Baryoner (qqq) och Antibaryoner ($\bar{q}\bar{q}\bar{q}$)

$\Psi_{spin} \longrightarrow SU(2)$ för qqq ?

$\Psi_{flavour} \longrightarrow SU(3)$ för qqq ?

$\Psi_{colour} \longrightarrow SU(3)$ för qqq ?

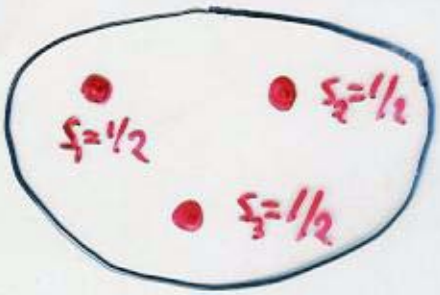
Baryonens

Ψ_{spinn} - SU(2)

Spinn upp = $\Psi^{1/2}_{1/2} = |\frac{1}{2}\ \frac{1}{2}\rangle = \alpha = \uparrow = \Psi_u$

Spinn ner = $\Psi^{1/2}_{-1/2} = |\frac{1}{2}\ -\frac{1}{2}\rangle = \beta = \downarrow = \Psi_d$

Baryonens spinn SU(2)



Vad är baryonens spinnvågfunktion förutsatt att man vet att den består av tre kvarkar med spinn = ½?

$S_1 = \frac{1}{2}$ $S_2 = \frac{1}{2}$ $S_3 = \frac{1}{2}$

Två kvarkar: $S_{12} = S_1 + S_2, \ldots |S_1 - S_2| = \begin{cases} 0 & S_z = -S \ldots S = 0 \\ 1 & S_z = -S \ldots S = -1, 0, 1 \end{cases}$

Tre kvarkar: $S = S_{12} + S_3 \ldots |S_{12} - S_3| = \begin{cases} \frac{1}{2} & S_z = -S \ldots S = -\frac{1}{2}, \frac{1}{2} \\ \frac{1}{2} & S_z = -S \ldots S = -\frac{1}{2}, \frac{1}{2} \\ \frac{3}{2} & S_z = -S \ldots S = -\frac{3}{2}, -\frac{1}{2}, \frac{1}{2}, \frac{3}{2} \end{cases}$

Två kvarkar: (Mesoner)

$$\psi^A_{spin} = |S\ S_z\rangle_{1\,2} = |0\ 0\rangle_{1\,2} = \frac{1}{\sqrt{2}}(\alpha\beta - \beta\alpha)$$ } Antisymmetrisk SU(2) singlett

$$\psi^S_{spin} = \begin{cases} |1\ -1\rangle_{1\,2} = \beta\beta \\ |1\ 0\rangle_{1\,2} = \frac{1}{\sqrt{2}}(\alpha\beta + \beta\alpha) \\ |1\ 1\rangle_{1\,2} = \alpha\alpha \end{cases}$$ } Symmetrisk SU(2) triplett

Tre kvarkar: (Baryoner)

$$\psi^{MA}_{spin} = \begin{cases} |\frac{1}{2}\ \frac{1}{2}\rangle_{1\,2\,3} = \frac{1}{\sqrt{12}}(\alpha\beta\alpha - \beta\alpha\alpha) \\ |\frac{1}{2}\ -\frac{1}{2}\rangle_{1\,2\,3} = \frac{1}{\sqrt{12}}(\alpha\beta\beta - \beta\alpha\beta) \end{cases}$$ } Mixed antisymmetrisk SU(2) dublett

$$\psi^{MS}_{spin} = \begin{cases} |\frac{1}{2}\ \frac{1}{2}\rangle = \frac{1}{\sqrt{6}}(\alpha\beta\alpha + \beta\alpha\alpha - 2\alpha\alpha\beta) \\ |\frac{1}{2}\ -\frac{1}{2}\rangle = \frac{1}{\sqrt{6}}(\alpha\beta\beta + \beta\alpha\beta - 2\beta\beta\alpha) \end{cases}$$ } Mixed symmetrisk SU(2) dublett

$$\psi^S_{spin} = \begin{cases} |\frac{3}{2}\ \frac{3}{2}\rangle = \alpha\alpha\alpha \\ |\frac{3}{2}\ \frac{1}{2}\rangle = \frac{1}{\sqrt{3}}(\alpha\alpha\beta + \alpha\beta\alpha + \beta\alpha\alpha) \\ |\frac{3}{2}\ -\frac{1}{2}\rangle = \frac{1}{\sqrt{3}}(\beta\beta\alpha + \beta\alpha\beta + \alpha\beta\beta) \\ |\frac{3}{2}\ -\frac{3}{2}\rangle = \beta\beta\beta \end{cases}$$ } Symmetrisk SU(2) kvartett

Mesoner har spinn 0 eller 1 !

Baryoner har spinn $\frac{1}{2}$ eller $\frac{3}{2}$!

Baryonens

Ψ_{flavour} - $SU(3)$

$I \; I_3 \; Y$

flavour up = $|\frac{1}{2} \; \frac{1}{2} \; \frac{1}{3}\rangle$ = u

flavour down = $|\frac{1}{2} \; -\frac{1}{2} \; \frac{1}{3}\rangle$ = d

flavour strange = $|0 \; 0 \; -\frac{2}{3}\rangle$ = s

	I	I_3	Y			
Symmetrisk SU(3) dekuplett	$\frac{3}{2}$	$\frac{3}{2}$	1	$\rangle = uuu$	$\otimes \psi^{sym}_{S=3/2} \Rightarrow$	Δ^{++}
	$\frac{3}{2}$	$\frac{1}{2}$	1	$\rangle = \frac{1}{\sqrt{3}}(duu+udu+uud)$		Δ^{+}
	$\frac{3}{2}$	$-\frac{1}{2}$	1	$\rangle = \frac{1}{\sqrt{3}}(ddu+udd+dud)$		Δ^{0}
	$\frac{3}{2}$	$-\frac{3}{2}$	1	$\rangle = ddd$		Δ^{-}
	1	1	0	$\rangle = \frac{1}{\sqrt{3}}(uus+suu+usu)$		Σ^{*+}
	1	0	0	$\rangle = \frac{1}{\sqrt{6}}(dsu+uds+sud+sdu+dus+usd)$		Σ^{*0}
	1	-1	0	$\rangle = \frac{1}{\sqrt{3}}(dds+sdd+dsd)$		Σ^{*}
	$\frac{1}{2}$	$\frac{1}{2}$	-1	$\rangle = \frac{1}{\sqrt{3}}(ssu+ssu+uss)$		Ξ^{*+}
	$\frac{1}{2}$	$-\frac{1}{2}$	-1	$\rangle = \frac{1}{\sqrt{3}}(dss+sds+ssd)$		Ξ^{*-}
	0	0	-2	$\rangle = sss$		Ω^{-}
Antisymmetrisk SU(3) singlett	0	0	0	$\rangle = \frac{1}{\sqrt{6}}(dsu+uds+sud-usd-sdu-dus)$		Λ^{0}_{1}
Mixed symmetrisk SU(3) oktett	$\frac{1}{2}$	$\frac{1}{2}$	1	$\rangle = \frac{1}{\sqrt{6}}(udu+duu-2uud)$,	$\frac{1}{\sqrt{2}}(udu-duu)$	p
	$\frac{1}{2}$	$-\frac{1}{2}$	1	$\rangle = -\frac{1}{\sqrt{6}}(udd+dud-2ddu)$,	$\frac{1}{\sqrt{2}}(udd-dud)$	n
	1	1	0	$\rangle = \frac{1}{\sqrt{6}}(usu+suu-2uus)$,	$\frac{1}{\sqrt{2}}(usu-suu)$	Σ^{+}
	1	0	0	$\rangle = \frac{1}{\sqrt{12}}(sdu+sud+dsu+usd-2dus-2uds)$,	$\frac{1}{\sqrt{4}}(dsu-usd-sud-sdu)$	Σ^{0}
Mixed antisymmetrisk SU(3) oktett	1	-1	0	$\rangle = \frac{1}{\sqrt{6}}(dsd+sdd-2dds)$,	$\frac{1}{\sqrt{2}}(dsd-sdd)$	Σ^{-}
	$\frac{1}{2}$	$\frac{1}{2}$	-1	$\rangle = \frac{1}{\sqrt{6}}(uss+sus-2ssu)$,	$\frac{1}{\sqrt{2}}(uss-sus)$	Ξ^{+}
	$\frac{1}{2}$	$-\frac{1}{2}$	-1	$\rangle = -\frac{1}{\sqrt{6}}(dss+sds-2ssd)$,	$\frac{1}{\sqrt{2}}(dss-sds)$	Ξ^{-}
	0	0	0	$\rangle = \frac{1}{\sqrt{12}}(dsu-usd+sdu-sud)$,	$\frac{1}{\sqrt{12}}(sdu-sud+usd-dsu-2dus-2uds)$	Λ^{0}_{2}

$\otimes \begin{cases} \psi^{M.anti}_{S=1/2} \\ \psi^{M.symm}_{S=1/2} \end{cases} \Rightarrow$

Hur kombineras spinnvågfunktionerna med flavourvågfunktionerna?

Mesoner:

Pseudoskalärmesoner (0^-): $\psi^A = \psi^A_{S=0} \cdot \psi^S_{flavour}$

Vektormesoner (1^-): $\psi^A = \psi^S_{S=1} \cdot \psi^A_{flavour}$

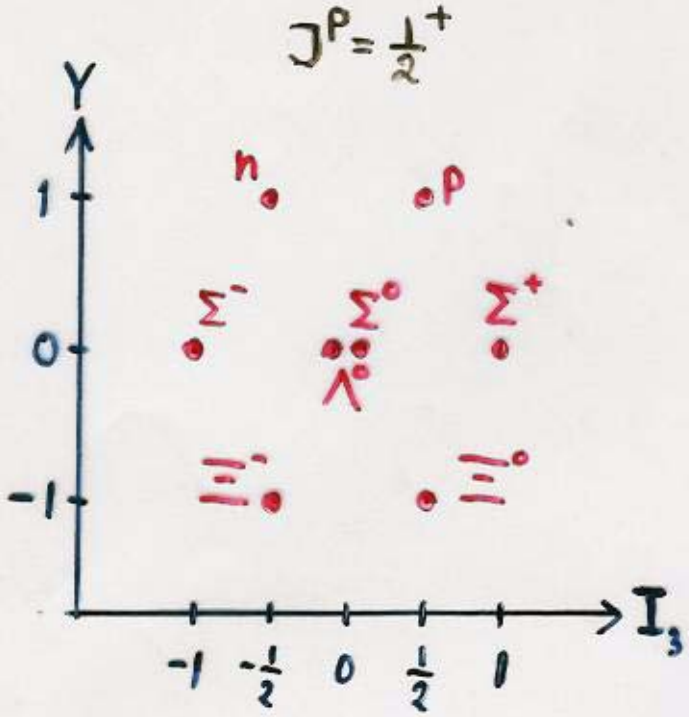
Skalärmesoner (0^+): $\psi^S = \psi^A_{S=0} \cdot \psi^A_{flavour}$

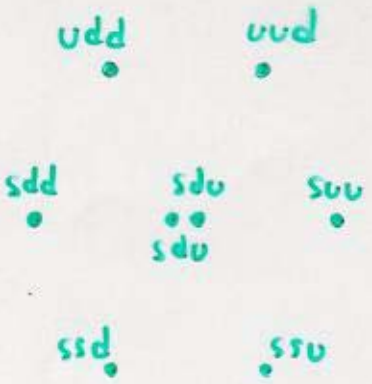
Axialvektormesoner (1^+): $\psi^S = \psi^S_{S=1} \cdot \psi^S_{flavour}$

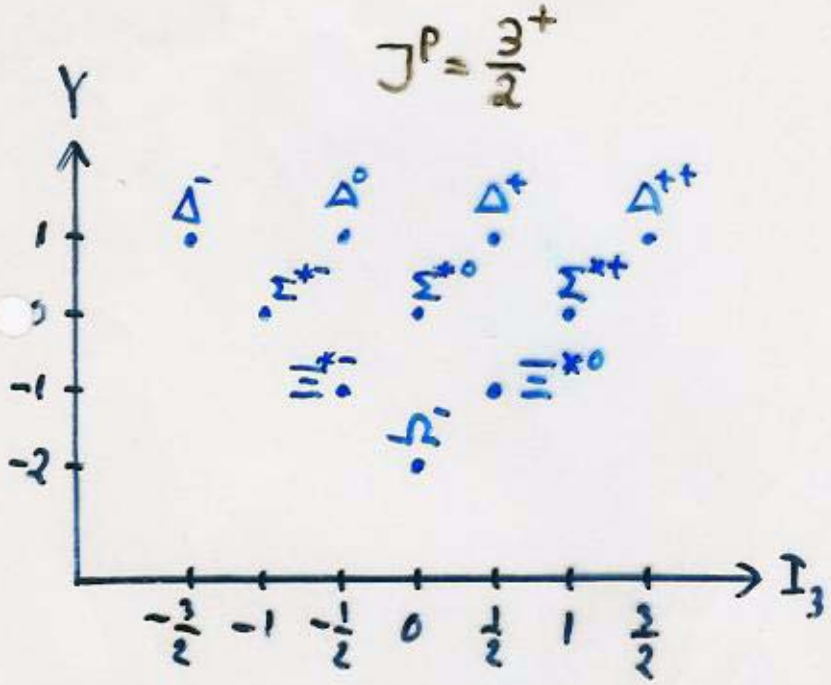
Baryoner:

$\Delta, \Sigma^*, \Xi^*, \Omega$ $\left(\frac{3}{2}^+\right)$: $\psi^S = \psi^S_{S=3/2} \cdot \psi^S_{flavour}$

$p, n, \Sigma, \Xi, \Lambda$ $\left(\frac{1}{2}^+\right)$: $\psi^S = \frac{1}{\sqrt{2}}\left(\psi^{M.S.}_{S=1/2}\,\psi^{M.S}_{flavour} + \psi^{M.A.}_{S=1/2} \cdot \psi^{M.A.}_{flavour}\right)$



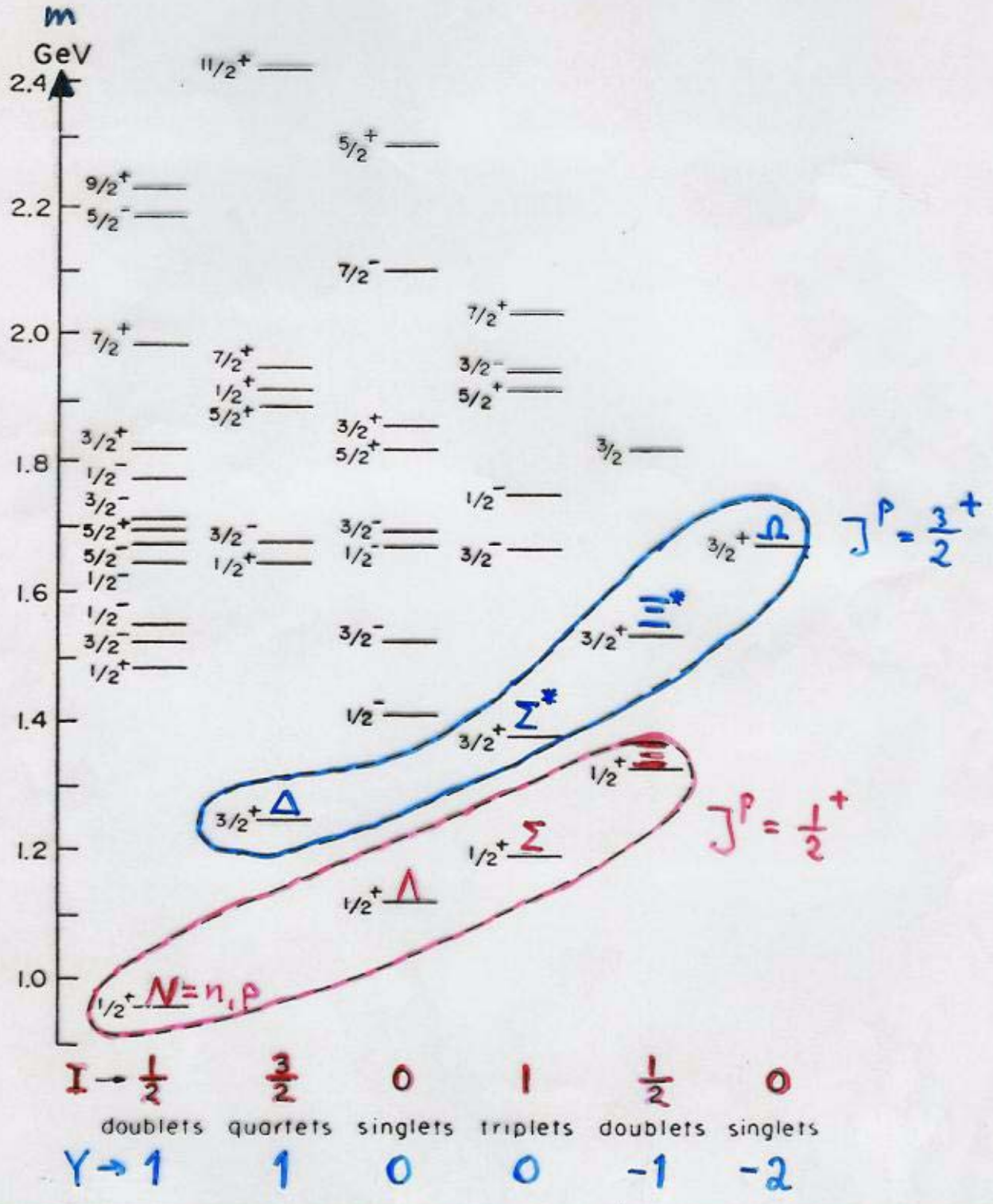




$Y = B + S$

$SU(3)_{flavour}$

Baryon Spectrum



Protonen är den enda baryonen som är fullständigt stabil och alla andra baryoner sönderfaller till protoner, leptoner och fotoner.

Exempel:

$\Sigma^+ \longrightarrow n + \pi^+$ 48%

$\hookrightarrow \mu^+ + \nu_\mu$ 100%

$n \hookrightarrow p + e^- + \bar{\nu}_e$ 100%

Baryonens

Ψ_{colour} - $SU(3)$

$I^c \; I_3^c \; Y^c$

colour red = $|\frac{1}{2} \; \frac{1}{2} \; \frac{1}{3}\rangle = r$

colour green = $|\frac{1}{2} \; -\frac{1}{2} \; -\frac{1}{3}\rangle = g$

colour blue = $|0 \; 0 \; -\frac{2}{3}\rangle = b$

$SU(3)_{colour}$

Kvarkar:

$I^c \; I_3^c \; Y^c$

$$\Psi_{colour} = \begin{cases} |\tfrac{1}{2}\ \tfrac{1}{2}\ \tfrac{1}{3}\rangle = r \\ |\tfrac{1}{2}\ -\tfrac{1}{2}\ -\tfrac{1}{3}\rangle = \bar{r} \\ |\tfrac{1}{2}\ -\tfrac{1}{2}\ \tfrac{1}{3}\rangle = g \\ |\tfrac{1}{2}\ \tfrac{1}{2}\ -\tfrac{1}{3}\rangle = \bar{g} \\ |0\ 0\ -\tfrac{2}{3}\rangle = b \\ |0\ 0\ \tfrac{2}{3}\rangle = \bar{b} \end{cases}$$

Gluoner:

$$\Psi_{colour} = \begin{cases} |1\,0\,0\rangle = \frac{1}{\sqrt{2}}(g\bar{g} - \bar{r}r) \\ |1\,1\,0\rangle = r\bar{g} \\ |1\,-1\,0\rangle = \bar{r}g \\ |\tfrac{1}{2}\ \tfrac{1}{2}\ 1\rangle = r\bar{b} \\ |\tfrac{1}{2}\ -\tfrac{1}{2}\ 1\rangle = g\bar{b} \\ |\tfrac{1}{2}\ -\tfrac{1}{2}\ -1\rangle = \bar{r}b \\ |\tfrac{1}{2}\ \tfrac{1}{2}\ -1\rangle = \bar{g}b \\ |0\,0\,0\rangle = \frac{1}{\sqrt{6}}(g\bar{g} - r\bar{r} - 2b\bar{b}) \end{cases}$$

Mesoner:

$$\Psi_{colour} = |0\,0\,0\rangle = \frac{1}{\sqrt{3}}(r\bar{r} + g\bar{g} + b\bar{b})$$

Baryoner:

$$\Psi_{colour} = |0\,0\,0\rangle = \frac{1}{\sqrt{6}}(rgb + brg + gbr - grb - bgr - rbg)$$

Stable Particle Table *(cont'd)*

Particle	$I^G(J^P)C$ [a]	Mass [b] (MeV)	Mean life [b] (sec) $c\tau$ (cm)	Partial decay mode: Mode	Fraction [b]	p or p_{max} [c] (MeV/c)
				$\tau^- \rightarrow$ (or $\tau^+ \rightarrow$ chg. conj.)		
τ (continued)				†[$K^{*-}(892)\nu$	(1.7 ± 0.7)%	669
				$K^{*-}(1430)\nu$	(<0.9)%	323
				$\pi^-\rho^0\nu$	(5.4 ± 1.7)%]	718
				e^- chgd.parts.		
				$+ \mu^-$ chgd.parts.	(<4)%	
				$\mu^-\gamma$	(<5.5)$\times 10^{-4}$	889
				$e^-\gamma$	(<6.4)$\times 10^{-4}$	892
				$\mu^-\mu^+\mu^-$	(<4.9)$\times 10^{-4}$	876
				$e^-\mu^+\mu^-$	(<3.3)$\times 10^{-4}$	886
				$\mu^-e^+e^-$	(<4.4)$\times 10^{-4}$	889
				$e^-e^+e^-$	(<4.0)$\times 10^{-4}$	892
				$\mu^-\pi^0$	(<8.2)$\times 10^{-4}$	884
				$e^-\pi^0$	(<2.1)$\times 10^{-3}$	887
				μ^-K^0	(<1.0)$\times 10^{-3}$	819
				e^-K^0	(<1.3)$\times 10^{-3}$	823
				$\mu^-\rho^0$	(<4.4)$\times 10^{-4}$	722
				$e^-\rho^0$	(<3.7)$\times 10^{-4}$	726

→ searches for massive neutrinos and lepton mixing
→ ν bounds from astrophysics and cosmology
→ heavy lepton searches

NONSTRANGE MESONS [a]

				$\pi^+ \rightarrow$ (or π^- →chg. conj.)			
$\pi^\pm$	$1^-(0^-)$	139.5673 ±0.0007	2.6030×10^{-8} ±0.0023	$\mu^+\nu$	100%		30
			$c\tau$=780.4	$e^+\nu$	(*1.232±0.024*)$\times 10^{-4}$	S=2.0*	70
	$m_{\pi^\pm}-m_{\mu^\pm}$	-33.9080 ±0.0008		†[$\mu^+\nu\gamma$	(1.24 ± 0.25)$\times 10^{-4}$		30
				$e^+\nu\gamma$	(5.6 ± 0.7)$\times 10^{-8}$]		70
				$e^+\nu\pi^0$	(1.033±0.034)$\times 10^{-8}$		5
				$e^+\nu e^+e^-$	(<5)$\times 10^{-9}$		70
				$\mu^+\bar{\nu}_e$	(*<1.5*)$\times 10^{-3}$		30
				$\mu^+\nu_e$	(*<8*)$\times 10^{-3}$		30
π^0	$1^-(0^-)+$	134.9630 ±0.0038	0.83×10^{-16} ±0.06 S=1.8*	$\gamma\gamma$	(98.802 ±0.030)%		67
			$c\tau=2.5\times10^{-6}$	γe^+e^-	(1.198)%		67
				$\gamma\gamma\gamma$	(<3.8)$\times 10^{-7}$		67
				$e^+e^-e^+e^-$	(3.24)$\times 10^{-5}$		67
				$\gamma\gamma\gamma\gamma$	(<4)$\times 10^{-6}$		67
				e^+e^-	(1.8 ± 0.7)$\times 10^{-7}$		67
				$\nu\nu$	(<2.4)$\times 10^{-5}$		67
	$m_{\pi^\pm}-m_{\pi^0}$	-4.6043 ±0.0037		$\mu^+e^- + \mu^-e^+$	(<7)$\times 10^{-8}$		26
η	$0^+(0^-)+$	548.8 ±0.6 S=1.4*	Γ=(0.88±0.12)keV	$\gamma\gamma$	(39.0 ± 0.8)%		274
			Neutral decays (70.9±0.7)%	$3\pi^0$	(31.8 ± 0.8)%	S=1.1*	180
				$\pi^0\gamma\gamma$	(0.10 ± 0.02)%		258
				$\pi^+\pi^-\pi^0$	(23.7 ± 0.5)%		175
				$\pi^+\pi^-\gamma$	(4.91± 0.13)%		236
				$e^+e^-\gamma$	(0.50± 0.12)%		274
				$\mu^+\mu^-\gamma$	(3.1 ± 0.4)$\times 10^{-4}$		253
				e^+e^-	(<3)$\times 10^{-4}$		274
				$\mu^+\mu^-$	(6.5 ± 2.1)$\times 10^{-6}$		253
			Charged decays (29.1±0.7)%	$\pi^+\pi^-e^+e^-$	(0.13± 0.13)%		236
				$\pi^+\pi^-\gamma\gamma$	(<0.21)%		236
				$\pi^+\pi^-\pi^0\gamma$	(<6)$\times 10^{-4}$		175
				$\pi^+\pi^-$	(<0.15)%		236
				$\pi^0e^+e^-$	(<5)$\times 10^{-5}$		258
				$\pi^0\mu^+\mu^-$	(<5)$\times 10^{-6}$		211
				$\pi^0\mu^+\mu^-\gamma$	(<3)$\times 10^{-6}$		211

Stable Particle Table *(cont'd)*

Particle	$I^G(J^P)$ [a]	Mass [b] (MeV)	Mean life [b] (sec) $c\tau$ (cm)	Partial decay mode: Mode	Fraction [b]	p or p_{max} [c] (MeV/c)
BOTTOM MESONS [a]						
B^+	$\frac{1}{2}(0^-)$ [n]	5270.8 ±3.0		B^+ → (or B^- → chg. conj.)		
				$\bar{D}^0\pi^+$	(4.2 ± 4.2)%	2303
				$D^{*-}\pi^+\pi^+$	(4.8 ± 3.0)%	2243
B^0 / $\bar{B}^0$	$\frac{1}{2}(0^-)$ [n]	5274.2 ±2.8		B^0 → (or $\bar{B}^0$ → chg. conj.)		
				$\bar{D}^0\pi^+\pi^-$	(13 ± 9)%	2298
				$D^{*-}\pi^+$	(2.6 ± 1.9)%	2253
$B^\pm, B^0, \bar{B}^0$ (not separated) [p]			$(14\pm4)\times10^{-13}$ $c\tau$=0.042	$e^\pm\nu$ hadrons	(13.0 ± 1.3)%	
				$\mu^\pm\nu$ hadrons	(12.4 ± 3.5)%	
				D^0 anything	(80 ±28)%	
				K anything	(seen)	
				p anything	(>3.6)%	
				Λ anything	(>2.2)%	
				e^+e^- anything	(<0.8)%	
				$\mu^+\mu^-$ anything	(<0.7)%	
NONSTRANGE BARYONS [a]						
p	$\frac{1}{2}(\frac{1}{2}^+)$	938.2796 ±0.0027	stable ($>10^{32}$y) [q]	stable		
				$\lvert q_p\rvert - \lvert q_e\rvert < 10^{-21}\lvert q_e\rvert$ [r]		
n	$\frac{1}{2}(\frac{1}{2}^+)$	939.5731 ±0.0027	898±16 $c\tau$=2.7×10^{13}	$pe^-\bar{\nu}$	100%	1.2
				$p\nu\bar{\nu}$ (chg.noncons.)	(<9)$\times10^{-24}$	1.3
	$m_p - m_n = -1.293323$ ±0.000016			$\lvert q_n\rvert < 10^{-21}\lvert q_e\rvert$ [r]		
STRANGENESS −1 BARYONS [a]						
Λ	$0(\frac{1}{2}^+)$	1115.60 ±0.05 S=1.2*	2.632×10^{-10} ±0.020 S=1.6* $c\tau$=7.89	$p\pi^-$	(64.2)%	100
				$n\pi^0$	(35.8 ± 0.5)%	104
				$pe^-\nu$	(8.37± 0.14)$\times10^{-4}$	163
				$p\mu^-\nu$	(1.57± 0.35)$\times10^{-4}$	131
				†[$p\pi^-\gamma$	[q] (8.5 ± 1.4)$\times10^{-4}$]	100
	$m_\Lambda - m_{\Sigma^0} = -76.86$ ±0.08					
Σ^+	$1(\frac{1}{2}^+)$	1189.36 ±0.06 S=1.8*	0.800×10^{-10} ±0.004 $c\tau$=2.40	$p\pi^0$	(51.64)%	189
				$n\pi^+$	(48.36± 0.30)%	185
				$p\gamma$	(1.20± 0.13)$\times10^{-3}$ S=1.2*	225
				†[$n\pi^+\gamma$	[q] (4.5 ± 0.5)$\times10^{-4}$]	185
				$\Lambda e^+\nu$	(2.0 ± 0.5)$\times10^{-5}$	71
	$m_{\Sigma^+} - m_{\Sigma^-} = -7.97$ ±0.07 S=1.3*		$\frac{\Gamma(\Sigma^+\to\ell^+n\nu)}{\Gamma(\Sigma^-\to\ell^-n\nu)} < .04$	$n\mu^+\nu$	(<3.0)$\times10^{-5}$	202
				$ne^+\nu$	(<5)$\times10^{-6}$	224
				pe^+e^-	(<7)$\times10^{-6}$	225
Σ^0	$1(\frac{1}{2}^+)$ [s]	1192.46 ±0.08	5.8×10^{-20} ±1.3 $c\tau$=1.7×10^{-9}	$\Lambda\gamma$	100%	74
				Λe^+e^-	[f] (5.45)$\times10^{-3}$	74
				$\Lambda\gamma\gamma$	(<3)%	74
Σ^-	$1(\frac{1}{2}^+)$	1197.34 ±0.05	1.482×10^{-10} ±0.011 S=1.3* $c\tau$=4.44	$n\pi^-$	100%	193
				$ne^-\nu$	(*1.022±0.034*)$\times10^{-3}$	230
				$n\mu^-\nu$	(4.5 ± 0.4)$\times10^{-4}$	210
				$\Lambda e^-\nu$	(5.74± 0.27)$\times10^{-5}$	79
	$m_{\Sigma^0} - m_{\Sigma^-} = -4.88$ ±0.06			†[$n\pi^-\gamma$	[q] (4.6 ± 0.6)$\times10^{-4}$]	193