SECTION 9

Slide 7

Fermi Theory of ν scattering $\sigma_{Fermi} = \frac{G_F^2 s}{\pi}$ (Appx F)

Use partial wave expansion to calculate maximum possible σ for any particles scattering (CM frame)
max Happens when probability $\equiv 1$

$$\sigma_{max} \sim \frac{4\pi}{E^2} = \frac{16\pi}{s}$$

$E_{cm} = 2E$
$s = 4E^2$

Unitarity violated when $\sigma_F > \sigma_{max}$

$$s = \frac{4\pi}{G_F}$$

$\sqrt{s} \sim 1\,TeV$
$E_\nu \sim 500\,GeV$

Any theory that predicts σ grows with E is a low-energy effective theory

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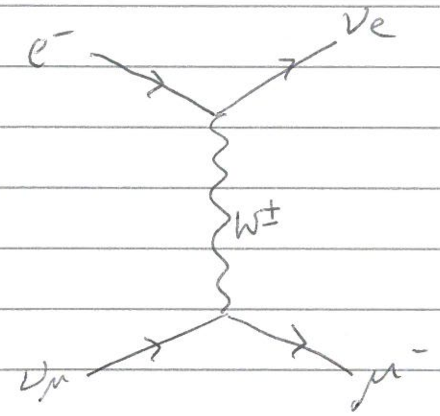

Propagator $\sim \frac{1}{q^2 - M_W^2}$

low energies $q^2 \ll M_W^2$

Propagator $\sim \frac{1}{-M_W^2}$

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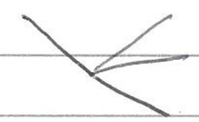
so at low energies



$|M| \sim G_F$

$|M| \sim \frac{g_W^2}{q^2 - M_W^2}$ ($q^2 \sim 0$)

$$G_F \sim \frac{g_W^2}{-M_W^2}$$

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Fermi theory

$\sigma \sim \frac{G_F^2 s}{\pi}$

Weak CC + adding in a massive propagator

$\sigma = \frac{G_F^2 M_W^2 s}{\pi (M_W^2 + s)}$

low energy $s \ll M_W^2$ $\sigma \sim \frac{G_F^2 s}{\pi}$

high energy $s \gg M_W^2$ $\sigma \sim \frac{G_F^2 M_W^2}{\pi}$

$\sigma \sim$ constant at high energy!

$\Rightarrow$ well behaved

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Total. ang. mom $J = |L-S| \ldots |L+S|$ <u>conserved</u>

($|L-S|$: $\vec{r} \times \vec{p}$; any direction relative to $\vec{p}$)

<u>BUT</u> the projection of S along $\vec{p}$ must be constant

HELICITY must be conserved

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$n \rightarrow p + e^- + \bar{\nu}_e$

p remains at rest

e^- & $\bar{\nu}_e$ back-to-back

$e^- \longleftarrow \bullet \longrightarrow \bar{\nu}_e$

Expect $\vec{S} \rightarrow$ (LH) $\vec{S} \rightarrow$ (RH)

and $\vec{S} \leftarrow$ (RH) $\vec{S} \leftarrow$ (LH)

but this <u>NEVER</u> happens!

So if helicity is not conserved, J is not conserved

To conserve J, L must change

$\therefore$ parity changes in weak int.

$\hat{J}$ is a <u>stronger</u> conservation than $\hat{P}$

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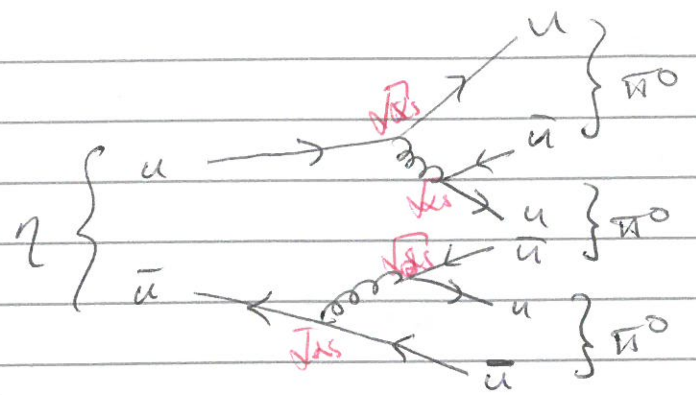
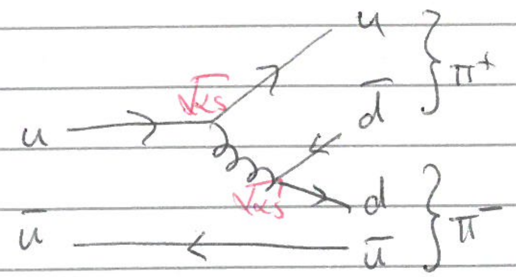
$\eta \rightarrow \pi^0 \pi^0 \pi^0$



BR = 32%

	Initial state	Final state	
J^P	0^-	$0^-0^-0^-$	
P	-1	$(-1)(-1)(-1)(-1)^{L_{12}+L_3}$	even L
J	0 + 0	$\|L \pm 0\| \ldots \|L+0\|$	$\Rightarrow L = 0 = L_{12} = L_3$

$\eta \rightarrow \pi^+ \pi^-$



BR < 0.1%

	Initial	Final	
J^P	0^-	0^-0^-	
P	-1	$(-1)(-1)(-1)^L$	- L needs to be odd
J	0+0	$\|L \pm 0\| \ldots \|L+0\|$	L needs to be 0 to conserve J

$\Rightarrow$ Parity violated

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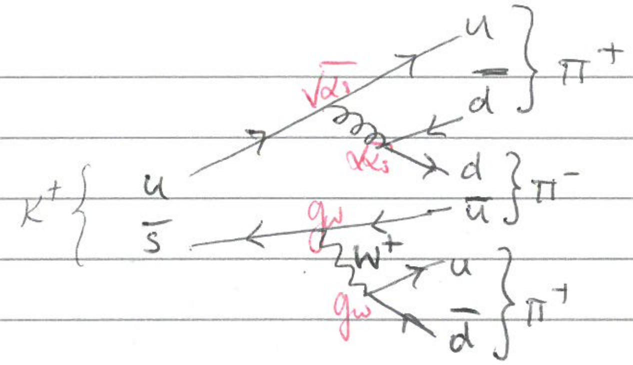
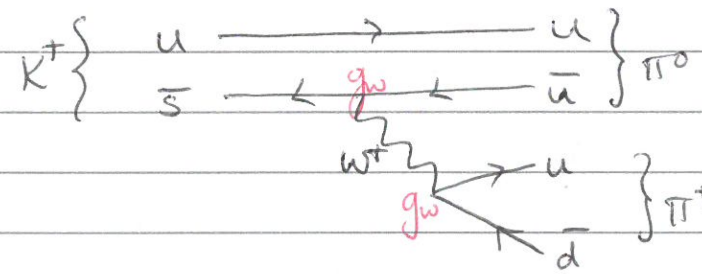
$K^+ \rightarrow \pi^+ \pi^- \pi^+$



BR ~ 6%

	Initial	Final	
J^P	0^-	$0^-0^-0^-$	
P	-1	$(-1)(-1)(-1)(-1)^{L_{12}+L_3}$	L even
J	0+0	$\|L \pm 0\| \ldots \|L+0\|$	$\Rightarrow L = 0$

$K^+ \rightarrow \pi^+ \pi^0$



BR ~ 21%

	Initial	Final	
J^P	0^-	0^-0^-	
P	-1	$(-1)(-1)(-1)^L$	$\rightarrow L = 1$
J	0+0	$\|L \pm 0\| \ldots \|L+0\|$	$\rightarrow L = 0$

Parity violated

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draw examples

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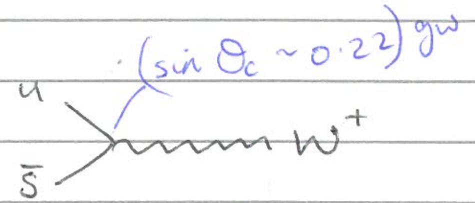
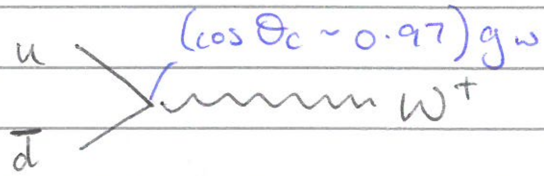
$K^+ \to \mu^+ \nu_\mu$



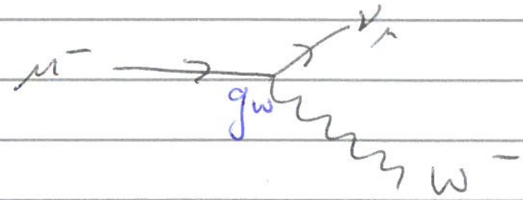
$\pi^+ \to \mu^+ \nu_\mu$



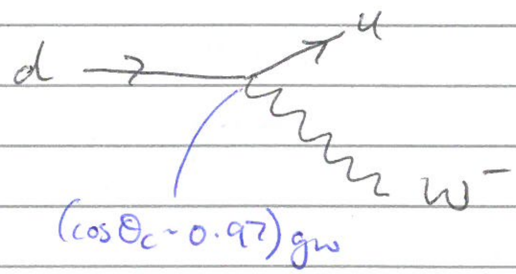
lower rate due to smaller coupling

μ decay vs n decay

$\mu^- \to W^- \nu_\mu$



$d \to W^- u$



explains ratio not = 1

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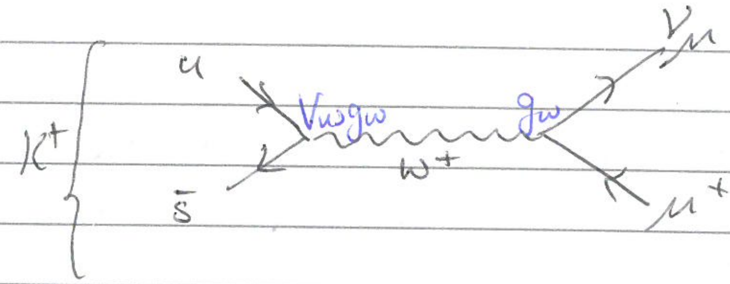
$K^+ \to \mu^+ \nu_\mu$



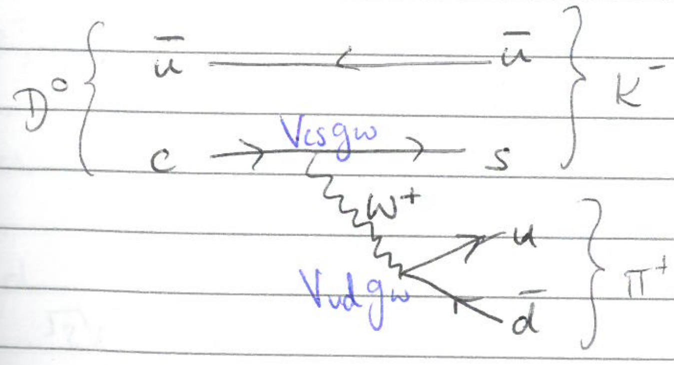
$|\mathcal{M}| \propto V_{us}\, g_w\, g_w$

$\Gamma \propto |\mathcal{M}|^2 \sim V_{us}^2\, g_w^4 \sim \sin^2\theta_c\, g_w^4$

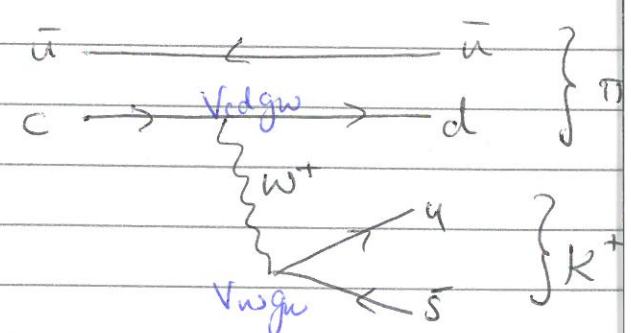
~~$\sim 0.005\, g_w^4$~~

$\sim 0.05\, g_w^4$

$D^0 \to K^- \pi^+$



$\to K^+ \pi^-$



$\Gamma \propto |\mathcal{M}|^2 \sim (V_{cs} V_{ud}\, g_w g_w)^2$

$\Gamma \propto (V_{cd} V_{us}\, g_w g_w)^2$

$$\frac{\Gamma(K^+\pi^-)}{\Gamma(K^-\pi^+)} = \frac{V_{cd}^2 V_{us}^2}{V_{cs}^2 V_{ud}^2} = \frac{\sin^4\theta_c}{\cos^4\theta_c} \sim 0.0028$$