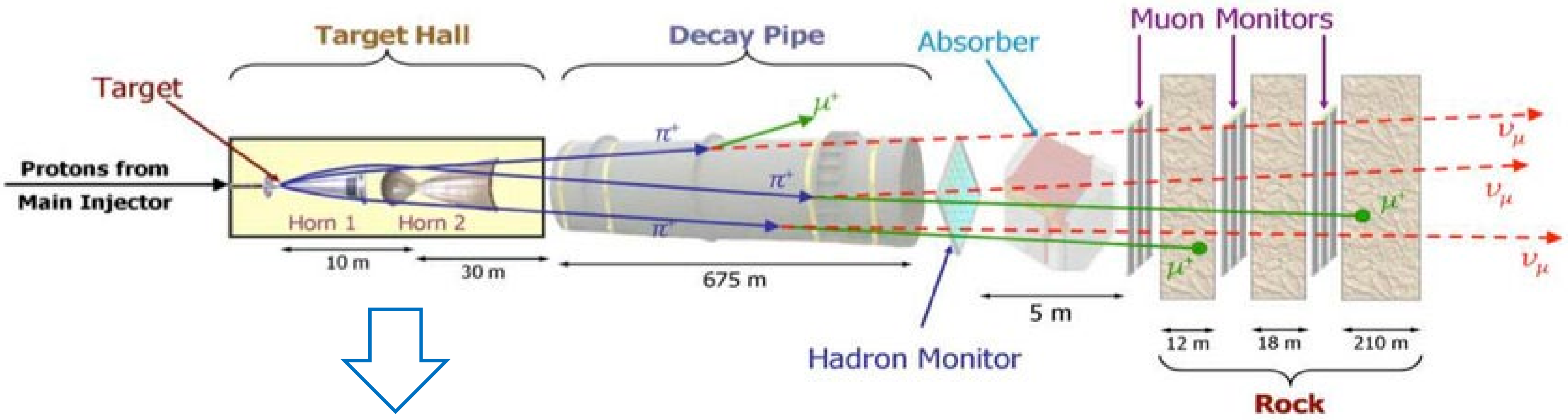
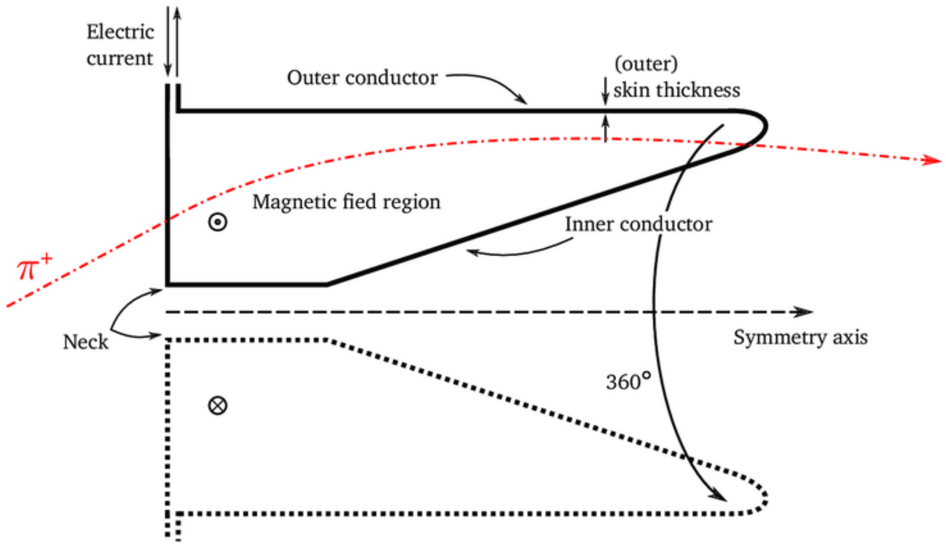
Neutrino beams:





Magnetic horn (S. v. d. Meer)

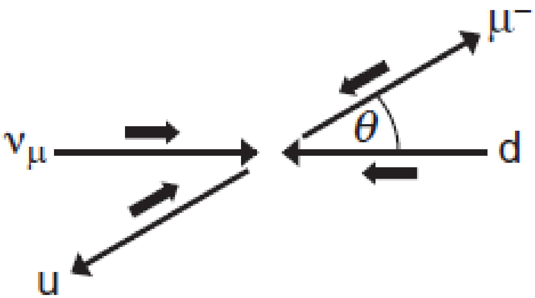
Pulsed “high-current” produced toroidal magnetic field which focuses one charge and sweeps away particle of the opposite charge: produce strong neutrino or anti-neutrino beam

Dirac Spinors in the Dirac-Pauli representation

Centre-of-mass system:

$p_3 : \varphi_3 = 0, \theta_3 = \theta$

$p_1 : \varphi_1 = 0, \theta_1 = 0$



$p_2 : \varphi_2 = \pi, \theta_2 = \pi$

$p_4 : \varphi_4 = \pi, \theta_4 = \pi - \theta$

CMS and neglecting masses:

$$|\vec{p}_i| = E_i = E$$

$$u_\downarrow(p_1) = \sqrt{E}\begin{pmatrix} 0 \\ 1 \\ 0 \\ -1 \end{pmatrix},\ u_\downarrow(p_2) = \sqrt{E}\begin{pmatrix} -1 \\ 0 \\ 1 \\ 0 \end{pmatrix},\ u_\downarrow(p_3) = \sqrt{E}\begin{pmatrix} -s \\ c \\ s \\ -c \end{pmatrix}\ u_\downarrow(p_4) = \sqrt{E}\begin{pmatrix} -c \\ -s \\ c \\ s \end{pmatrix}$$

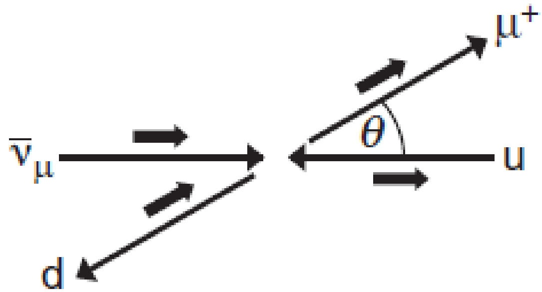
with $c = \cos\frac{\theta}{2}, \quad s = \sin\frac{\theta}{2}$

Additional spinors for anti-neutrino scattering:

Centre-of-mass system:

$$p_3 : \varphi_3 = 0, \theta_3 = \theta$$

$$p_1 : \varphi_1 = 0, \theta_1 = 0$$



$$p_2 : \varphi_2 = \pi, \theta_2 = \pi$$

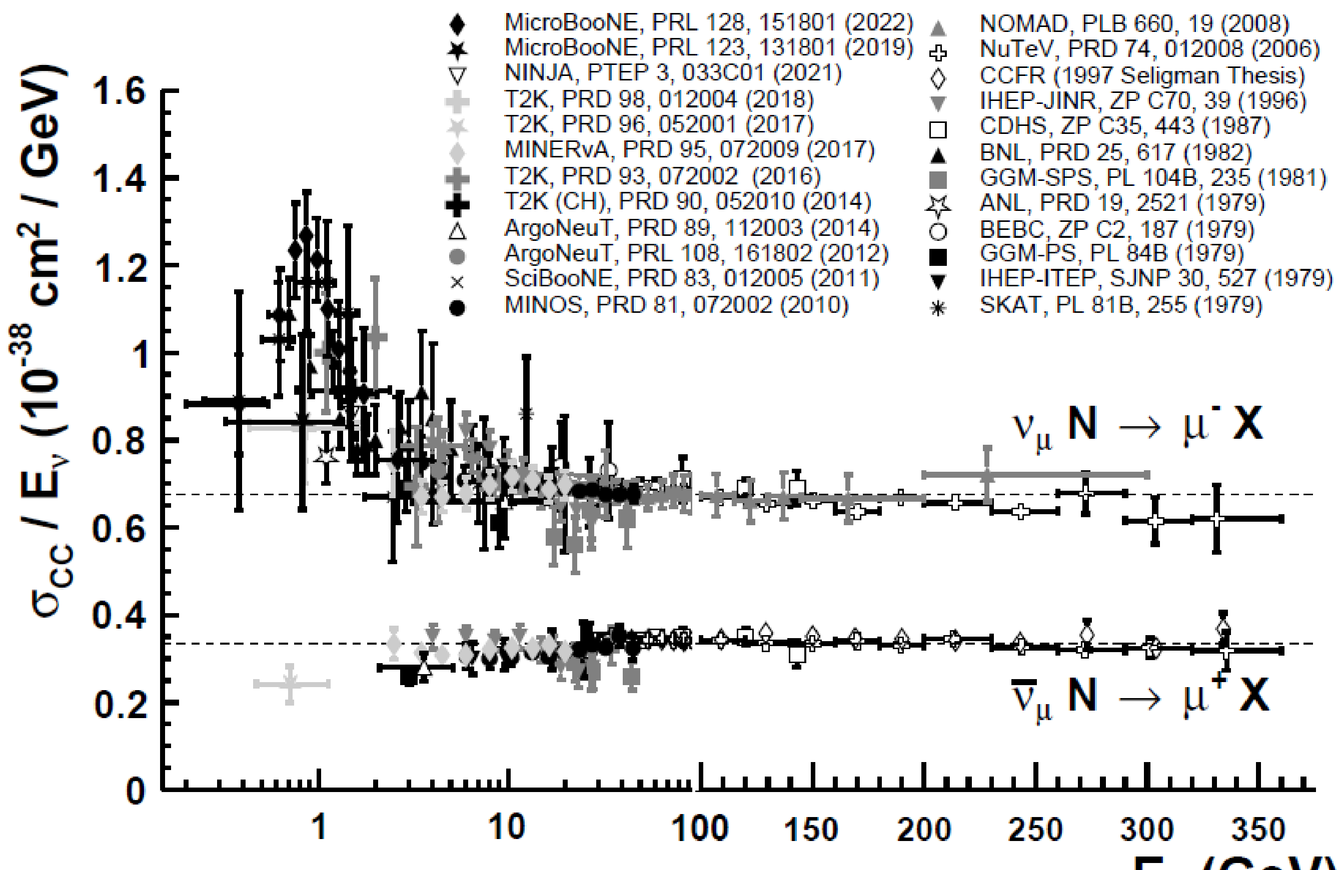
$$p_4 : \varphi_4 = \pi, \theta_4 = \pi - \theta$$

$$v_\uparrow(p_3) = \sqrt{E}\begin{pmatrix} s \\ -c \\ s \\ c \end{pmatrix}$$

$$v_\uparrow(p_1) = \sqrt{E}\begin{pmatrix} 0 \\ -1 \\ 0 \\ 1 \end{pmatrix}$$

with $c = \cos\frac{\theta}{2}, \quad s = \sin\frac{\theta}{2}$

Neutrino/antineutrino nucleon scattering



$$\hat{s}_{\nu q} \sim s_{\nu N} \approx 2 m_N E_\nu$$

Remark:

ratio of neutrino/anti-neutrino nucleon scattering is about 0.5 and not as predicted from quark scattering 1/3: **nucleons also contain anti-quarks!**

Fermion couplings to the Z-boson: (Recap)

V, A couplings: $c_V^f = I_3^f - 2Q_f \sin^2\theta_W \qquad c_A^f = I_3^f$

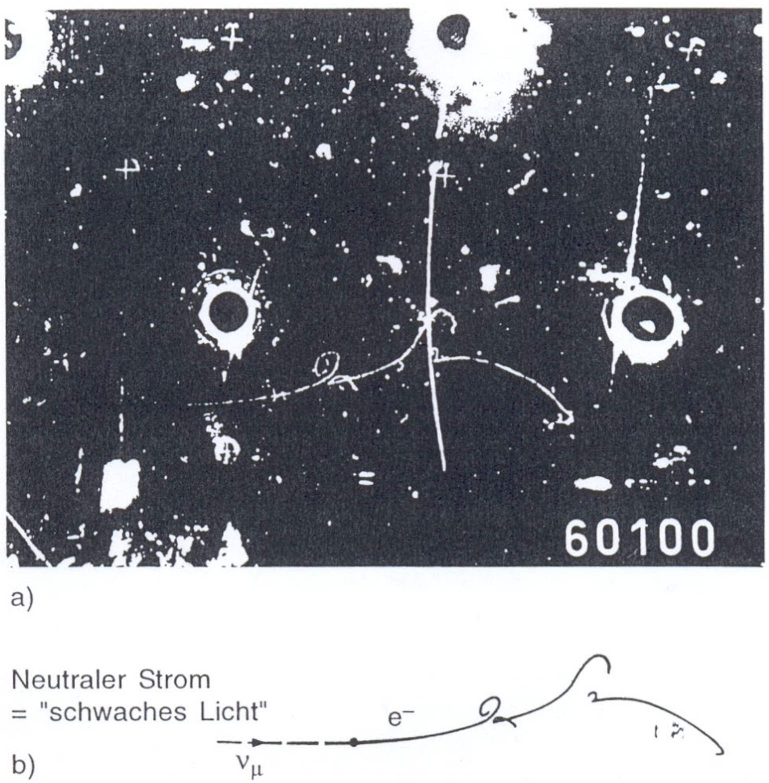
L, R couplings: $c_L^f = \frac{1}{2}(c_V^f + c_A^f) \qquad c_R^f = \frac{1}{2}(c_V^f - c_A^f)$

In the lecture we often use $g_{V,A}$ and $g_{L,R}$ instead of $c_{V,A}$ and $c_{L,R}$.
It is just the same – only different symbols!

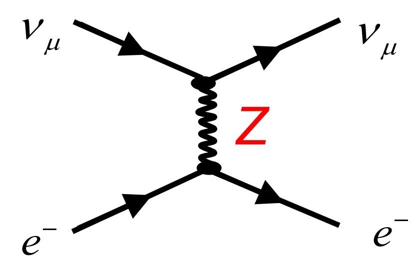
	g_V	g_A	g_V	g_A	g_L	g_R
ν	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	0
ℓ^-	$-\frac{1}{2} + 2\sin^2\theta_W$	$-\frac{1}{2}$	-0.04	$-\frac{1}{2}$	-0.27	$+0.23$
$u-quark$	$+\frac{1}{2} - \frac{4}{3}\sin^2\theta_W$	$\frac{1}{2}$	$+0.19$	$\frac{1}{2}$	$+0.35$	-0.15
$d-quark$	$-\frac{1}{2} + \frac{2}{3}\sin^2\theta_W$	$-\frac{1}{2}$	-0.35	$-\frac{1}{2}$	-0.42	$+0.08$

$\sin^2\theta_w \approx 0.231$

Discovery of Neutral Currents (NC) in neutrino scattering:

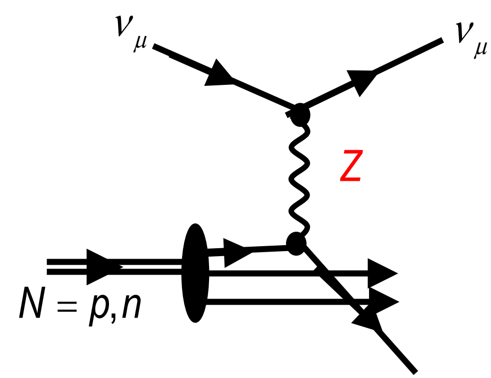


$$\nu_\mu + e^- \rightarrow \nu_\mu + e^-$$

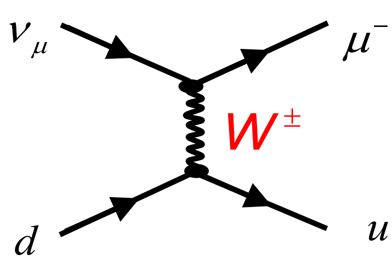


Clean but very rare.

More frequent: NC νN events.



Comparison with charged current events



$$R_\nu = \frac{\sigma_{NC}(\nu N \rightarrow \nu X)}{\sigma_{CC}(\nu N \rightarrow \mu X)} = 0.2.17 \pm 0.026$$

$$R_{\bar{\nu}} = \frac{\sigma_{NC}(\bar{\nu} N \rightarrow \bar{\nu} X)}{\sigma_{CC}(\bar{\nu} N \rightarrow \bar{\mu} X)} = 0.43 \pm 0.12$$

First determination:

$$\sin^2 \theta_W = 0.39 \pm 0.05$$

(not too good)

https://inis.iaea.org/collection/NCLCollectionStore/_Public/25/075/25075390.pdf