol{\alpha}\cdot\boldsymbol{p} + g(W_0 + \boldsymbol{\Sigma}\cdot\vec{W}) - g(\boldsymbol{\alpha}\cdot\vec{W} + \gamma_5 W_0) \\ &\equiv \beta m + \mathcal{O} + \mathcal{E},\end{aligned}$$



$$\mathcal{O} = \boldsymbol{\alpha}\cdot\boldsymbol{p} - g(\boldsymbol{\alpha}\cdot\vec{W} + \gamma_5 W_0),$$

$$\mathcal{E} = g(W_0 + \boldsymbol{\Sigma}\cdot\vec{W}),$$

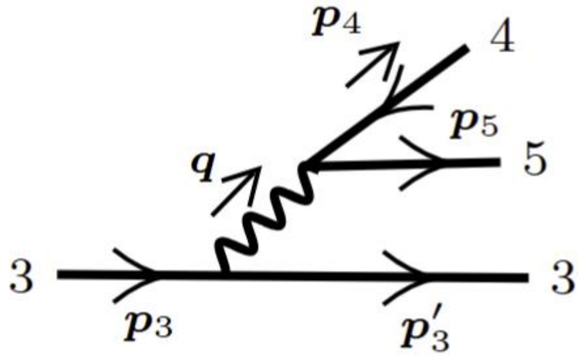


在 FW 变换下，我们将 $\mathcal{H}$ 对角化至 $1/m^2$ 阶，

$$\mathcal{H} = \beta m + \mathcal{E} + \frac{1}{2m}\beta\mathcal{O}^2 - \frac{1}{8m^2}[\mathcal{O},[\mathcal{O},\mathcal{E}]] - \frac{i}{8m^2}[\mathcal{O},\dot{\mathcal{O}}].$$

# 科研工作二：对十重态超子Ω的两体强子弱衰变的研究

$$\mathcal{H} \equiv O_0 W_0 + \vec{O} \cdot \vec{W},$$



$1 \to 3$

对于 “1 → 3” 的发射过程，我们先考虑 $q_3(\boldsymbol{p}_3) \to q_3'(\boldsymbol{p}_3') + W(\boldsymbol{q})$ 这个相互作用顶点，

$$O_0(1) = g\left\{1(V) - \frac{\boldsymbol{\sigma}\cdot(\boldsymbol{p}_3+\boldsymbol{p}_3')}{2m}(A) - \frac{(\boldsymbol{p}_3-\boldsymbol{p}_3')^2}{8m^2}(V) - \frac{i\boldsymbol{\sigma}\cdot(\boldsymbol{p}_3\times\boldsymbol{p}_3')}{4m^2}(V) - \frac{q_0\boldsymbol{\sigma}\cdot(\boldsymbol{p}_3-\boldsymbol{p}_3')}{8m^2}(A)\right\},$$

$$\vec{O}(1) = g\left\{\boldsymbol{\sigma}(A) - \frac{\boldsymbol{p}_3+\boldsymbol{p}_3'}{2m}(V) + \frac{i\boldsymbol{\sigma}\times(\boldsymbol{p}_3-\boldsymbol{p}_3')}{2m}(V) + \frac{i(\boldsymbol{p}_3\times\boldsymbol{p}_3')}{4m^2}(A) - \frac{q_0(\boldsymbol{p}_3-\boldsymbol{p}_3')}{8m^2}(V) + \frac{iq_0\boldsymbol{\sigma}\times(\boldsymbol{p}_3+\boldsymbol{p}_3')}{8m^2}(V) \right.$$
$$\left. - \frac{(\boldsymbol{p}_3+\boldsymbol{p}_3')^2\boldsymbol{\sigma} - 2(\boldsymbol{\sigma}\cdot\boldsymbol{p}_3')\boldsymbol{p}_3 - 2(\boldsymbol{\sigma}\cdot\boldsymbol{p}_3)\boldsymbol{p}_3'}{8m^2}(A)\right\},$$

- 得到$1/\mathrm{m}^2$阶的$W \to q_5\bar{q}_4$的相互作用算符。
- 预期有一个小的宇称破坏（$D$-wave）振幅，使得$\alpha$很小却不严格为零。