HYPERON PHYSICS:

AN OVERVIEW

(A PERSONAL)

B. HOLSTEIN

UMASS

Outline

a) $B \to B'\pi$ - CP Violation

b) $B \to B' e \nu_e$ - SU(3) Violation

$\sin\theta_c$ / Unitarity

c) $B \to B'\gamma$ - Hara's Theorem

Asymmetries

d) Hyperon Polarizabilities

e) Polarization Issues

f) Etc.

GOOD S-WAVE FIT $\Rightarrow$ POOR P-WAVE FIT

OR

GOOD P-WAVE FIT $\Rightarrow$ POOR S-WAVE FIT

PROBLEM IS THEORETICAL – IMPROVED DATA WON'T HELP.

INTEREST LIES INSTEAD IN STD. MODEL? CP VIOLATION

$$A = |A| e^{i\delta_S + i\phi_1}$$

$$B = |B| e^{i\delta_P + i\phi_2}$$

CP VIOLATING PHASES

MEASURE VIA COMPARING B AND $\bar{B}$ DECAY

$$B \to B'\pi \qquad W(\theta) \sim 1 + \alpha\, \underset{\sim}{P}_B \cdot \hat{p}_{B'}$$

$$\langle \underset{\sim}{P}_{B'} \rangle = \frac{1}{W(\theta)} \Big((\alpha + \underset{\sim}{P}_B \cdot \hat{p}_{B'})\, \hat{p}_{B'} + \beta\, \underset{\sim}{P}_B \times \hat{p}_{B'} + \gamma\, (\hat{p}_{B'} \times (\underset{\sim}{P}_B \times \hat{p}_{B'})) \Big)$$

FIND

$$^{R}\mathcal{B} \equiv \frac{\beta + \bar{\beta}}{\beta - \bar{\beta}} \simeq \sin(\phi_1 - \phi_2)$$

$$^{R}A \equiv \frac{\alpha + \bar{\alpha}}{\alpha - \bar{\alpha}} \simeq - \sin(\phi_1 - \phi_2) \sin(\delta_s - \delta_p)$$

$$^{R}C \equiv \frac{\Gamma - \bar{\Gamma}}{\Gamma + \bar{\Gamma}} \sim - \frac{2}{(|A_1|^2 + |\bar{B}_1|^2)}$$

$$\Big(A_1 A_3 \sin(\delta_1^s - \delta_3^s) \sin(\varphi_1' - \varphi_3')$$

$$+ \bar{B}_1 \bar{B}_3 \sin(\delta_1^p - \delta_3^p) \sin(\phi_1^2 - \phi_3^2) \Big)$$

Then $\quad ^{R}A \sim \sin(\delta_s - \delta_p)\ ^{R}\mathcal{B} \sim 0.1\ ^{R}\mathcal{B}$

$$^{R}C \sim \sin(\delta_1 - \delta_3) \cdot \frac{\theta_3}{\theta_1}\ ^{R}\mathcal{B} \sim 0.1 \cdot 0.1\ ^{R}\mathcal{B}$$

ASIDE: FURTHER "THEORETICAL" ISSUE

$$\Delta I = \tfrac{1}{2} \text{ RULE} - \quad \frac{\text{Amp}(1/2)}{\text{Amp}(3/2)} \sim 20$$

SAME SEEN ELSEWHERE BUT

$\hookrightarrow$ $K \to \pi\pi$

$K \to \pi\pi\pi$

NONMESONIC HYPERNUCLEAR DECAY

FREE Λ: $\Lambda \to N\pi$

BOUND Λ: $\Lambda + p \to n + p$

$\Lambda + n \to n + n$

PRESENT DATA ON ${}_{\Lambda}H^4$, ${}_{\Lambda}He^4$

$$\frac{A(1/2)}{A(3/2)} \sim 1$$

Hyperon β - Decay

What is it?

$$\Lambda \to p e \bar{\nu}_e$$
$$\Sigma^- \to n e \bar{\nu}_e$$
$$\Xi^- \to \Lambda, \Sigma^0 e \bar{\nu}_e$$
$$\Sigma^- \to \Lambda e \bar{\nu}_e$$
$$\Sigma^+ \to \Lambda e \nu_e$$

Describe via

$$\langle B' | V_\mu | B \rangle = \bar{u}(p') \left(f_1 \gamma_\mu + \frac{f_2}{2\bar{M}} \cdot -i \sigma_{\mu\nu} q^\nu + \frac{f_3}{2\bar{M}} q_\mu \right) u(p)$$

$$\langle B' | A_\mu | B \rangle = \bar{u}(p') \left(g_1 \gamma_\mu + \frac{g_2}{2\bar{M}} \cdot -i \sigma_{\mu\nu} q^\nu + \frac{g_3}{2\bar{M}} q_\mu \right) \gamma_5 u(p)$$

Issues: KM Unitarity

$$V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 1$$

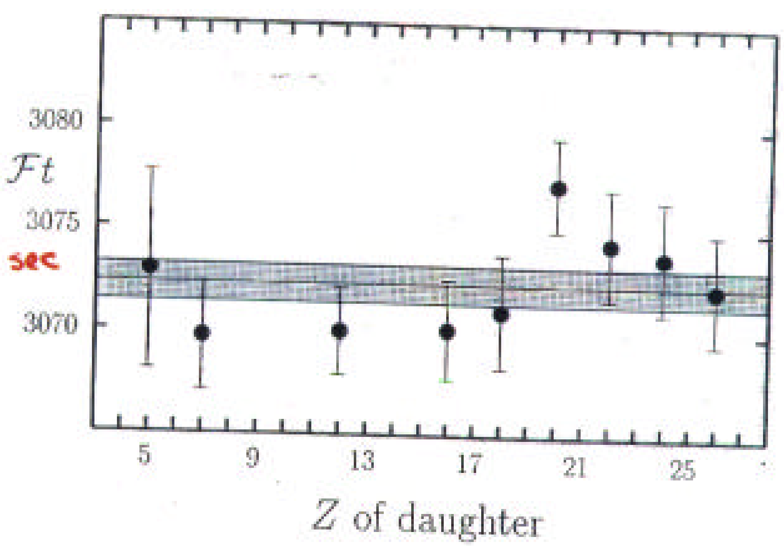
$V_{ub} \simeq 0.003$ from B-Decay

Negligible Contribution to Unitarity

Determine V_{ud} from superallowed $(0^+ \to 0^+)$ via

	Q_{EC} (keV)	$t_{1/2}$ (ms)	R (%)	P_{EC} (%)	ft (s)	$\mathcal{F}t$ (s)
^{10}C	1907.77(9)	19290(12)	1.4645(19)	0.296	3038.7(45)	3072.9(48)
^{14}O	2830.51(22)	70603(18)	99.336(10)	0.087	3038.1(18)	3069.7(26)
^{26m}Al	4232.42(35)	6344.9(19)	$\geq$ 99.97	0.083	3035.8(17)	3070.0(21)
^{34}Cl	5491.71(22)	1525.76(88)	$\geq$ 99.988	0.078	3048.4(19)	3070.1(24)
^{38m}K	6044.34(12)	923.95(64)	$\geq$ 99.998	0.082	3049.5(21)	3071.1(27)
^{42}Sc	6425.58(28)	680.72(26)	99.9941(14)	0.095	3045.1(14)	3077.3(23)
^{46}V	7050.63(69)	422.51(11)	99.9848(13)	0.096	3044.6(18)	3074.4(27)
^{50}Mn	7632.39(28)	283.25(14)	99.942(3)	0.100	3043.7(16)	3073.8(27)
^{54}Co	8242.56(28)	193.270(63)	99.9955(6)	0.104	3045.8(11)	3072.2(27)
					Average, $\overline{\mathcal{F}t}$	3072.3(9)
					χ^2/ν	1.10

$\overline{\mathcal{F}t}$: 3072.3 ± 0.9 sec



$$V_{ud}^2 = \frac{2\pi^3 \ln 2 \; m_e^{-5}}{2 G_F^2 (1 + \Delta_R^V) \overline{\mathcal{F}t}}$$

↳ 2.40 ± 0.08 %

↓

V_{ud} = 0.9740 ± 0.0005

Take $V_{us} = 0.2196 \pm 0.0023$ from $K_{\ell 3}$

$\Downarrow$

$$\boxed{\sum_j V_{uj}^2 = 0.9968 \pm 0.0014}$$

Can we determine V_{us} from Hyperon β-Decay with Comparable Precision?

Requires:

a) Good Experimental Data Base (Inc. Pol.)

b) Solid theoretical Calculation of SU(3) Breaking

Example: Donoghue, Holstein, Klimt

SU(3) Invariant Fit $\quad \chi^2/\text{doF} = 2.0$

SU(3) Broken Fit $\quad \chi^2/\text{doF} = 0.85$

Yielded $V_{us} = 0.220 \pm 0.003$

But other (Garcia et al) $V_{us} = 0.2176 \pm 0.0026$

Need rates AND asymmetries!

Additional Issue:

$n \to p e^- \bar{\nu}_e$ $\qquad$ $\underbrace{g_2 = f_3 = 0}$ from $G = C \exp i\pi I_2$ Inv.

"No Second Class Currents"

Similarly

$\Lambda \to p e^- \bar{\nu}_e$ $\qquad$ $g_2 = f_3 = 0$ from $C \exp i\pi V_2$ Inv.

etc.

SU(3) breaking (V-spin Violation) implies

$$g_2, f_3 \neq 0$$

Quark Model Calculations: $g_2/g_1 \sim -0.2$

Need rates AND asymmetries!

Radiative Nonleptonic Hyperon Decay

What is it?

$\Lambda \to n\gamma$

$\Sigma^+ \to p\gamma$

$\Xi^0 \to \Lambda, \Sigma^0\gamma$

$\Xi^- \to \Sigma^-\gamma$

Describe via

$$\langle B'\gamma | \mathcal{H}_w | B \rangle = \bar{u}(p')\left(C\,\epsilon_\mu \sigma^{\mu\nu} q_\nu + D\,\epsilon_\mu \sigma^{\mu\nu} q_\nu \gamma_5\right) u(p)$$

M1 $\qquad\qquad\qquad\qquad$ E1

Issues: Longstanding Problem – Hara's Theorem

Y. Hara (1964) – U Spin Invariance $\Rightarrow D = 0$

if B, B' are members of U-spin Multiplet

Predicts zero Asymmetry parameter for $\Sigma^+ \to p\gamma$, $\Xi^- \to \Sigma^-\gamma$

Exp. $\alpha_\gamma = \dfrac{2\,\mathrm{Re}\, C^* D}{|C|^2 + |D|^2} = -0.76 \pm 0.08$ $\qquad \Sigma^+ \to p\gamma$

i.e. $|C| \sim |D|$

MANY THEORETICAL STUDIES OVER THE YEARS

POLE MODEL

$$\langle p | \mathcal{H}_w^{PC} | \Sigma^+ \rangle \neq 0$$

$$\langle p | \mathcal{H}_w^{PV} | \Sigma^+ \rangle = 0 \qquad \text{LEE-SWIFT THEOREM}$$

MANY TRIES — LITTLE SUCCESS — ONE EXCEPTION

YAOUANC ET AL (1979)

RECENTLY RESURRECTED BY BORASOY & HOLSTEIN IN CHIRAL APPROACH

SU(6) $70, 1^- \longrightarrow \frac{1}{2}^-, \frac{1}{2}^+$ INT. ST.

LARGE NEGATIVE $\alpha_\gamma^{\Sigma_p^+}$ "NATURAL"

BUT CONFIRMATION OF THIS OR ANY MODEL REQUIRES

DATA ON RATES AND ASYMMETRIES!

Hyperon Polarizability

What is it?

Σ^+

$$\mathbf{p} = 4\pi\alpha_E \mathbf{E}$$

Electric Polarizability

Similarly $\boldsymbol{\mu} = 4\pi \beta_M \mathbf{H}$

Magnetic Polarizability

Corresponding energy is

$$U = -\frac{1}{2}\mathbf{p}\cdot\mathbf{E} - \frac{1}{2}\boldsymbol{\mu}\cdot\mathbf{H}$$

$$= -\frac{1}{2}4\pi\alpha_E \mathbf{E}^2 - \frac{1}{2}4\pi\beta_M \mathbf{H}^2 \longrightarrow H_{eff}$$

Measure in Compton Scattering

$$\text{Amp} = \hat{\epsilon}_f\cdot\hat{\epsilon}_i\left(-\frac{e^2}{M} + \omega\omega' 4\pi\alpha_E\right) + \hat{\epsilon}_f\times \mathbf{q}_f\cdot\hat{\epsilon}_i\times\mathbf{q}_i\, 4\pi\beta_M + \cdots$$

THEN

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{M^2}\left(\frac{\omega'}{\omega}\right)^2\left(\frac{1}{2}(1+\cos^2\theta) - \frac{M\omega\omega'}{\alpha}\left[\frac{\alpha_E+\beta_M}{2}(1+\cos\theta)^2 + \frac{\alpha_E-\beta_M}{2}(1-\cos\theta)^2\right] + \cdots\right)$$

IN THIS WAY RECENT SAL, MAMI MEASUREMENTS GIVE FOR PROTON

$$\alpha_E = (12.1 \pm 0.8 \pm 0.5) \times 10^{-4}\ \text{fm}^3$$

$$\beta_M = (2.1 \mp 0.8 \mp 0.5) \times 10^{-4}\ \text{fm}^3$$

WHAT'S IT MEAN?

CLASSIC QM CALCULATION

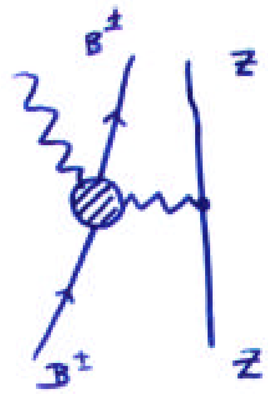
$$\alpha_E^H = \frac{9}{2} a_0^3$$

BUT

$$\alpha_E^p \sim 10^{-3} \langle r_p^3 \rangle$$

STRONGLY BOUND!

HOW TO MEASURE FOR HYPERONS (CHARGED)



PRIMAKOFF EFFECT

HAS BEEN EMPLOYED BY ANTIPOV ET AL TO MEASURE π^+ POLARIZABILITY.

THEORETICAL CALCULATIONS: BERNARD ET AL

$$\alpha_E^{\Sigma^+} \sim 9.4 \times 10^{-4}\ \text{fm}^3$$

$$\alpha_E^{\Xi^-} \sim 2.1 \times 10^{-4}\ \text{fm}^3$$

Polarization in Hyperon Production

What is it? Found in 1976 at FNAL

$$p\,(300\ \mathrm{GeV}/c) + Be \to \vec{\Lambda} + X$$

General dependence on s, $x_F = \dfrac{p_\Lambda^{\parallel}}{p_P}$, p_Λ^T

Properties:

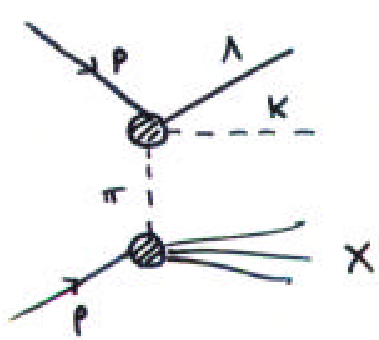
1) $E\, d^3\sigma/dp^3 = f(x_F, p_\Lambda^T)$

2) $\underset{\sim}{P} \cdot \underset{\sim}{\hat{p}}_{inc} \times \underset{\sim}{\hat{p}}_\Lambda < 0$

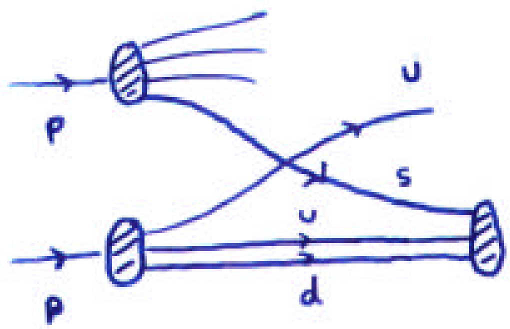
3) P independent of s

Various theoretical approaches

a) Reggeized Meson Exchange (Soffer + Törnqvist)



b) QUARK - PARTON APPROACH (DEGRAND & MIETTINEN)



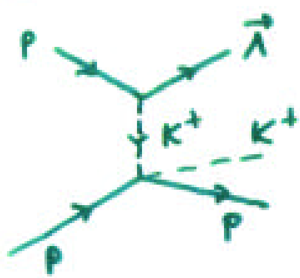
(THOMAS PRECESSION!)

ALSO RECENT NEAR THRESHOLD DATA FROM SATURNE

ON

$$\vec{p} + p \to p + \vec{\Lambda} + K^+$$

SHOWS DOMINANCE OF K^+ EXCHANGE



CONNECTION WITH $A_N > 0$ IN

$$\vec{p} + p \to \pi^+ + X$$

CONCLUSION

STILL MUCH TO STUDY (AND TO BE LEARNED!) ABOUT

STRONG

ELECTROMAGNETIC

WEAK

INTERACTION PROPERTIES OF

HYPERONS!

Nonleptonic Hyperon Decay

What is it? $\Lambda \to p\pi^-, n\pi^0$

$\Sigma^+ \to p\pi^0, n\pi^+$

$\Xi^- \to \Lambda\pi^-$

Describe via

$$\langle B'_\pi | \mathcal{H}_w | B\rangle = \bar{u}(p')\,(A + B\gamma_5)\,u(p)$$

S-wave ↵ ↳ P-wave

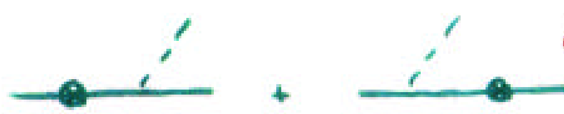
P-viol P-cons.

Issues: Longstanding Problem – S/P Wave

Theory: S-wave – $\langle \pi^a B' | \mathcal{H}_w | B\rangle = -\frac{i}{F_\pi}\langle B' | [F_a, \mathcal{H}_w] | B$

P-wave – Pole Model

SAME



BUT