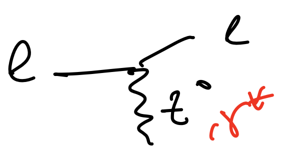
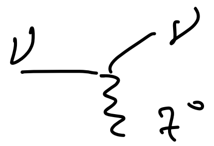
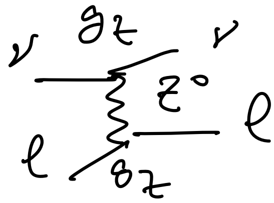
Neutral weak Current





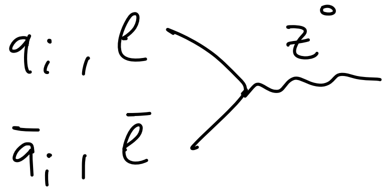
massive boson

Indirect evidence



$g_Z^2 \frac{1}{q^2 - m_Z^2}$

Direct evidence: produce Z° on shell.



$\sqrt{s} = m_Z$

1961: Glashow proposed unification of weak and EM interaction. mixture of γ and Z° fields.

1967: weinberg-Salam: unification as sponatenous symmetry breakup of gauge fields

$SU(2)_{weak} \times U(1)_{EM}$

1971: t'Hooft proved that gauge theory is renormalizable

If theory correct: find experimental evidence for W, Z

1979: Nobel Glashow-weinberg-Salam (GWS)

Indirect experimental evidence

No electric charge $q=0 \Rightarrow$ No EM

No color $\Rightarrow$ No QCD

$\nu_e + X \longrightarrow \nu_e + X \qquad X = e^-, p, n$

Challenges
1) beam of neutrinos
2) high intensity
3) Focused beam

4) Cross section very small.

$\bar{\nu} + p \rightarrow e^+ + n$ (Reines-Cowan experiment)

$\sigma \sim 10^{-55}\ cm^2$

$$\frac{dN_r}{dt} = \sigma \frac{dN_p}{dt} \underbrace{n_{target.}}_{\text{target density}} \underbrace{\Delta x}_{\text{thickness.}}$$

Experiment @ CERN 1973

$p + Be \rightarrow \pi^+ + X$

$\pi^- + X$

$K^+ K^- + X$

X: ≥ 1 charged ≥ 0 neutral particles.

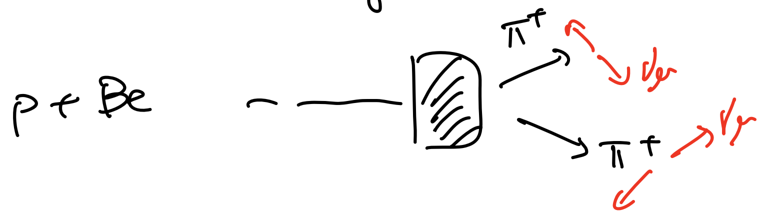
$$\left.\begin{array}{ll} \pi^\pm \rightarrow \mu^\pm\ \nu_\mu/\bar{\nu}_\mu & \sim 100\% \\ K^\pm \rightarrow \mu^\pm\ \nu_\mu/\bar{\nu}_\mu & \sim 60\% \end{array}\right\} \text{signal}$$

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

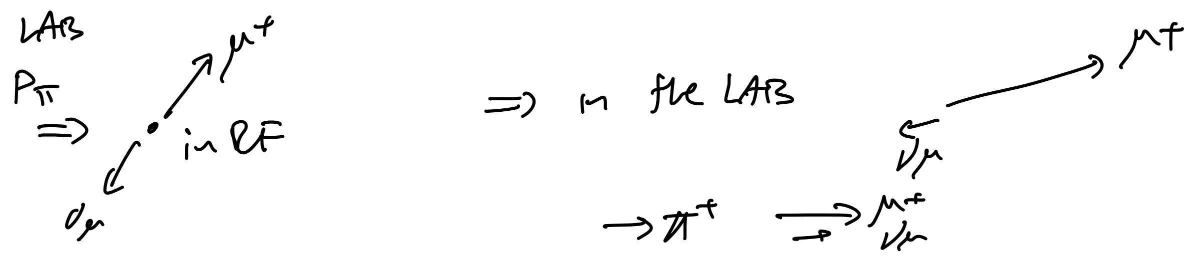
$\pi^0\ e^+\ \nu_e$

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
$\mu^+\nu_\mu$	$(63.56\pm0.11)\ \%$	S=1.2	236
$\pi^0 e^+\nu_e$	$(5.07\pm0.04)\ \%$	S=2.1	228
Called K^+_{e3}.			
$\pi^0\mu^+\nu_\mu$	$(3.352\pm0.033)\ \%$	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			
$\pi^+\pi^0$	$(20.67\pm0.08)\ \%$	S=1.2	205
$\pi^+\pi^0\pi^0$	$(1.760\pm0.023)\ \%$	S=1.1	133
$\pi^+\pi^+\pi^-$	$(5.583\pm0.024)\ \%$		125

Select $\pi^\pm \Rightarrow$ produce beam of $\nu_\mu/\bar{\nu}_\mu$ pure at 99%



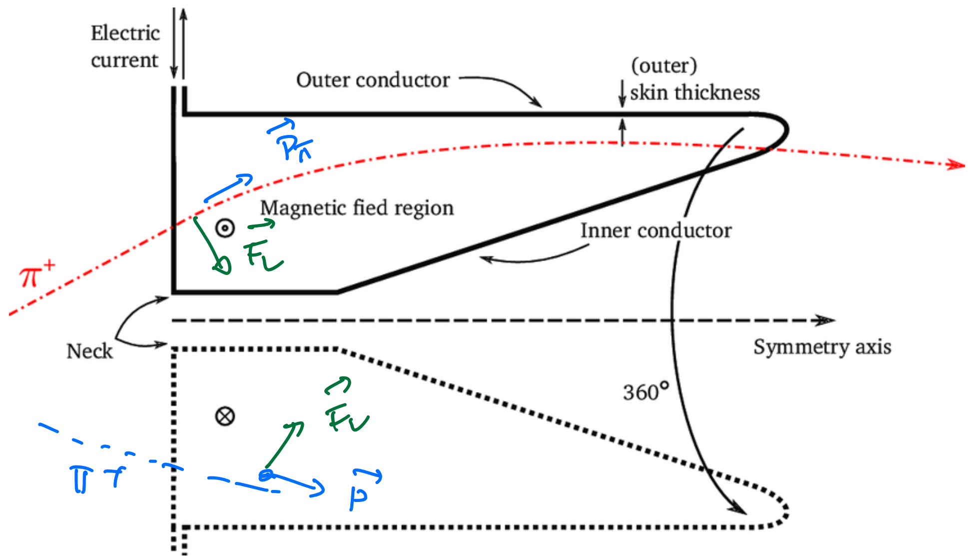
In π^+ rest frame $\quad \mu^+ \leftarrow \overset{\pi^+}{\bullet} \rightarrow \nu_\mu$



Magnetic Horn

Simon van der Meer

$$\vec{F}_L = q\,\vec{v}\times\vec{B}$$



Focus $\pi^{+/-}$ beam

$\Rightarrow$ Focus $\nu_\mu/\bar{\nu}_\mu$

$$\mu^+ \longleftarrow \overset{\pi^+}{\bullet} \longrightarrow \nu_\mu \qquad Q = m_\pi - m_\mu - m_\nu \simeq 29\ \text{MeV}$$

in rest frame $E_\pi = m_\pi = E_\mu + E_\nu = \sqrt{m_\mu^2 + p^2} + p$

$$\Rightarrow \quad p = \frac{1}{2m_\pi}\left(m_\pi^2 - m_\mu^2\right) \simeq 25\ \text{MeV}.$$

Iron Shield π, K, hadrons: nuclear interaction, ionization

$e^{\pm}$: ionization, EM shower

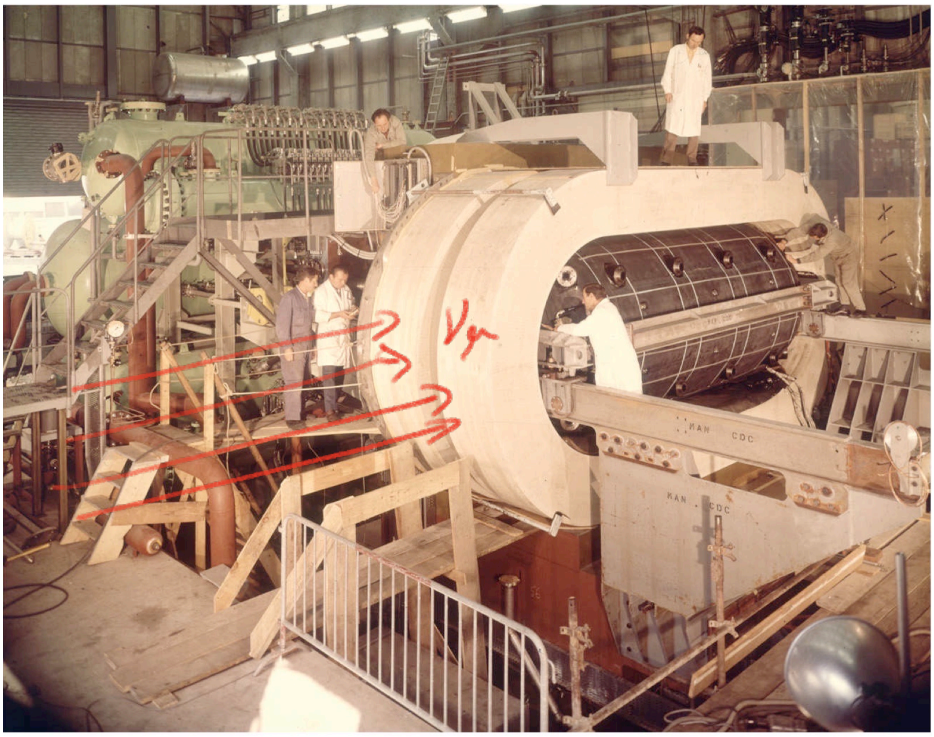
$\mu^{\pm}$: ionization (not stopped)

Gargamelle

Steel cylinder filled with Freon CF_3Br (liquid)

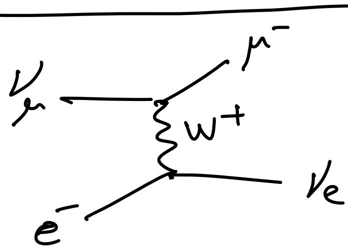
2T magnetic field

Bubble Chamber

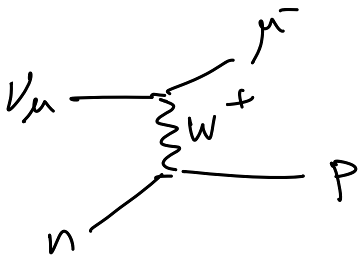


$$\nu + \left\{ \begin{matrix} e^- \\ p \\ n \end{matrix} \right\} \rightarrow \nu + X$$

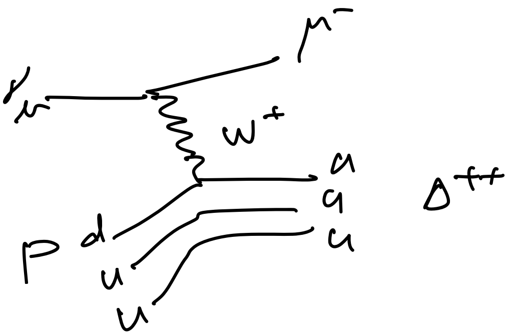
Charged current process (CC)



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



$\nu_\mu + n \longrightarrow \mu^- + p \,/\, X$

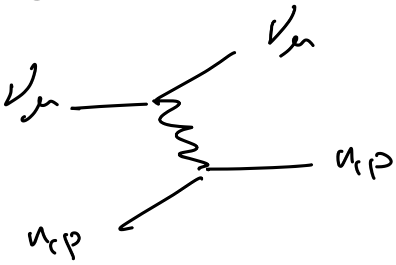


$\nu_\mu + p \longrightarrow \mu^- + \Delta^{++} \,/\, X$

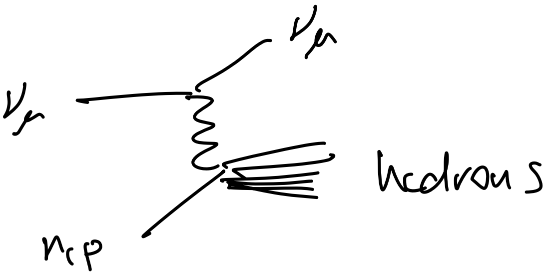
CC events have μ^- in final state.

if Z^0 exists (NC) $\Rightarrow$ additional processes

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

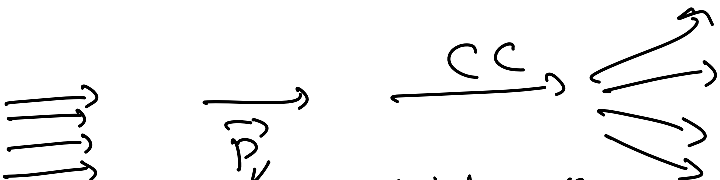


$\nu_\mu + \binom{n}{p} \longrightarrow \nu_\mu + \binom{n}{p}$ elastic



$\nu_\mu + \binom{n}{p} \longrightarrow \nu_\mu +$ hadrons.

Inelastic.

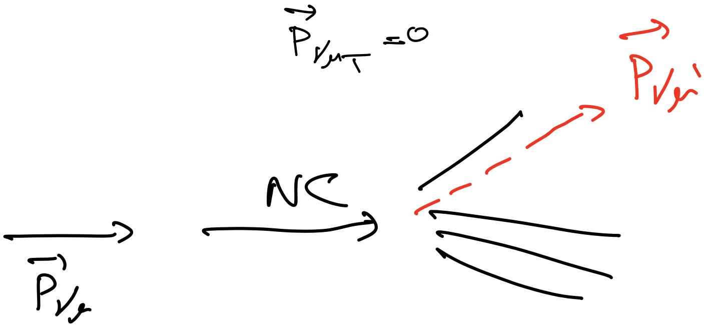


charged particles.

$\sum_i^{\text{charged}} P_{T_i} = 0$

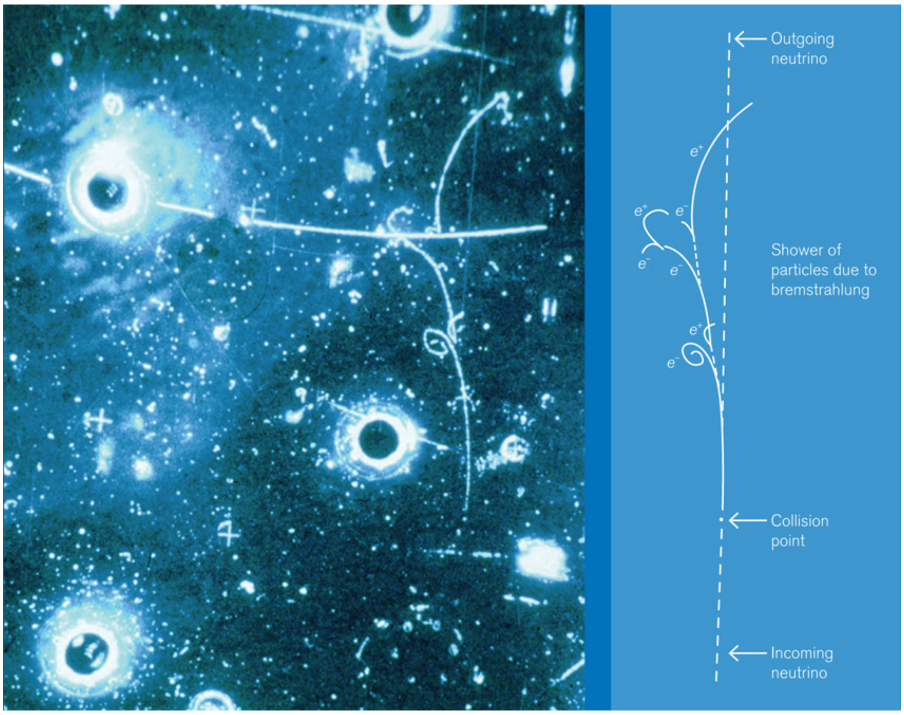
initial transverse mom $= 0$.

$\vec{P}_{\nu_{\mu T}} = 0$

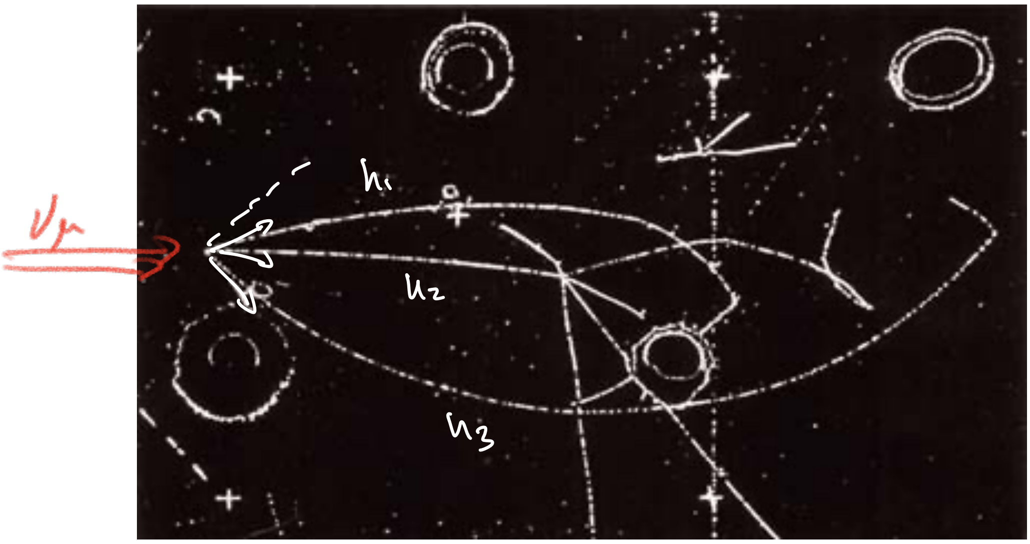


$\sum_i^{\text{charged}} P_{T_i} \neq 0.$

$P_{T_\nu} = - \sum_i^{\text{charged}} P_{T_i}$



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



$\nu_\mu + n/p \rightarrow \nu_\mu +$ hadrons

inelastic.

$\pi^+ \rightarrow \nu_\mu$ beam : 102 NC, 428 CC, 15n

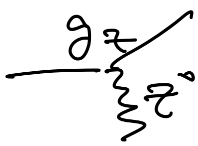
$\pi^- \rightarrow \bar{\nu}_\mu$ beam : 64 NC, 148 CC, 12n

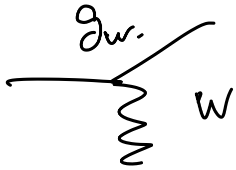
Expected Background from neutrons

Conclusions

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

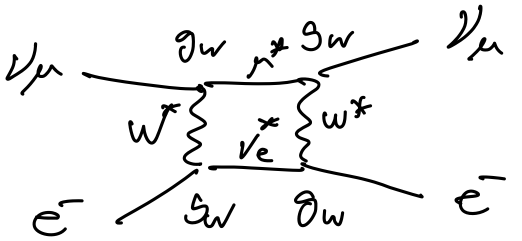
2) $\frac{NC}{CC} \simeq \frac{1}{3}$





$g_Z \neq g_W$

3) $1/3 \gg 2^{nd}$ order effects with no Z^0

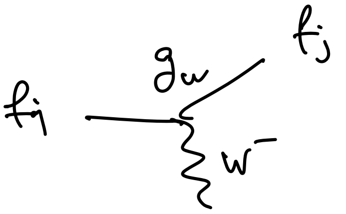


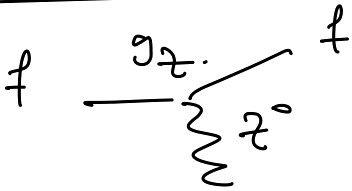
$$\mathcal{M} \quad \frac{g_W^2}{m_W^2} \; \frac{g_W^2}{m_W^2} \sim G_F^2$$

$\Rightarrow |\mathcal{M}|^2 \sim G_F^4$ much suppressed

$\frac{NC}{CC} \approx 1/3 \gg 2^{nd}$ order W-only diagram (G_F^4)

Glashow - Weinberg - Salam Theory of Electroweak int.





$f_i = \ell^\pm, \nu_e, \bar{\nu}_e, q_i$

i : flavors of quarks.

$\frac{i}{2\sqrt{2}} g_W \gamma^\mu (1-\gamma^5)$

V-A theory.

$\frac{i}{2\sqrt{2}} g_Z \gamma^\mu (c_V - c_A \gamma^5)$

vector coupling, axial coupling.

theory predicts c_V, c_A for all fermions.

$SU(2)_{weak} \times U(1)_{EM}$.

$\downarrow \qquad\qquad \downarrow$

$W^1, W^2, W^3 \qquad B \qquad$ gauge bosons.

$W^1, W^2 \rightarrow (W_1 \pm i W_2) = W^\pm$ physical bosons.

$$\begin{pmatrix} Z^0 \\ A \end{pmatrix} = \begin{pmatrix} \cos\theta_W & -\sin\theta_W \\ \sin\theta_W & \cos\theta_W \end{pmatrix} \begin{pmatrix} W_3 \\ B \end{pmatrix}$$

θ_W : weak mixing angle

$\hookrightarrow$ physical neutral vector bosons.

$\Rightarrow$ experimentally 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	$-\frac{1}{2} + \frac{2}{3}\sin^2\theta_w$	$-\frac{1}{2}$

$$\alpha_{EM} = \frac{e^2}{4\pi} \Rightarrow g_e = \frac{e}{\sqrt{4\pi}}$$

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

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

$$M_W = M_Z \times \cos\theta_W$$

$$\Rightarrow \theta_W \simeq 29^\circ \qquad \sin^2\theta_W = 0.23 \qquad \sin\theta_W \simeq 0.48$$