$\not{CP}$ in $\Lambda \to p\pi^-$ and $\Xi^- \to \Lambda\pi^-$

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In the previous talk we learned:

$$A(\Lambda^0_-) \equiv \frac{\alpha+\bar{\alpha}}{\alpha-\bar{\alpha}} \simeq -\tan(\delta_p-\delta_s)\sin(\phi_p-\phi_s)$$

I. Strong phases for $\Delta I = 1/2$, S, P amplitudes

δ_s, δ_p : $A(\Lambda^0_-)$ vs $A(\Xi^-_-)$

II. Weak phases : ϕ_s, ϕ_p

- within SM
- beyond SM

III. Conclusions + two comments

Strong Phases

1) $\Lambda \to N\pi$

Watson's thm $\to$ same as $N\pi$ scattering at $E_{cm} = M_\Lambda$

For $A(\Lambda^0_-)$ need δ for $I = 1/2$, s, P waves

- measured and small: $\delta_s^{1/2} \sim 6°$

$\delta_p^{1/2} \sim -1.1°$

- errors? $\pm 1°$?

2) $\Xi \to \Lambda\pi$ $(\Omega \to \Xi\pi)$

Watson's thm: $\Lambda\pi$ $(\Xi\pi)$ scattering at $E_{cm} = M_\Xi$ (M_Ω)

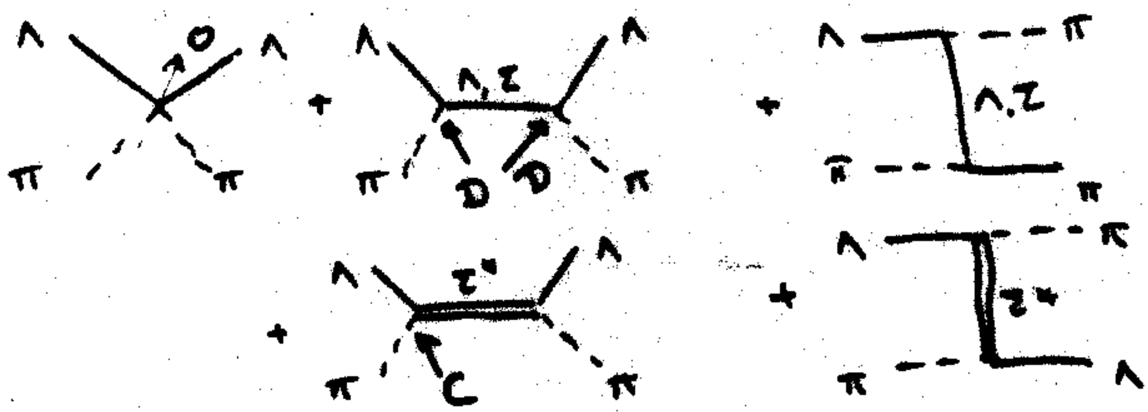
- not measured

Old model: Nath, Kumar Nuov. Cim. 36 (1965) 669

$\Xi \to \Lambda\pi$ $\delta_s^{I=1} \sim -20°$ <u>large</u>

New χPT: small

$\Lambda-\pi$ scattering Lu, Wise, Savage
Datta, Pakvasa
J. Tandean, G.V.



Again, χPT a la Jenkins, Manohar

Again, depends on $\underbrace{D\ (F)}_{0.5\,-\,0.8}$, $\underbrace{C}_{1.2\,-\,1.6}$ and 20-30% kinematic dependence

at $E_{cm} = M_{\Xi}$

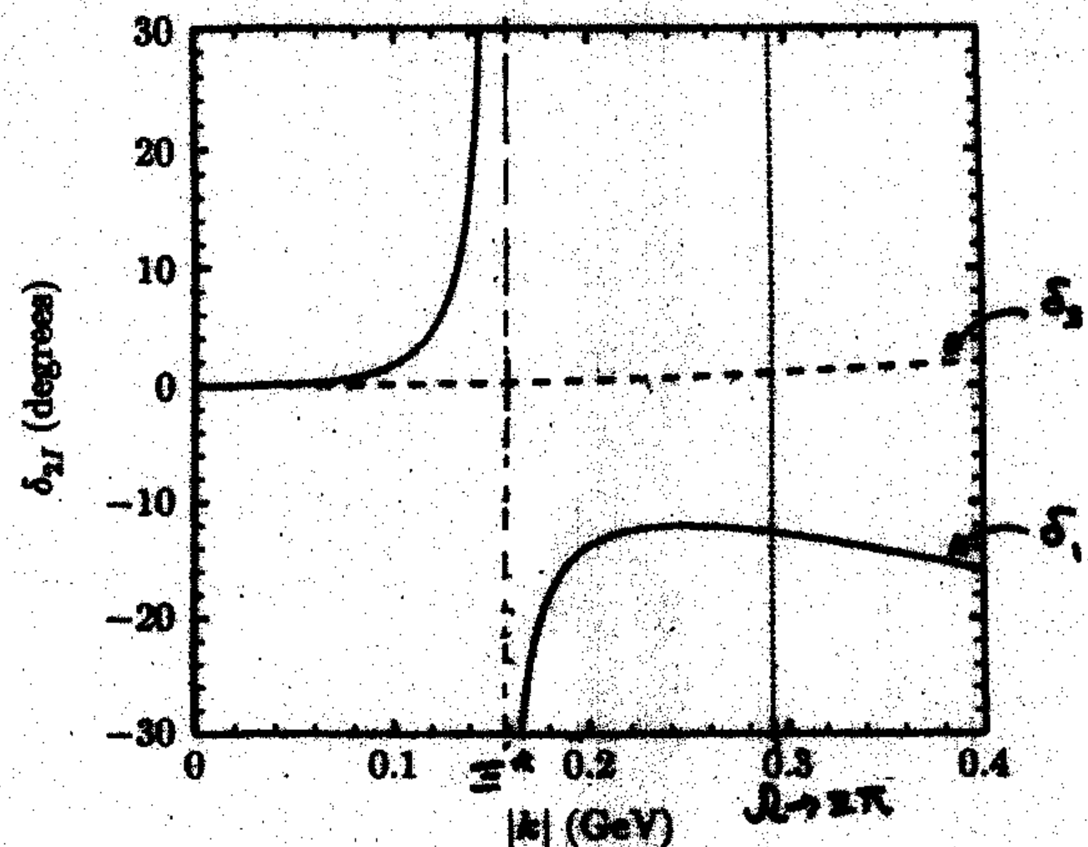
$$\delta_p = \frac{-|k|^3 M_\Lambda}{24\pi f_\pi^2 M_\Xi}\left[\frac{2D^2}{M_\Xi - M_\Sigma} + \frac{2/3\ D^2}{M_\Xi - 2M_\Lambda + M_\Sigma} - \frac{2/3\ C^2}{M_\Xi - 2M_\Lambda + M_{\Sigma^*}}\right]$$

$\sim -1.8°$

$\delta_s = 0$

at next order in χPT $\delta_s \neq 0$ (Lu, Savage, Wise)

$\Xi\pi$ scattering



pion momentum in CM

at Ω mass:

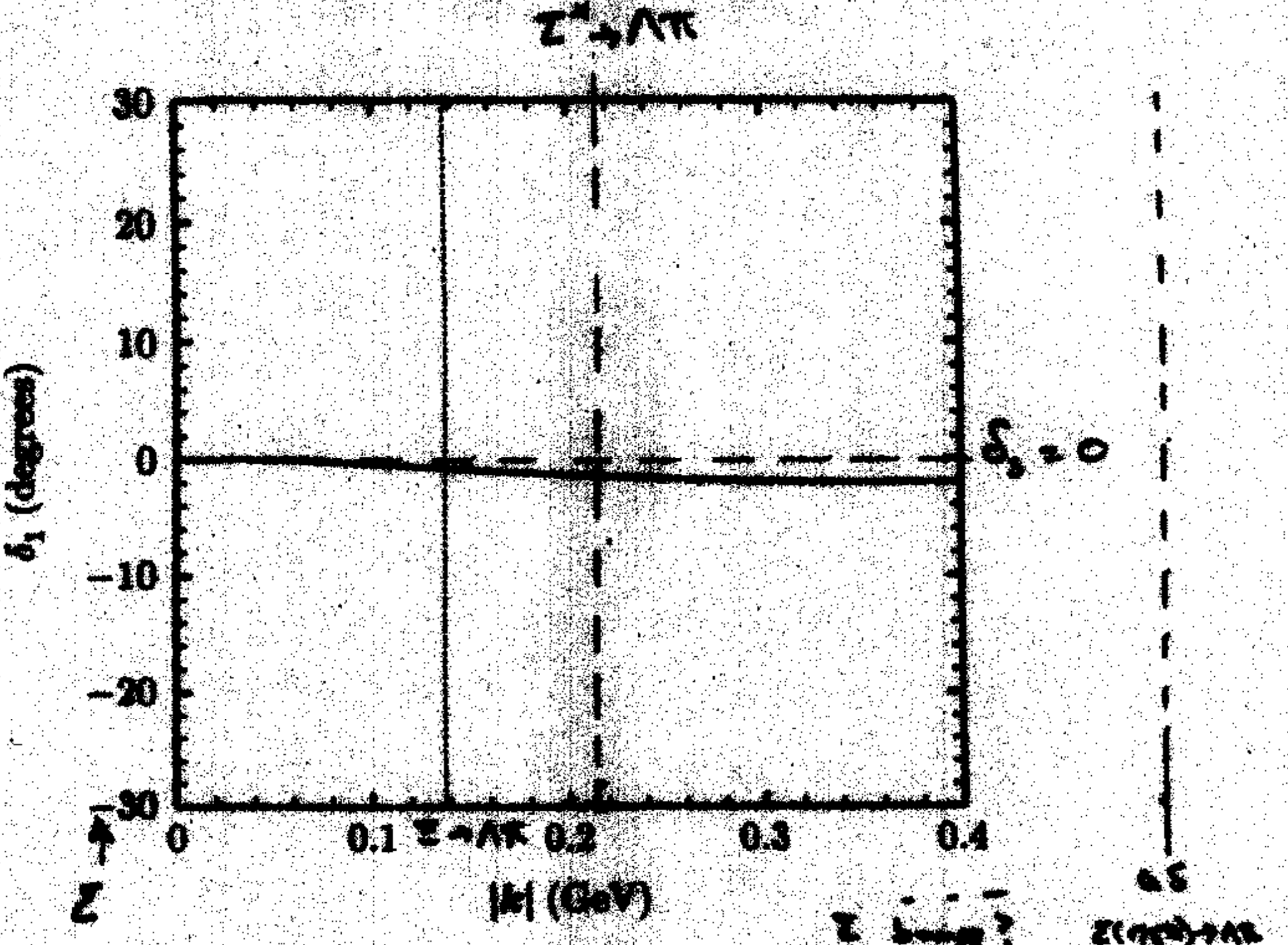
$$\delta_1^P = \frac{-|k|^3 M_\Xi}{24\pi F_\pi^2 M_\Omega}\left[\frac{(D-F)^2}{M_\Omega - M_\Xi} + \frac{\gamma_\Xi\, C^2}{M_\Omega - M_{\Xi^*}} + \frac{\gamma_{\Xi^*} C^2}{M_\Omega - 2M_\Xi + M_{\Xi^*}}\right]$$

$\delta_1^P \simeq -13°$ $\qquad$ $\delta_3 \simeq 1°$ $\qquad$ uncert: ~30% + 30%
$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \uparrow_C \qquad \uparrow_{\text{"kin"}}$

Ξ^* : M = 1530 $\quad \Gamma$ = 9.1

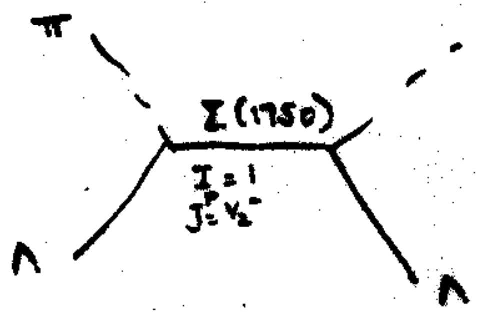
Ω : M = 1670

} we expect



$\Sigma^* \to \Lambda\pi$
30
20
10
0
-10
-20
-30
δ_1 (degrees)
$\delta_3 = 0$
0
0.1
$\Sigma \to \Lambda\pi$
0.2
0.3
0.4
$|k|$ (GeV)
Σ

Datta + Pakvasa : look for resonance in the $J = 1/2$
$\not{P}$ channel



use $\Sigma \to \Lambda\pi$ decay as unknown and

Γ: $60\text{ MeV} \leq \Gamma \leq 160\text{ MeV}$

Need $M_\Xi = 1319$ MeV

Find $\delta_s \lesssim \underline{0.5^\circ}$

<u>Ultimate resolution</u> : measure $(\delta_s - \delta_p)$

a) $\Xi \to \Lambda\pi e\nu$

b) Ignore CP then in $\Xi \to \Lambda\pi$ $\beta/\alpha = \tan(\delta_s - \delta_p)$

Weak Phases

Standard Model: $H_{eff}^{\Delta S=1} = \frac{G_F}{\sqrt{2}} V_{ud}^* V_{us} \sum_{i=1}^{12} c_i(\mu) O_i(\mu)$ + h.c.

- $c_i(\mu)$ - short distance - well known (Buras et al)
- $\langle \pi N | O_i(\mu) | \Lambda \rangle$ - model dependent
  - not known precisely

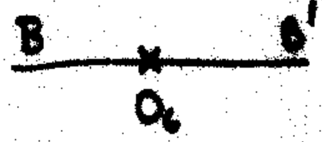
Usual method: calculate $\mathrm{Im}\left(\langle \pi N | O_i | \Lambda \rangle\right)$

get $\mathrm{Re}\left(\langle \pi N | O_i | \Lambda \rangle\right)$ from experiment.

What is known about $\mathrm{Im}\left(\langle \pi N | O_i | \Lambda \rangle\right)$?

- using vacuum saturation (factorization): $y_6 O_6$ dominates He, Steger, CV
  - dominant penguin
  - no large cancellation Q_6 vs Q_8 as in ϵ'/ϵ
  - purely $\Delta I = 1/2$ observable
  - $y_6 \approx -0.08$
  - uncertainty from dropping $Q_i \neq O_6$ smaller than hadronic uncertainty

Bag Model   Donoghue, Golowich, Holstein, Ponce

 $\Rightarrow$ d, F

S-wave :  soft-pion or χPT leading order

P-wave : 

leading χPT   next-order χPT

$$\phi_s - \phi_p \sim (-0.12 + 2.24)\, y_6 A^2 \lambda^4 M$$

$A(\Lambda^0_-) \simeq -2 \times 10^{-5}$ using $A^2 \lambda^4 M = 10^{-3}$

- Next order χPT corrections? factor of 2 ?
- Error in bag model ? $A(\Lambda^0_-) = (-3 \pm 2.6) \times 10^{-5}$

$A(\Xi^-_-) \simeq -3 \times 10^{-6}$
- with $(\delta_s - \delta_p) \sim 2^\circ$
- same sign as $A(\Lambda^0_-)$ in bag model
- same sign in factorization

- but can see that sign in general is not predicted

Error Estimate for $\Lambda \to p\pi^-$

CP conserving — Bijnens & Sonoda & Wise

$A_s(\text{exp}) = 1.47 \pm 0.01$

$A_s(\chi PT)_{l.o.} = 1.5$

$\Delta A_s(\chi PT)(m_s \ln m_s) = 0.3$

$A_p(\text{exp}) = 9.98 \pm 0.24$

$A_p(\chi PT)_{l.o.} = 10.4$

$\Delta A_p(\chi PT)(m_s \ln m_s) = 9.0$

$\therefore$ Assign an overall factor of 2 uncertainty

- Allow an extra 30% uncorrelated error in A_p

Beyond the Standard Model

I. Explicit Models

Donoghue & He & Pakvasa: big model, $\boxed{\text{Fit } (\epsilon)_{LO}}$

$A(\Lambda^0_-) = -2 \times 10^{-5}$ SM

$= -2 \times 10^{-5}$ ≈ Higgs

$= -1 \times 10^{-3}$ LR (no W_L–W_R mixing)

Chang & He & Pakvasa $= 6 \times 10^{-4}$ LR with (W_L–W_R mixing)

Superweak $= 0$

II. Model independent: can $A(\Lambda^0_-)$ be large ($> 10^{-4}$) given ϵ'/ϵ? He & Valencia (95)

Look at all dim 6 operators compatible with SM

$H_{eff} = H_{eff}^{SM} + \sum \lambda_i O_i^{new}$, allow λ_i a phase

O_i^{new} $\left\{ \begin{array}{l} \underline{\text{P-even}} \to \text{generates } \underline{\phi_P}\text{, long distance cont. to } \underline{\epsilon} \\ \quad \to \epsilon'/\epsilon = 0 \\ \underline{\text{P-odd}} \to \text{generates } \underline{\phi_S} \\ \quad \to \underline{\epsilon'/\epsilon \neq 0} \quad \text{demand } (\epsilon'/\epsilon)_{new} < 1.5 \times 10^{-3} \end{array} \right.$

FIND: a few can give $A(\Lambda^0_-) \sim 5\times10^{-4}$ level

Largest: P conserving $O \sim \bar{d}\,\sigma_{\mu\nu} t^a s\, G^a_{\mu\nu}$

But recently: ϵ'/ϵ appears to be large

compared to SM

Masiero, Murayama & others reexamine SUSY

One new large contribution to ϵ'/ϵ

$$H_{eff} = (\delta^d_{12})_{LR}\, C_g\, \bar{d}\sigma_{\mu\nu} t^a (1+\gamma_5) s\, G^a_{\mu\nu}$$

$$+ (\delta^d_{12})_{RL}\, C_g\, \bar{d}\sigma_{\mu\nu} t^a (1-\gamma_5) s\, G^a_{\mu\nu}$$

* $\delta_{12} C_g$ in SUSY can be large enough to explain ϵ'/ϵ

$\delta \to$ SUSY mixing in mass insertion approximation
squark mass matrix

$C_g \to$ loop factors

Hyperons : He + Murayama + Pakvasa + Valencia

- $(\delta^d_{12})_{LR}$ – similar to old "Weinberg" model)
  – large A in principle but $\phi_S - \phi_P$ cancel to a large extent

- $(\delta^d_{12})_{RL}$ – no cancellation

∴ "Explain" ϵ'/ϵ with $(\delta^d_{12})_{LR,\,RL} \to$ large $A(\Lambda^0_-)$

Even better ...

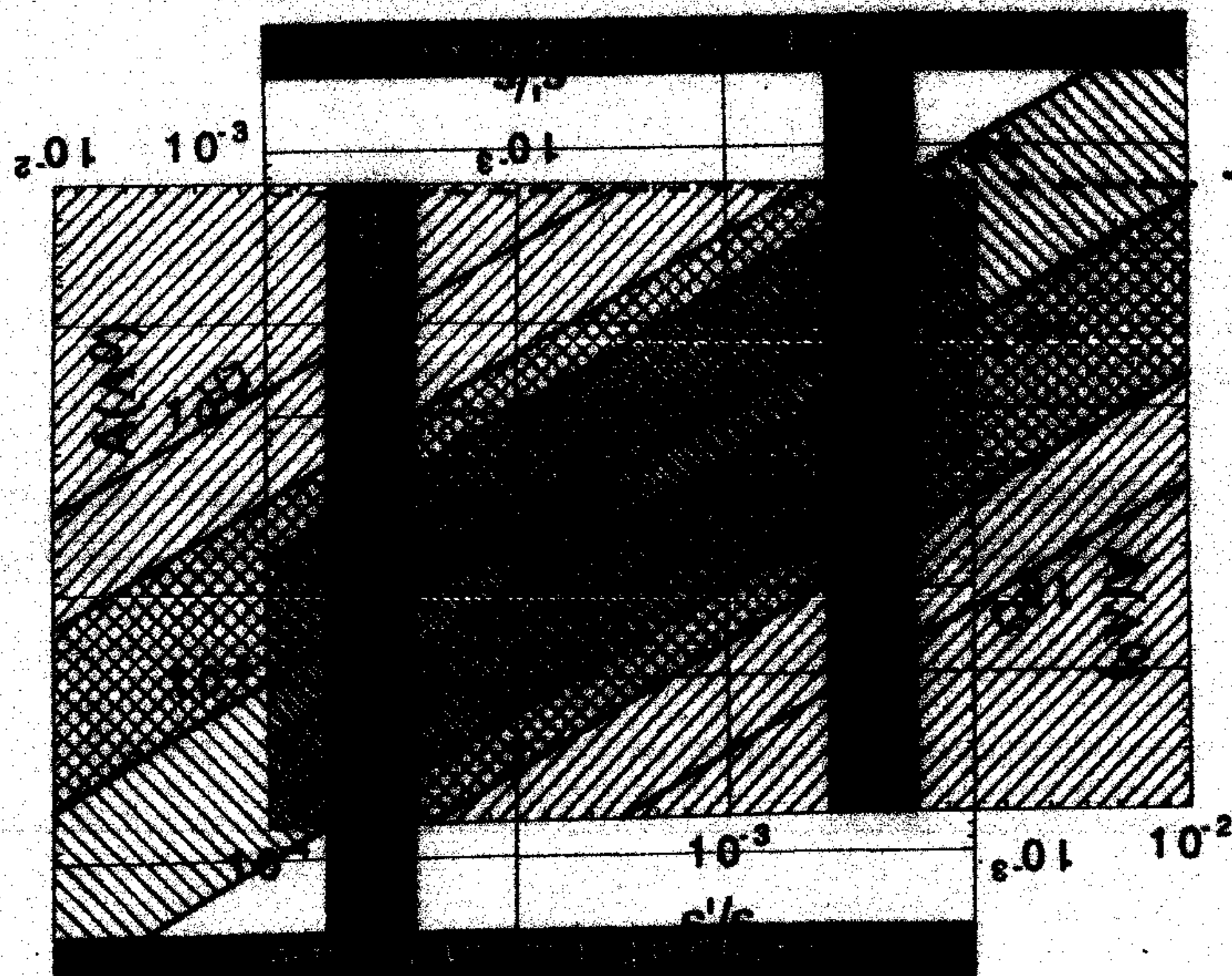
Models by Barbieri, Dvali, Hall + others

that naturally give $\lambda \sim \sqrt{m_d/m_s}$ have

$\mathrm{Im}(\delta^d_{12})_{LR} = \mathrm{Im}(\delta^d_{12})_{RL} \Rightarrow$ P conserving operator!

∴ No ϵ'/ϵ

very large $A(\Lambda^0_-)$ is possible!



7.3 x10^{-4}
computed from
ε

From [illegible]
to appear in the web in next few days

Conclusions

- $A(\Lambda^0_-)$ is likely to be larger than $A(\Xi^-)$
- $|A(\Lambda^0_-)|$ in SM $\sim$ 3×10^{-5}
- $|A(\Lambda^0_-)|$ BSM can be much larger up to 10^{-3}
    - this scenario has good motivation in SUSY

A non-zero measurement by E871 is not only possible but it would be providing information that is complementary to ϵ'/ϵ

Other

- Search for $\Delta S = 2$ $\Xi \to N\pi$ will test new

    $\Delta S = 2$, $\cancel{CP}$ interactions that do not affect K-$\bar{K}$ mix.

- $\Delta(\Omega \to \Xi\pi)$ could be 2×10^{-5} within SM
    and 10 times larger BSM