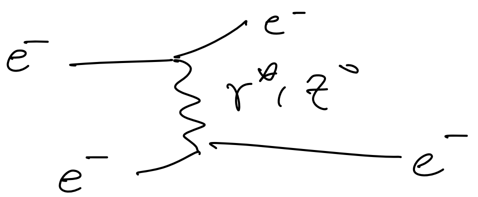
Neutral Currents

No W^0 flavor-changing neutral current.
Look for Z^0 flavor conserving.



$\gamma^* \sim \frac{1}{q^2}$ $\quad Z^0 \sim \frac{1}{q^2 - M_Z^2}$.

$\Rightarrow$ use $\nu_e, \nu_\mu, \bar{\nu}_e, \bar{\nu}_\mu$ $\quad q_{EM} = 0 \Rightarrow$ NO EM.
leptons $\Rightarrow$ No QCD.

$\Rightarrow$
1) beam of neutrinos.
2) high intensity
3) focused beam.
4) σ_ν small $\Leftrightarrow$ large and dense detector.

IN 1973 @ CERN.

$p + Be \longrightarrow \pi^+ + X$
$\pi^- + X$
$K^+ K^- + X$

$p + Be \longrightarrow \{\pi^\pm, K^\pm\} + X$

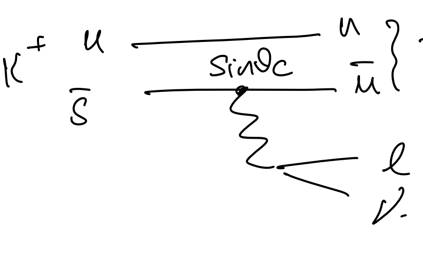
$\tau_\pi \sim 10^{-8}$ s.
$\ell_\pi \sim \beta\gamma c\tau_\pi$

$\pi^\pm \longrightarrow \mu^\pm + \nu_\mu / \bar{\nu}_\mu$

$K^+ \longrightarrow \mu^+ \nu_\mu$

produce ν_e from

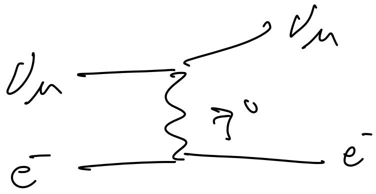
$K^+ \longrightarrow \pi^0 e^+ \nu_e$.

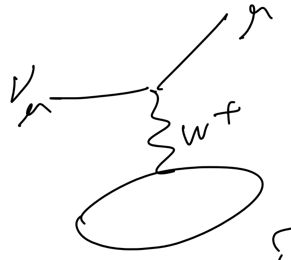


K^+ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Leptonic and semileptonic modes			
$e^+\nu_e$	$(1.582\pm0.007)\times10^{-5}$		247
$\mu^+\nu_\mu$	(63.56 ± 0.11) %	S=1.2	236
$\pi^0 e^+\nu_e$	(5.07 ± 0.04) %	S=2.1	228
Called K^+_{e3}.			
$\pi^0\mu^+\nu_\mu$	(3.352 ± 0.033) %	S=1.9	215
Called $K^+_{\mu3}$.			
$\pi^0\pi^0 e^+\nu_e$	$(2.55\pm0.04)\times10^{-5}$	S=1.1	206
$\pi^+\pi^- e^+\nu_e$	$(4.247\pm0.024)\times10^{-5}$		203
$\pi^+\pi^-\mu^+\nu_\mu$	$(1.4\pm0.9)\times10^{-5}$		151
$\pi^0\pi^0\pi^0 e^+\nu_e$	$< 3.5\times10^{-6}$	CL=90%	135
Hadronic modes			
$\pi^+\pi^0$	(20.67 ± 0.08) %	S=1.2	205
$\pi^+\pi^0\pi^0$	(1.760 ± 0.023) %	S=1.1	133
$\pi^+\pi^+\pi^-$	(5.583 ± 0.024) %		125

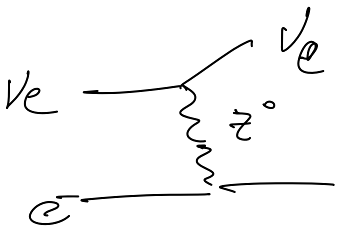
Selecting $\pi^\pm$ $\longrightarrow$ produce 99% pure beam of $\nu_\mu / \bar{\nu}_\mu$.

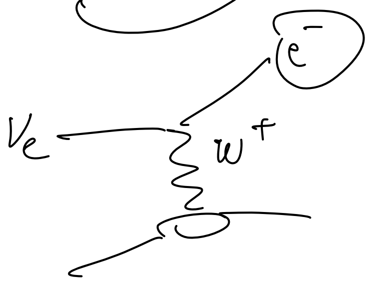
ν_μ instead of ν_e



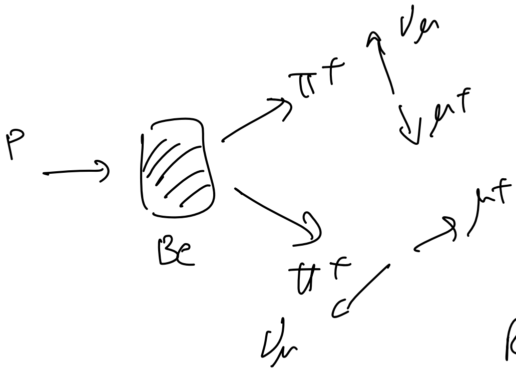


easy to identify.





more challenging to identify w/ calorimeter.



in π^+ RF. $\nu_\mu \longleftarrow \overset{\pi^+}{\circ} \longrightarrow \mu^+$.

$M_\pi > M_\mu + m_\nu$.

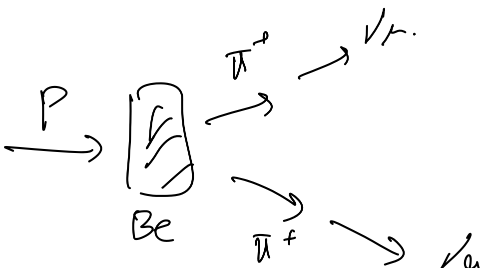
$Q = m_\pi - m_\mu - m_\nu = 29$ MeV.

RF.

$\pi^+ \longrightarrow (\nu_\mu \longleftarrow \circ \longrightarrow \mu^+)$

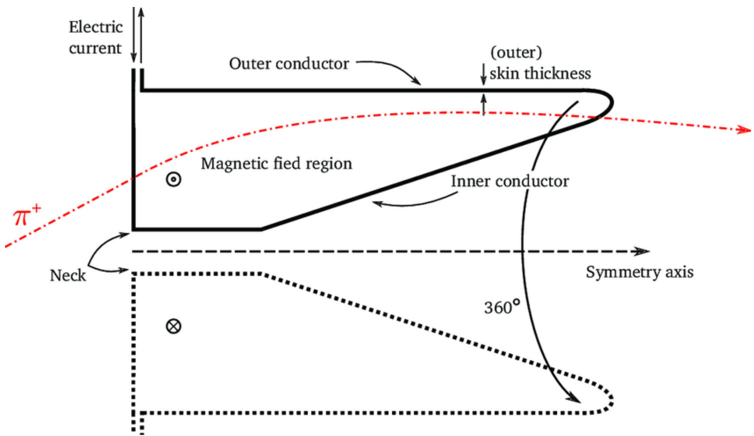
β^*_ν

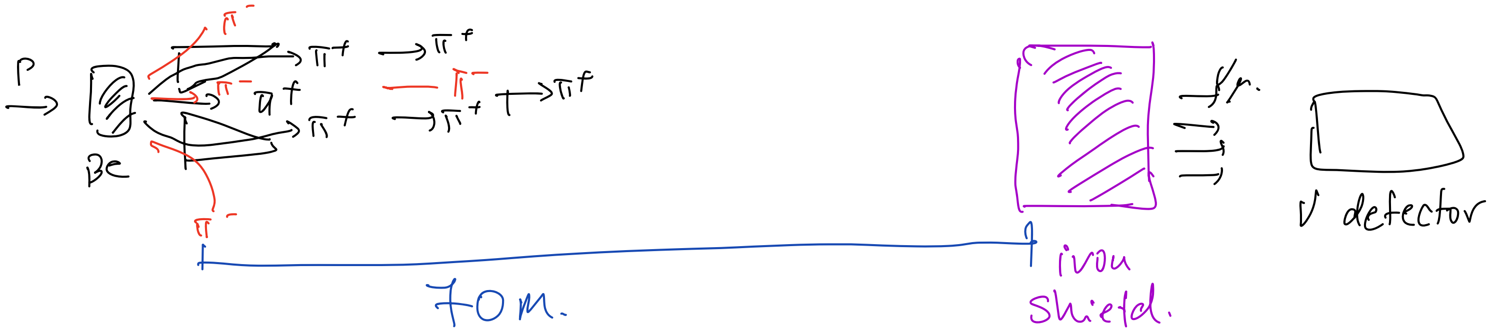
if $\beta_\pi^{LAB} > \beta^*_\nu \Rightarrow \pi^+ \longrightarrow \begin{matrix} \xrightarrow{} \nu_\mu \\ \xrightarrow{} \mu^+ \end{matrix}$



$\Rightarrow$ Focus $\pi^\pm$ after production $\Rightarrow$ focus ν_μ beam.

Simon Van der Meer



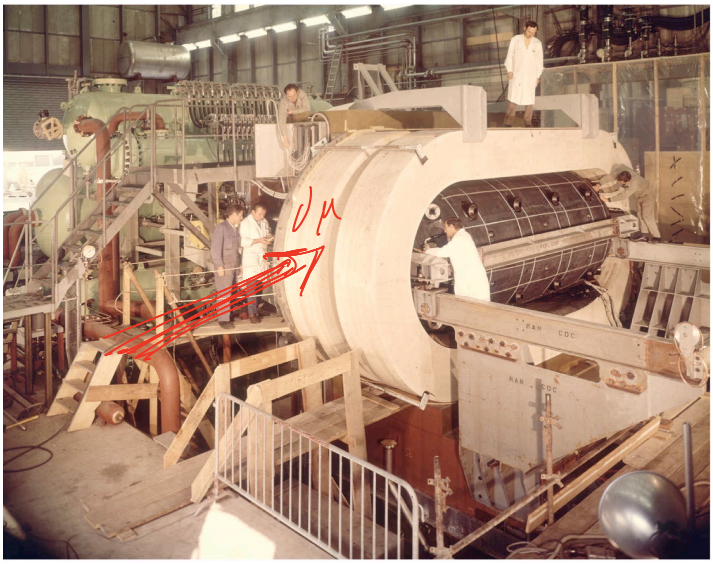


iron shield: $\pi^\pm, K^\pm$, baryons, n, p.
nuclear interaction. w/ λ_{int}.

$$N_{surv.} \sim e^{-x/\lambda_{int}}$$

$\mu^\pm$: ionization.

$e^\pm$: ionization, shower

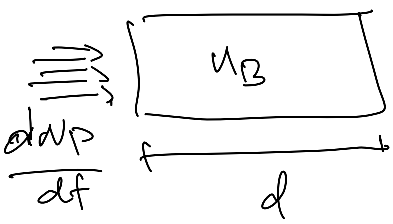


Gargamelle

Steel cylinder bubble chamber. filled with freon liquid. CF_3Br

similar function to cloud chamber.

$$\frac{dN_\nu}{dt} = \frac{dN_p}{dt}\,\sigma\,n_B\,d$$



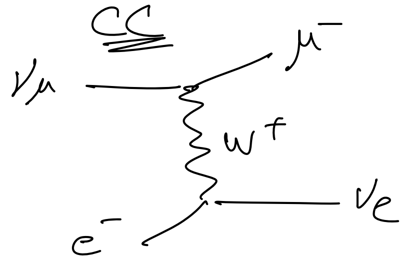
$\sigma_\nu << 1.$

liquid $n_B >>$ gas n_B
$\sim 10^3$

magnetic field of 2T

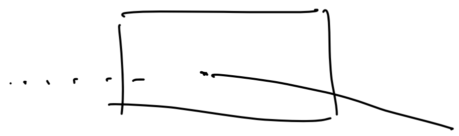
$\nu_\mu + \begin{Bmatrix} e^- \\ p \\ n \end{Bmatrix} \longrightarrow$

CC

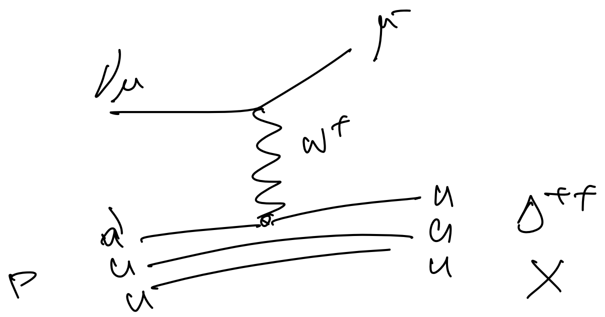


$\nu_\mu + e^- \rightarrow \mu^- + \nu_e$.

$\underbrace{\mu^-}$ well identified.



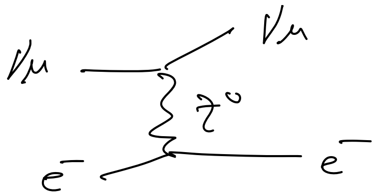
$\nu_\mu + n \rightarrow \mu^- + p$



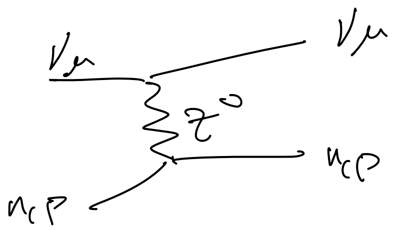
$\nu_\mu + p \rightarrow \mu^- + X$

CC is background identified by μ^- in the detector.

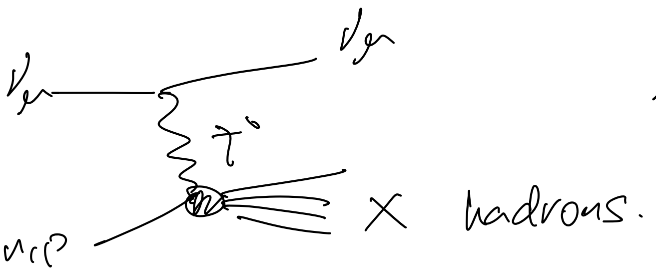
if Z^0 exists $\Longrightarrow$ additional processes by NC.



$\nu_\mu + e^- \rightarrow \nu_\mu + e^-$



$\nu_\mu + \begin{Bmatrix} n \\ p \end{Bmatrix} \rightarrow \nu_\mu + \begin{Bmatrix} n \\ p \end{Bmatrix}$ elastic scattering.



$\nu_\mu + \begin{Bmatrix} n \\ p \end{Bmatrix} \longrightarrow \nu_\mu +$ hadrons.

inelastic scattering.

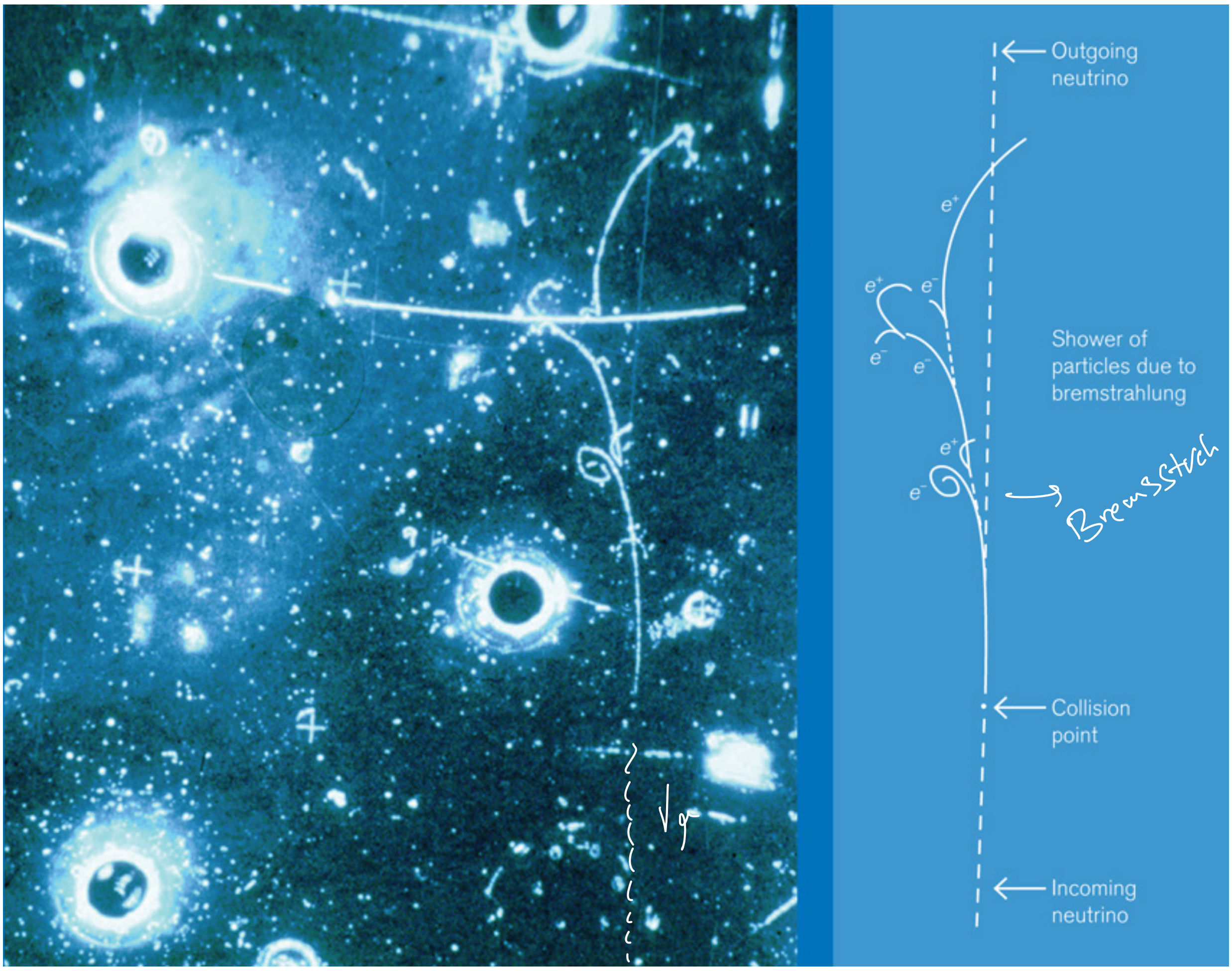
Momentum conservation.

ν_μ $\quad \vec{P}_{\nu_\mu} \quad \xrightarrow{CC}$ $\quad$ charged $\sum_i P_{T_i} \simeq 0.$ $\quad$ Balanced.

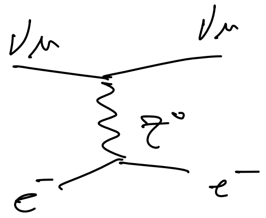
$P_{T\nu_\mu} = 0.$

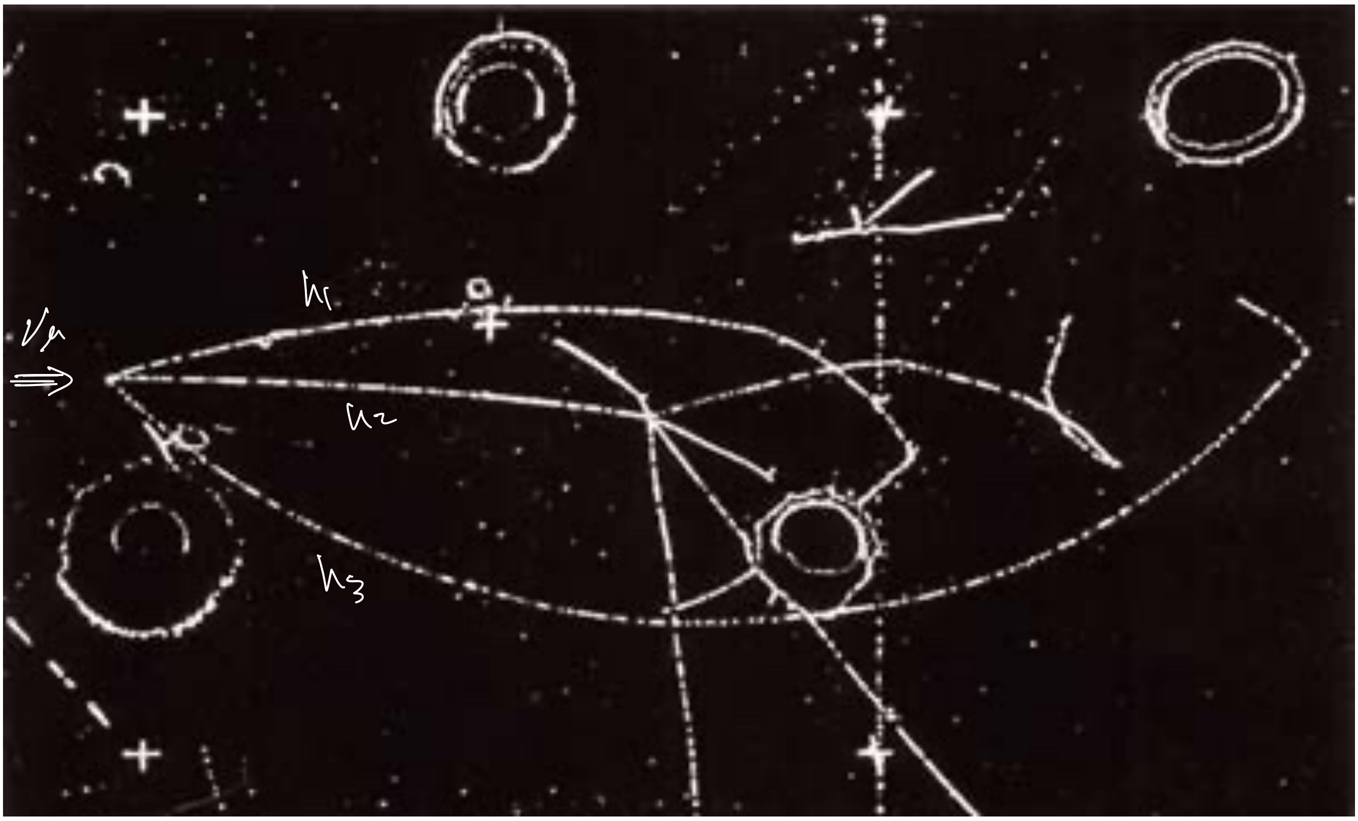
ν_μ $\quad \vec{P}_{\nu_\mu} \quad \xrightarrow{NC}$ $\quad \vec{P}_{\nu_\mu}$ $\quad$ charged. $\quad$ charged $\sum_i P_{T_i} \neq 0.$ $\quad$ unbalanced.

$$\left.\begin{array}{l} - \text{presence of } \mu^- \\ - \text{unbalanced charged } \sum P_{T_i} \end{array}\right\} \Rightarrow \text{Discriminate CC vs NC.}$$

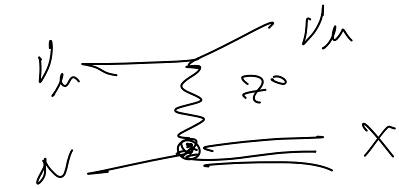


$\nu_\mu + e^- \to \nu_\mu + e^-$





$\nu_\mu + N \rightarrow \nu_\mu + 3$ hadrons.



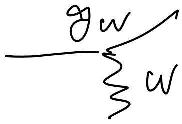
ν_μ beam: 102 NC, 428 CC, 15 n background.

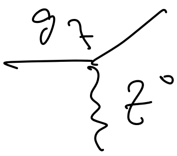
$\bar{\nu}_\mu$ beam: 64 NC, 148 CC, 12 n background.

$$\frac{NC}{CC} \neq 0. \qquad \frac{NC}{CC} \simeq \frac{1}{3}.$$

1) $\frac{NC}{CC} \neq 0 \Rightarrow$ NC exists.

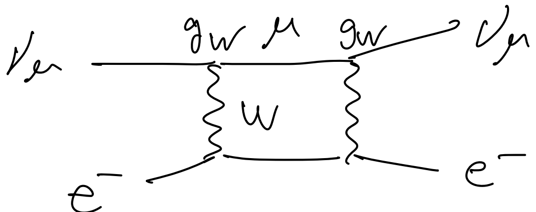
2)





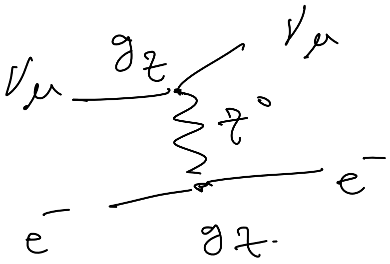
$g_W \neq g_Z$

3) 1/3 large enough that excludes higher order CC

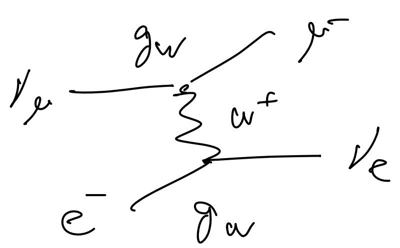


$$\mu \sim \left(\frac{g_W^2}{M_W^2}\right)\left(\frac{g_W^2}{M_W^2}\right) \sim G_F^2$$

$\frac{1}{3} \gg G_F^2 \Rightarrow$ NC exists.



$$\frac{g_Z^2}{M_Z^2}$$

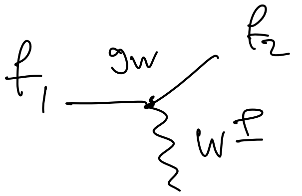


$$\frac{g_W^2}{M_W^2}$$

events different $\Rightarrow$ $g_W \neq g_Z$

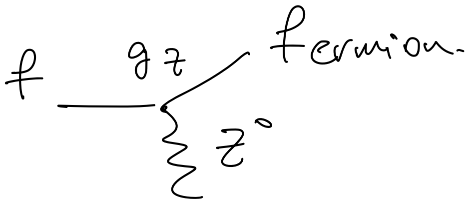
NC and CC Couplings

CC



$f_i = \ell^\pm, \nu_\ell, \bar{\nu}_\ell, q_i$ i = flavors of quarks.

$g_W \gamma^\mu (1-\gamma^5)$ V−A structure.



$$g_Z \gamma^\mu (\underbrace{c_V^f}_{\text{vector coupl}} - \underbrace{c_A^f}_{\text{axial coup.}} \gamma^5)$$

depends on lepton, quark flavor.

Glashow–Weinberg–Salam.

predicts c_V^f, c_A^f Nobel 1979

Electroweak theory $SU(2)_W \times U(1)_{EM}$.

$SU(2)_W \to$ W^1, W^2, W^3 bosons.

$U(1)_{EM} \to$ B boson.

$W^1, W^2 \longrightarrow W^\pm$ $(W^1 \pm i W^2)$ 2 charged heavy bosons.

$$\begin{pmatrix} Z^0 \\ A \end{pmatrix} = \begin{pmatrix} \cos\theta_W & -\sin\theta_W \\ \sin\theta_W & \cos\theta_W \end{pmatrix} \begin{pmatrix} W^3 \\ B \end{pmatrix}$$

$\hookrightarrow$ physical bosons Z^0, γ

θ_W : weak mixing angle (weinberg angle)

$\hookrightarrow$ not fixed in theory.

$\Rightarrow$ Must measure θ_W.

f	c_V	c_A
ν_e, ν_μ, ν_τ	$\frac{1}{2}$	$\frac{1}{2}$
e^-, μ^-, τ^-	$-\frac{1}{2} + 2\sin^2\theta_w$	$-\frac{1}{2}$
u, c, t	$\frac{1}{2} - \frac{4}{3}\sin^2\theta_w$	$\frac{1}{2}$
d, s, b	$-\frac{1}{2} + \frac{2}{3}\sin^2\theta_w$	$-\frac{1}{2}$

$$g_W = \frac{g_e}{\sin\theta_W}$$

$$g_Z = \frac{g_e}{\sin\theta_W \cos\theta_W}$$

$$g_e = \frac{e}{\sqrt{4\pi}}$$

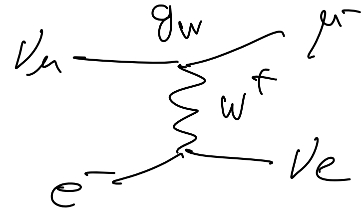
predicts $M_W = M_Z \cos\theta_W$

$\Rightarrow$ measure $\frac{M_W}{M_Z}$ $\Rightarrow$ provides $\theta_W \simeq 29°$

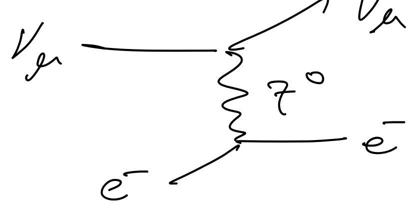
$\sin^2\theta_W = 0.23$

→ produce W, Z on shell.

→ precision test of Glashow-Weinb.-Salam predictions.



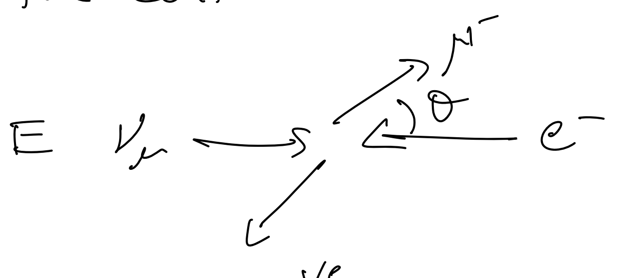
$g_W = f(C_V, C_A)$



$g_Z = f(C_V, C_A)$

$\nu_\mu + e^- \rightarrow \mu^- + \nu_e$

In the center of mass.



Griffiths 9.6.

if $q^2 << M_Z^2, M_W^2$

$$\sigma \sim \left(\frac{g_Z}{M_Z}\right)^4 E^2 (C_V^2 + C_A^2 + C_V C_A)$$

$$\frac{\sigma_{NC}}{\sigma_{CC}} = \frac{\sigma(\nu_\mu + e^- \rightarrow \nu_\mu + e^-)}{\sigma(\nu_\mu + e^- \rightarrow \mu^- + \nu_e)} = \frac{1}{4} - \sin^2\theta_W + \frac{4}{3}\sin^2\theta_W = 0.09$$

from theory

Exp: 0.11