RADIATIVE and NONLEPTONIC HYPERON DECAYS in BROKEN SU(3)

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Puzzle #1: „S:P problem in NLHD"

50 years old

parity violating – parity conserving amplitudes

Non-Leptonic Hyperon Decays ($\Sigma^+ \to p\pi^0$, etc.)

- **SU(3) amplitudes (f,d) -**

Experimental values (Donoghue, Golowich, Holstein (DGH) 1986 review) :

Parity viol. $f_S = 3.0 \times 10^{-5}$ MeV $d_S = -1.2 \times 10^{-5}$ MeV

Parity cons. $f_P = 4.7 \times 10^{-5}$ MeV $d_P = -2.6 \times 10^{-5}$ MeV

$d_P / d_S \approx 2.2$ $f_P / d_P \approx -1.8$ $f_S / d_S \approx -2.5$

- **Current algebra (CA), PCAC, soft-pion theorems (1960's):**

$f_S = f_P$

$d_S = d_P$ **?**

Puzzle #2: „large negative asymmetry in $\Sigma^+ \to p\gamma$"

40 years old

WRHD - Weak Radiative Hyperon Decays

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

A) Hara's theorem (1964):

"Parity-violating amplitude $D(\Sigma^+ \to p\gamma)$ must vanish in SU(3) limit"

For broken SU(3) (c.f. magnetic moments) **expect small asymmetry:**

$$|\alpha(\Sigma^+ \to p\gamma)| \sim 0.2$$

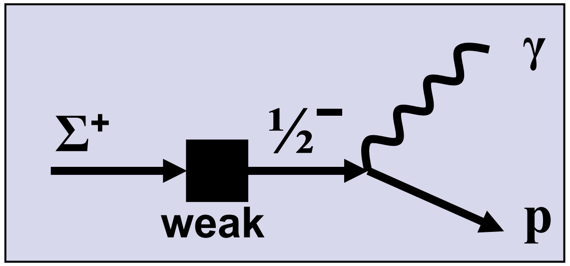
B) PDG now: $\alpha(\Sigma^+ \to p\gamma) = -0.76 \pm 0.08$

C) Theoretical conflicts between various approaches to parity-violating amplitudes

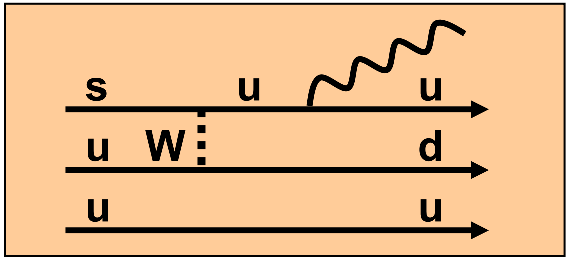
(no deep problems with parity conserving amplitudes)

Theoretical conflicts between various approaches to parity-violating amplitudes

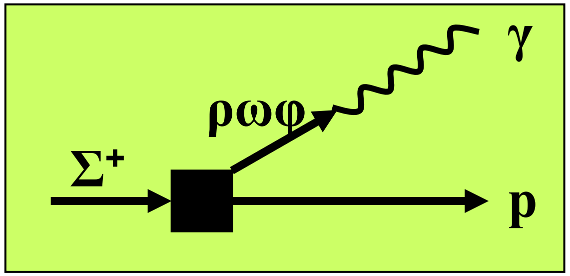
1) Hadron-level pole model (Gavela et al. 1981):
- agrees with Hara's theorem in SU(3) limit
Negative α ($\Sigma^+ \rightarrow p\gamma$) **~ − 0.8** for broken SU(3)



2) Simple quark model (Kamal Riazuddin 1983):
- violates Hara's theorem in SU(3) limit
Negative α ($\Sigma^+ \rightarrow p\gamma$) ~ − **0.6** for broken SU(3)



3) Hadron-level VMD+SU(6) model (P.Ż. 1989):
- violates Hara' theorem in SU(3) limit
Negative α ($\Sigma^+ \rightarrow p\gamma$) ~ − **0.9** for broken SU(3)



Experimental resolution of puzzle #2

NA48 – BEACH 2004

A) 1995 – J. Lach & P.Ż.: Status of Hara's theorem may be clarified through measurement of α ($\Xi^0 \to \Lambda\gamma$) asymmetry:

Process:	$\Sigma^+ \to p\gamma$	$\Lambda \to n\gamma$	$\Xi^0 \to \Lambda\gamma$	$\Xi^0 \to \Sigma^0\gamma$
Hara's - OK	– (0)	–	– 0.8	–
Hara's - viol.	–	+	+ 0.8	–

Large theory errors
Experimentally hard

Small theory errors: ± 0.15

B) 2004 – NA48, A.Lai et al..,Phys.Lett.B584,251(2004); BEACH 2004:

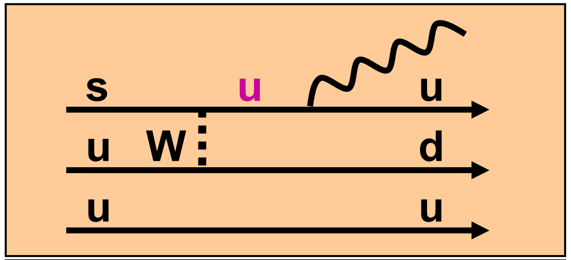
$$\alpha (\Xi^0 \to \Lambda\gamma) = -0.78 \pm 0.19$$

HARA OK

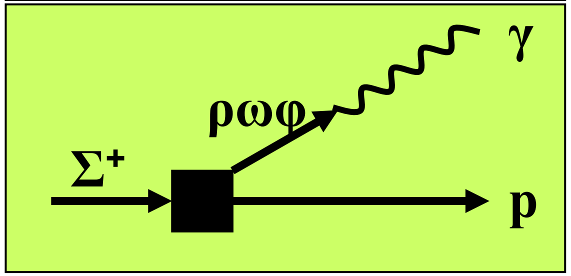
Theoretical resolution of puzzle #2

P.Ż. – BEACH 2002, Acta Phys. Pol. B34 (2003)

A) Quark model calculations violate confinement:
in SU(3) limit intermediate quark enters its mass shell
and propagates to infinity



B) VMD+SU(6) calculation violates proper connection between weak couplings of pseudoscalar and vector mesons:



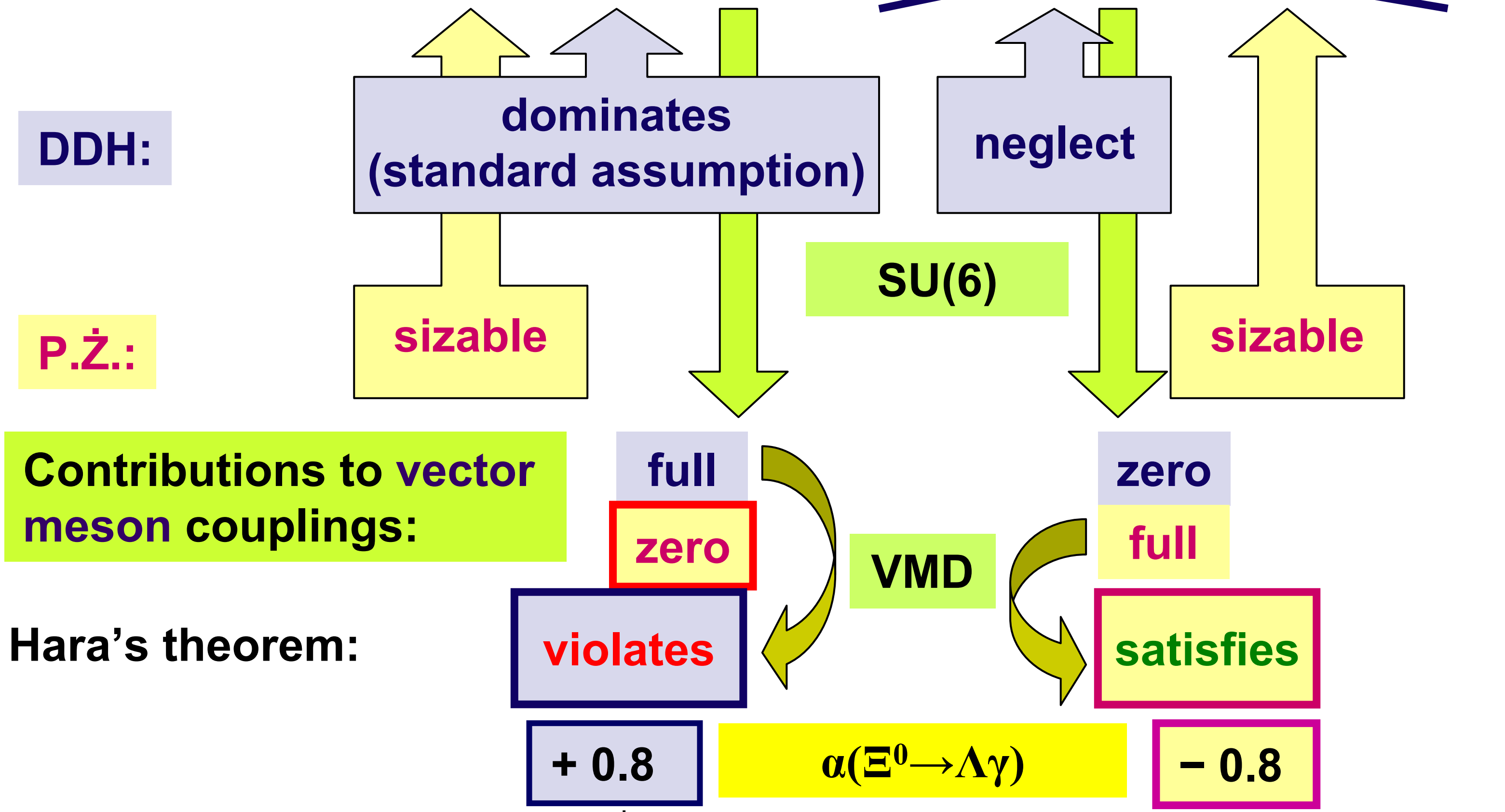
In VMD+SU(6) calculation (P.Ż.,1989)
weak parity-violating couplings of vector mesons to hyperons and nucleons evaluated from Non-Leptonic Hyperon Decays (pseudoscalar couplings)

as in Desplanques, Donoghue, Holstein (DDH,1980) calculations
of weak NNρ,... couplings (needed in nuclear parity violation)

„DDH” versus „non-soft pion ↔ vector meson”

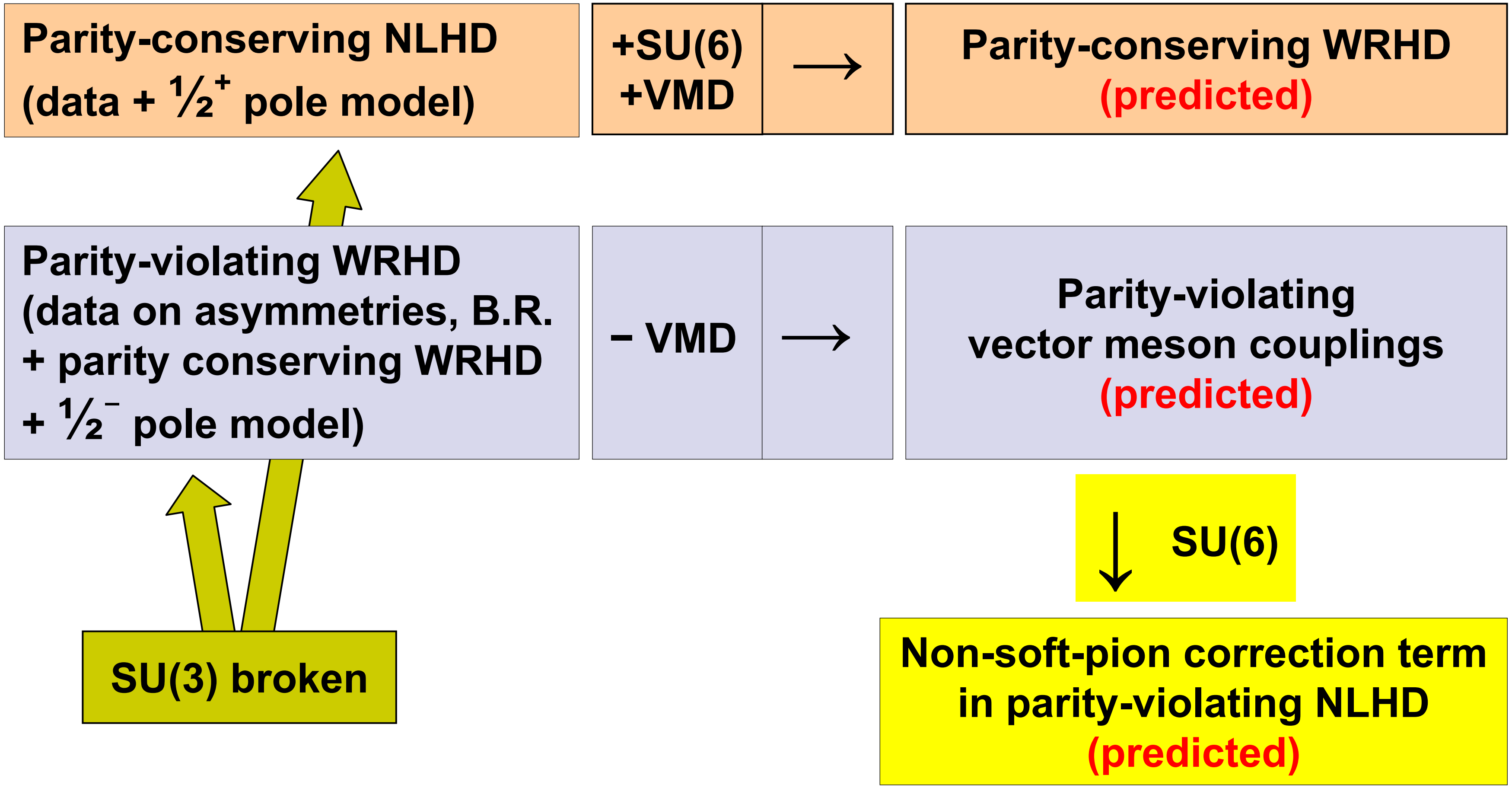
P.Ż. – BEACH 2002, Acta Phys. Pol. B34 (2003)

Par.viol. A(NLHD) = commutator term + ~~non-soft-pion correction term~~



NLHD & WRHD for broken SU(3)

P.Ż. – Phys. Rev. D73, 076005 (2006)



Parity- conserving amplitudes

NLHD → WRHD

details

$$B(\Sigma^+ \to p\pi^0) = \frac{1}{\sqrt{2}}\left(\frac{f_P}{d_P} - 1\right)\left(1 - \frac{F}{D}\right)N$$

$m_8 = 1130\,MeV$
$\Delta m_s = 190\,MeV$

$F = 0.44$
$D = 0.81$

$$N = \frac{2m_8}{F_\pi}\frac{Dd_P}{\Delta m_s}$$

$F_\pi = 94\,MeV$

...

	Σ^+_0	Σ^+_+	Σ^-_-	Λ^0_-	Ξ^-_-
data	26.6±1.3	42.4±0.4	-1.4±0.2	22.1±0.5	16.6±0.8
P.Ż.	28.6	41.3	0.9	18.8	15.4

P.Ż.
$d_P = -3\times10^{-5}$
$f_P = 5.8\times10^{-5}$

DGH review:
$d_P = -2.6\times10^{-5}$
$f_P = 4.7\times10^{-5}$
(kaon poles)

$$C(B_i \to B_f\gamma) = \frac{e}{g}\frac{1}{(m_i + m_f)\sqrt{2}}B(B_i \to B_f U^0)$$

...

***e/g* - VMD factor; *g* = 5.0**

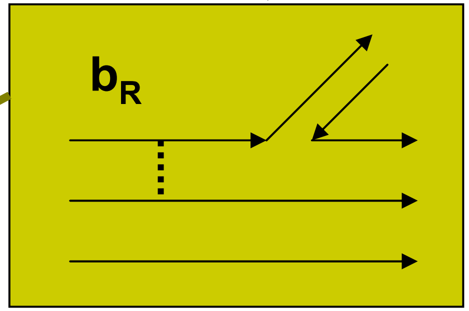
$$B(\Sigma^+ \to pU^0) = \sqrt{2}\left(\frac{f_P}{d_P} - 1\right)(\mu_{\Sigma+} - \mu_p)\frac{N}{\mu_p D}$$

Parity-violating amplitudes

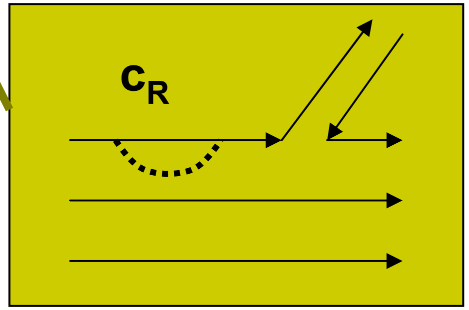
WRHD → Correction terms in NLHD (f_R, d_R)

$$D(B_i \to B_f \gamma) = \frac{e}{g}\frac{1}{(m_i - m_f)\sqrt{2}} A(B_i \to B_f U^0)$$

$$A(\Sigma^+ \to p U^0) = \frac{1}{9\sqrt{2}}\frac{6x + (1-\varepsilon)(1-x)}{1-x^2} b_R + \frac{1}{3\sqrt{2}} s_R$$



s_R contains c_R



$$x = \frac{\Delta m_s}{\Delta \omega} \approx \frac{190\ MeV}{570\ MeV} \approx \frac{1}{3}$$

ε – additional SU(3) breaking
(as in magnetic moments)

Data on B.R. & asymmetries
+ parity conserving WRHD amplitudes

→ $b_R \approx +5.3 \times 10^{-7}$
$s_R \approx -0.75 \times 10^{-7}$

B.R. ($\Xi^- \to \Sigma^- \gamma$) small

$b = 4d/F_\pi$
$c = 6(f+d)/F_\pi$

$c_R \approx 0$ → Corections f_R, d_R to f_S, d_S

Results

20% errors at amplitude level

Branching ratios

	data	this approach
$\Sigma^+ \to p\gamma$	1.23±0.05	0.72
$\Lambda \to n\gamma$	1.75±0.15	0.77
$\Xi^0 \to \Lambda\gamma$	1.16±0.08	1.02
$\Xi^0 \to \Sigma^0\gamma$	3.33±0.10	4.42
$\Xi^- \to \Sigma^-\gamma$	0.127±0.023	0.16

Sensitive to SU(3) breaking in par.cons. amplitudes

uncertain

reliable

Asymmetries

	data	this approach
$\Sigma^+ \to p\gamma$	−0.76±0.08	−0.67
$\Lambda \to n\gamma$		−0.93
$\Xi^0 \to \Lambda\gamma$	−0.78±0.19	−0.97
$\Xi^0 \to \Sigma^0\gamma$	−0.63±0.09	−0.92
$\Xi^- \to \Sigma^-\gamma$	+ 1.0±1.3	+0.80

Resolution of PUZZLE #2

Coefficients at b_R (relative size of two-quark contribution)

	SU(3) $x=0, \varepsilon=1$	SU(3) broken $x=1/3, \varepsilon=2/3$
$\Sigma^+ \to p\gamma$	0	0.196
$\Lambda \to n\gamma$	0.192	0.048
$\Xi^0 \to \Lambda\gamma$	−0.192	−0.128
$\Xi^0 \to \Sigma^0\gamma$	−0.333	−0.5

Resolution of puzzle #2 (S:P in NLHD)

Commutator contribution in p.v. only:

$f_S = f_P$
$d_S = d_P$

⇔

$b_S = b_P$
$c_S = c_P$

→ (in units of 10^{-7})
$-5 \approx -11.1$
$12 \approx 13.4$

With non-soft pion contribution →

$b_S = b_P + b_R/(1+x)$
$c_S \approx c_P$

→ With $x = 1/3$
(in units of 10^{-7})
$-5 \approx -6.6$
$12 \approx 13.4$

If $x: \approx 0$
$d_P/d_S \approx 2$
$f_P/d_P \approx -1.8$
$f_S/d_S \approx -2.6$

Differences between S and P waves mainly from two-quark contributions

Conclusions:

simultaneous description of WRHD and NLHD

in SU(3)-breaking VMD model

Commutator + non-soft-pion correction

All WRHD described
In particular:
large negative $\Sigma^{+} \rightarrow p\,\gamma$ asymmetry
through SU(3) breaking

Simultaneous resolution
of the dominant part
of the S:P problem in NLHD

Questions:
relation to nuclear parity-violation
(Desplanques, Donoghue, Holstein paper)