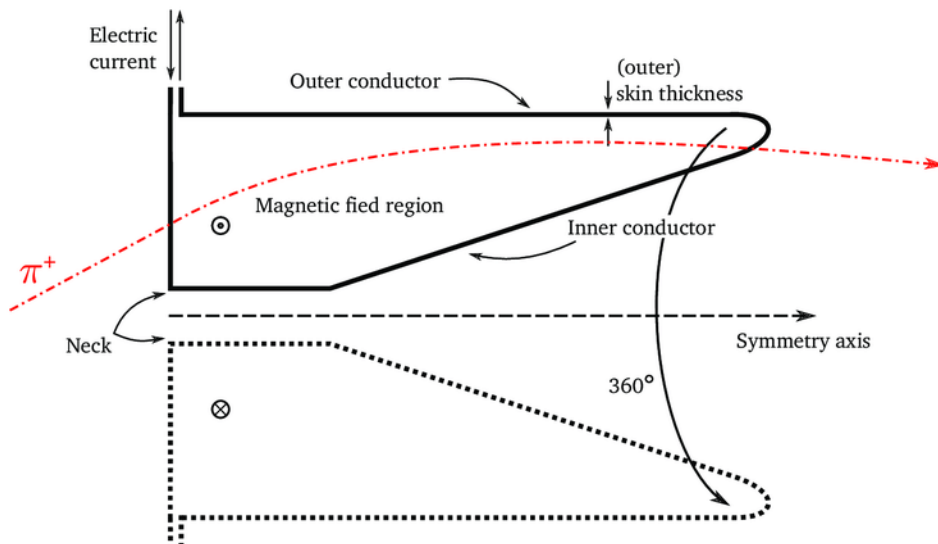
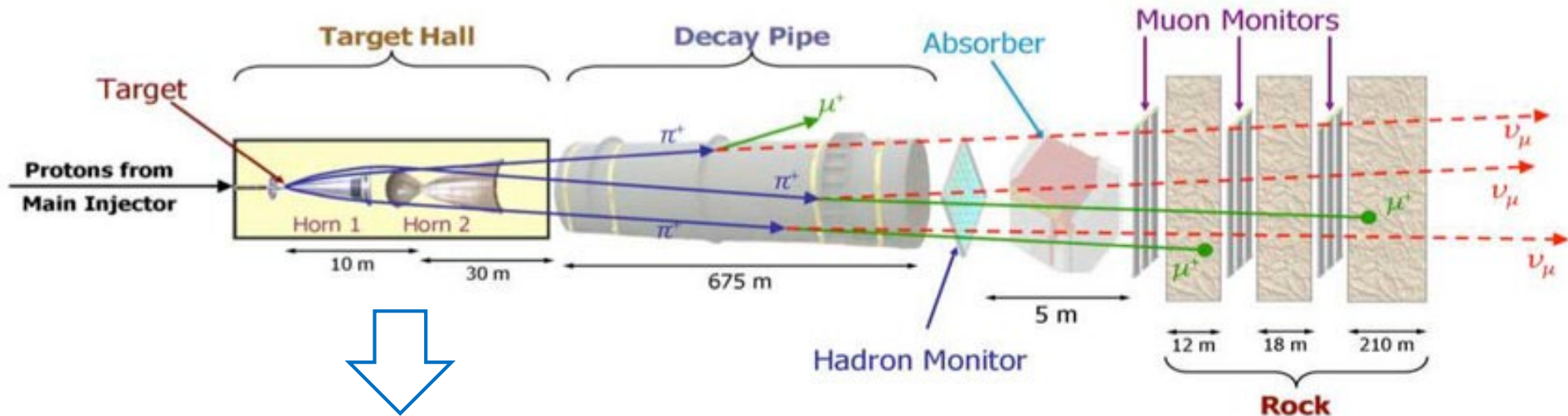


Neutrino beams:

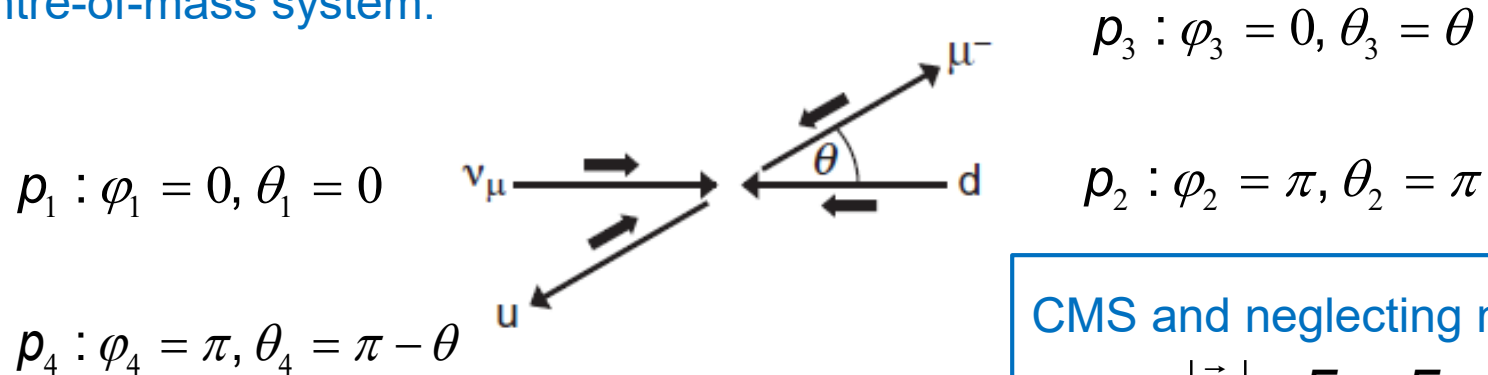


Magnetic horn (S. v. d. Meer)

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:



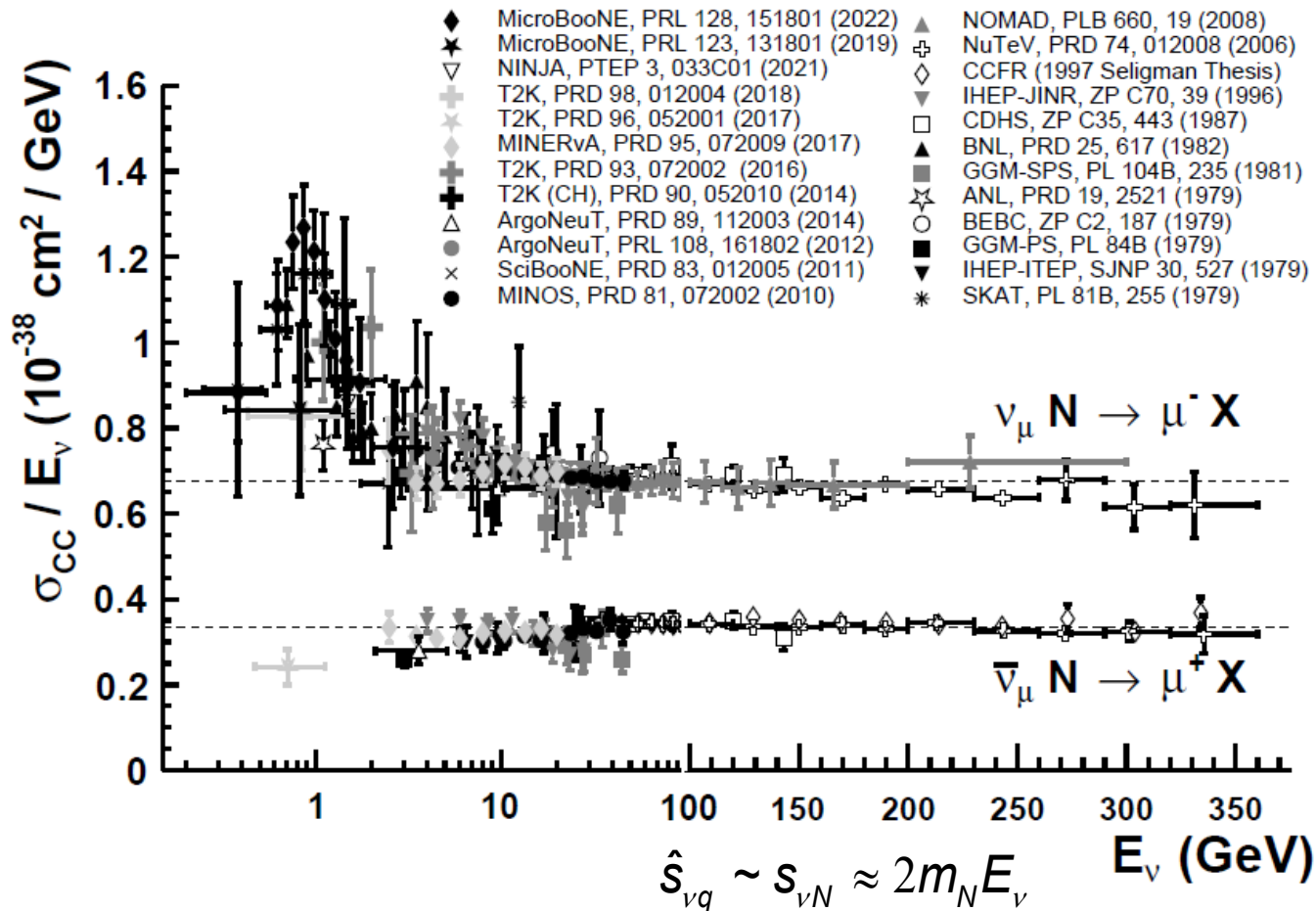
CMS and neglecting masses:

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

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

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

Neutrino/antineutrino nucleon scattering



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!** 3

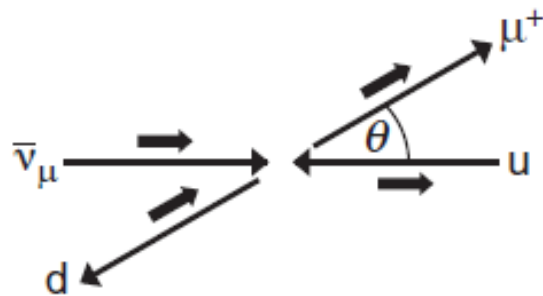
Additional spinors for anti-neutrino scattering:

Centre-of-mass system:

$$\rho_1 : \varphi_1 = 0, \theta_1 = 0$$

$$\rho_4 : \varphi_4 = \pi, \theta_4 = \pi - \theta$$

$$v_{\uparrow}(\rho_1) = \begin{pmatrix} 0 \\ -1 \\ 0 \\ 1 \end{pmatrix}$$



$$\rho_3 : \varphi_3 = 0, \theta_3 = \theta$$

$$\rho_2 : \varphi_2 = \pi, \theta_2 = \pi$$

$$v_{\uparrow}(\rho_3) = \begin{pmatrix} s \\ -c \\ s \\ c \end{pmatrix}$$

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


Fermion couplings to the Z-boson: (Recap)

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

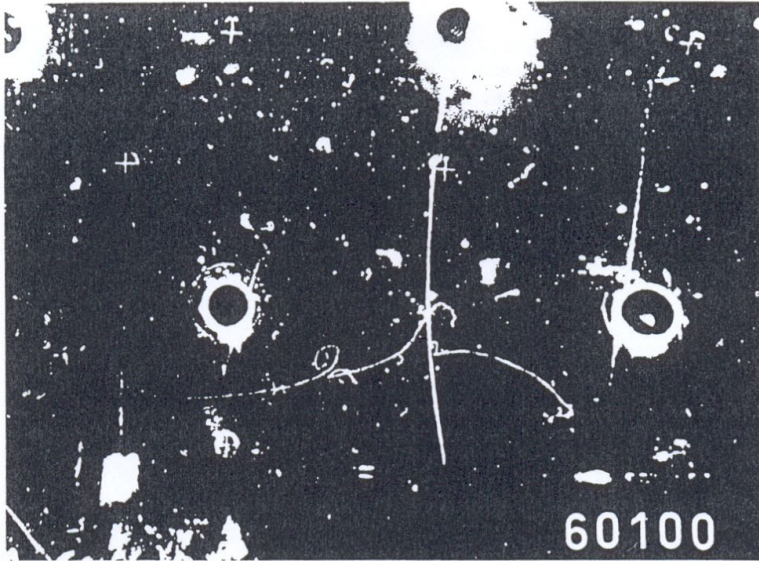
L, R couplings: $c_L^f = \frac{1}{2}(c_V^f + c_A^f)$ $c_R^f = \frac{1}{2}(c_V^f - c_A^f)$

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


 $\sin^2 \theta_W \approx 0.231$

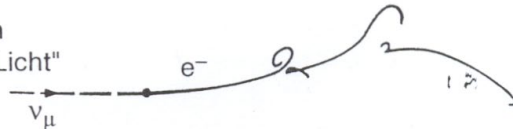
Discovery of Neutral Currents (NC) in neutrino scattering:



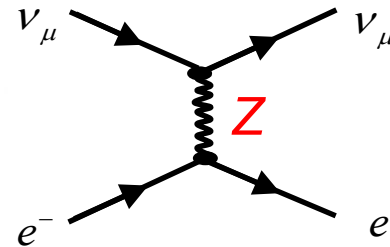
a)

Neutraler Strom
= "schwaches Licht"

b)

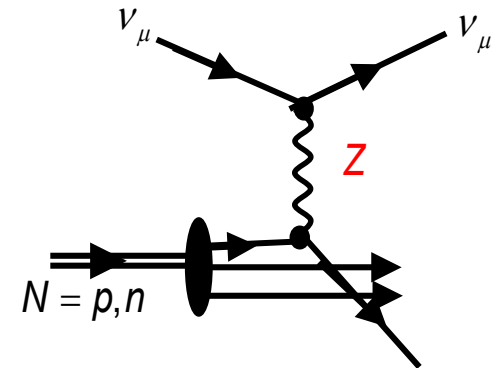


$$\nu_{\mu} + e^{-} \rightarrow \nu_{\mu} + e^{-}$$

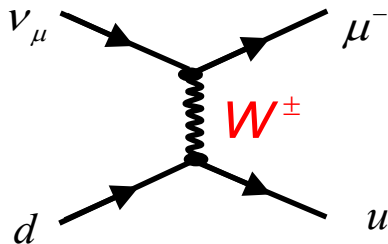


Clean but
very rare.

More frequent:
NC νN events.



Comparison with charged current events



$$R_{\nu} = \frac{\sigma_{NC}(\nu N \rightarrow \nu X)}{\sigma_{CC}(\nu N \rightarrow \mu X)} = 0.307 \pm 0.008 \quad \Rightarrow \quad \sin^2 \theta_W = 0.39 \pm 0.05$$