WEAK INTERACTION OF LEPTONS

LEPTON UNIVERSALITY

INTERACTION RATE!

FROM THE DECAY RATES OF e, μ, τ THEY ALL "SEE" THE WEAK INTERACTION WITH THE SAME STRENGTH

THEY COULD HAVE HAD DIFFERENT WEAK CHARGES

NOTE THAT THE e, μ, τ HAVE THE SAME ELECTRIC CHARGES

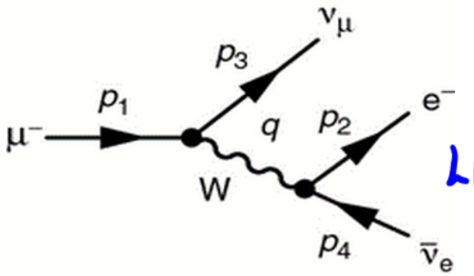
AGAIN THEY COULD (???) HAVE BEEN DIFFERENT.

THERE IS SOMETHING VERY IMPORTANT GOING ON

ALL LEPTONS SEE SAME WEAK CHARGE, ν.... ℓ.....

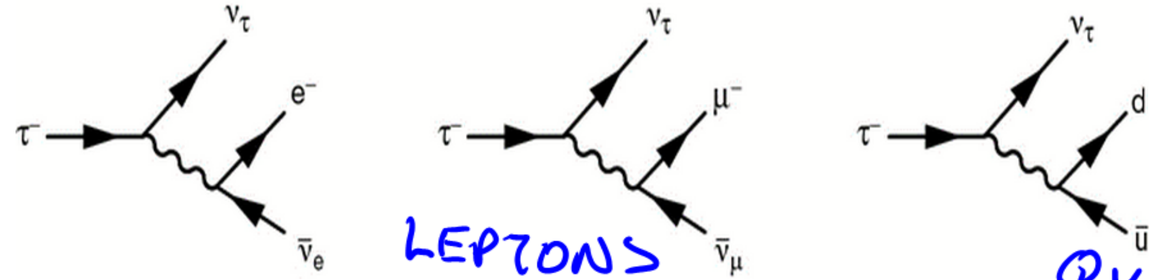
ALL LEPTONS HAVE ELECTRIC CHARGES $1 \times e$ OR $0 \times e$

ALL QUARK CHARGES $-\frac{1}{3}$, $+\frac{2}{3}$ HAVE A DIFFERENCE WHICH IS EQUAL TO e ???



LEPTONS

μ-DECAY



LEPTONS

QUARKS

τ-DECAY

μ DECAY INVOLVES TWO VERTICES $\mu^- \nu_\mu W$

$W e^- \bar{\nu}_e$

THESE TWO VERTICES COULD(??) HAVE HAD DIFFERENT COUPLINGS

$$\Gamma(\mu^- \to e^- \bar{\nu}_e \nu_\mu) = \frac{1}{\tau_\mu} = \frac{G_F^{(e)} G_F^{(\mu)} m_\mu^5}{192\pi^3} \qquad 12.1$$

$$\Gamma(\tau^- \to e^- \bar{\nu}_e \nu_\tau) = \frac{G_F^{(e)} G_F^{(\tau)} m_\tau^5}{192\pi^3} \qquad 12.2$$

THE μ CAN ONLY DECAY INTO AN e, DUE TO ENERGY CONSERVATION.

THE τ IS MASSIVE, IT CAN DECAY INTO μ OR MESONS COMPOSED OF LIGHT QUARKS

τ LIFETIME EXPRESSED AS TOTAL DECAY RATE

$$\frac{1}{\tau_\tau} = \Gamma = \sum_i \Gamma_i$$ ← PARTIAL DECAY RATES

RATIO OF PARTIAL WIDTH $\Gamma(\tau^- \to e^- \bar{\nu}_e \nu_\tau)$ TO THE TOTAL DECAY RATE GIVES THE BRANCHING RATIO

$$Br(\tau^- \to e^- \bar{\nu}_e \nu_\tau) = \frac{\Gamma(\tau^- \to e^- \bar{\nu}_e \nu_\tau)}{\Gamma} = \Gamma(\tau^- \to e^- \bar{\nu}_e \nu_\tau) \times \tau_\tau$$

WITH 12.2 THIS GIVES

$$\tau_\tau = \frac{192\pi^3}{G_F^e G_F^\tau M_\tau^5} \cdot Br(\tau^- \to e^- \bar{\nu}_e \nu_\tau) \quad 12.4$$

COMPARE EXPRESSIONS FOR τ_μ, τ_τ IN

12.1, 12.4

$$\frac{G_F^{(\tau)}}{G_F^{\mu}} = \frac{m_\mu^5 \tau_\mu}{m_\tau^5 \tau_\mu} Br\left(\tau^- \to e^- \bar{\nu}_e \nu_\tau\right)$$

MEASURED BRANCHING RATIOS ARE:

$Br\left(\tau^- \to e^- \bar{\nu}_e \nu_\tau\right) = 0.1783(5)$ $\quad$ $Br\left(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau\right) = 0.1741(4)$

MASSES AND LIFETIMES!

$m_\mu = 0.1056583715(35)\ \mathrm{GeV}$ $\quad$ $\tau_\mu = 2.1969811(22) \times 10^{-6}\ \mathrm{s}$

$m_\tau = 1.77682(16)\ \mathrm{GeV}$ $\quad$ $\tau_\tau = 0.2906(10) \times 10^{-12}\ \mathrm{s}$

$$\frac{G_F^{\tau}}{G_F^{\mu}} = 1.0023 \pm .0033 \qquad \frac{G_F^{e}}{G_F^{\mu}} = 1.006 \pm 0.004$$

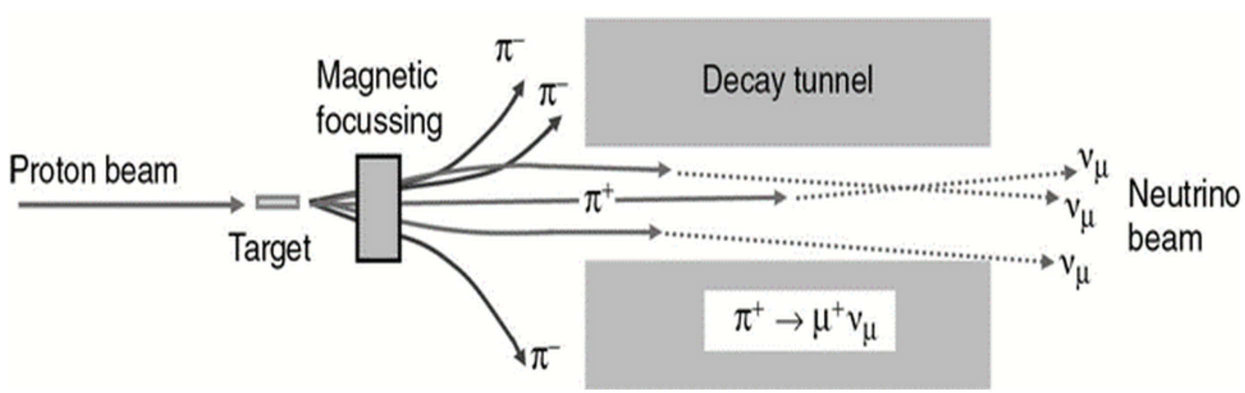
NEUTRINO SCATTERING

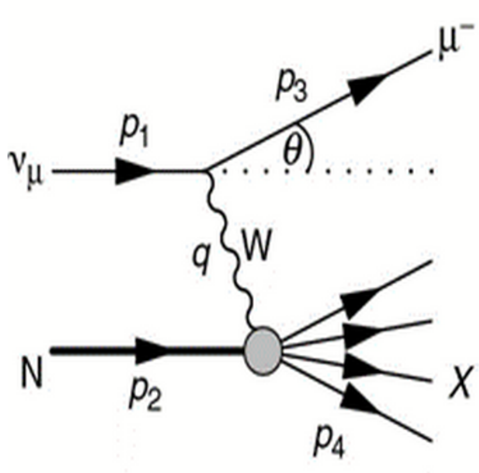
NEUTRINOS INTERACT VERY FEEBLY WITH MATTER

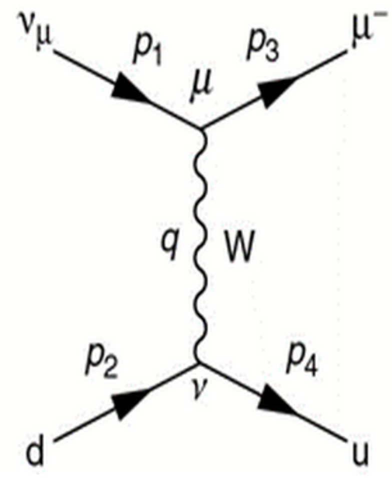
$$\sigma = 10^{-42}\,\mathrm{cm}^2 \cdot E_\nu\,(\mathrm{GeV})$$

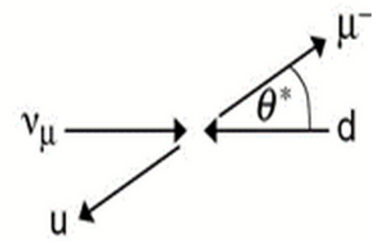
WITH A SUFFICIENTLY HIGH FLUX CAN SEE NEUTRINO INTERACTIONS

- POWER REACTOR β-DECAY
- SUN "
- SUPERNOVA "
- INTENSE ACCELERATOR BEAM









- AT $Q^2 < (1\,\mathrm{GeV})^2$ $\qquad \nu_\mu n \to \mu^- p$
- AT $Q^2 \sim (1\,\mathrm{GeV})^2$ $\qquad \nu_\mu n \to \mu^- \Delta^{++} \to \mu^- p \pi^0$
- $Q^2 > (10\,\mathrm{GeV})^2 \to$ DEEP INELASTIC SCATTERING

IN NUCLEON CMS

$$s = (p_1 + p_2)^2 = (E_\nu + m_N)^2 - E_\nu^2 = 2 m_N E_\nu + m_N^2$$

$$Q^2 = (s - m_N)^2 x y = 2 m_N E_\nu x y$$

$$Q^2 \leq 2 m_N E_\nu$$

HIGHEST ENERGY NEUTRINOS TEVATRON @FERMILAB

$E_\nu = 400\ \mathrm{GeV}, \quad Q^2 \lesssim 750\ \mathrm{GeV}^2$

AT THIS Q^2

$$\frac{-i\, g_{\mu\nu}}{q^2 - m_W^2} \longrightarrow \frac{i\, g_{\mu\nu}}{m_W^2}$$

$m_W^2 = 6.4 \times 10^3$

FOR E_ν LARGE, AS ABOVE

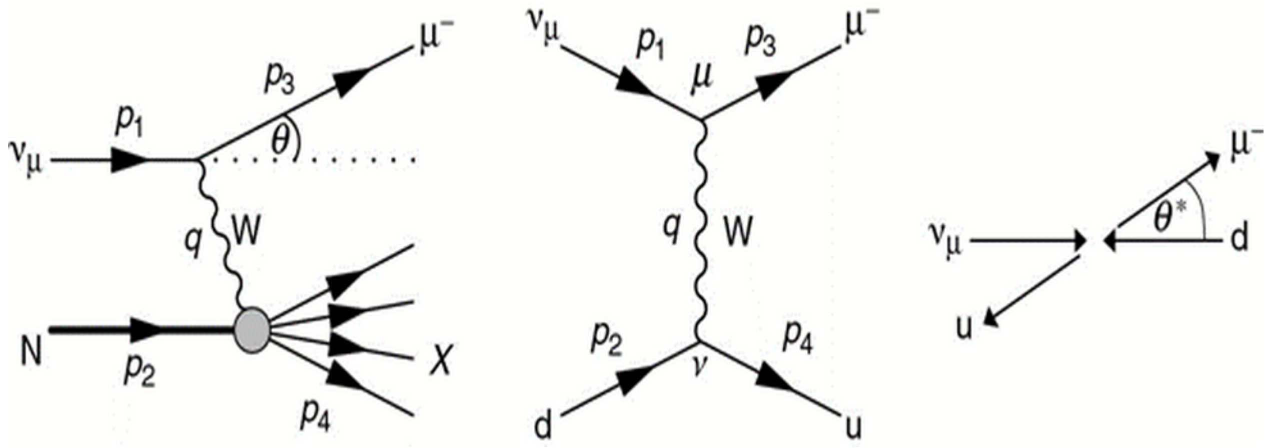
$$s = 2 m_N E_\nu + m_N^2 \longrightarrow 2 m_N E_\nu$$

$$\left.\begin{array}{l} \nu_\mu\, d \to \mu^- u \\ \nu_\mu\, \bar{u} \to \mu^- \bar{d} \end{array}\right\}$$

ONLY LH PARTICLES AND RH ANTIPARTICLES CONTRIBUTE

ONE HELICITY COMBINATION IN EACH SUB-PROCESS

NEUTRINO – QUARK SCATTERING



$$-i\mathcal{M}_{fi} = \left[-i\frac{g_W}{\sqrt{2}}\,\bar{u}(p_3)\gamma^\mu \frac{1}{2}(1-\gamma^5)u(p_1)\right] \times \frac{i g_{\mu\nu}}{m_W^2}$$

$\nu \rightarrow$

$$\left[-i g_W\,\bar{u}(p_4)\gamma^\nu \frac{1}{2}(1-\gamma^5)u(p_2)\right]$$

QUARK

$$\mathcal{M}_{fi} = \frac{g_W^2}{2m_W^2}\, g_{\mu\nu}\left[\bar{u}(p_3)\gamma^\mu \frac{1}{2}(1-\gamma^5)u(p_1)\right]\left[\bar{u}(p_4)\gamma^\nu \frac{1}{2}(1-\gamma^5)u(p_2)\right]$$

$$u_\downarrow = \underbrace{\frac{1}{2}\left(1-\frac{p}{E+m}\right)u_R + \frac{1}{2}\left(1+\frac{p}{E+m}\right)u_L}_{\text{CHIRAL}}$$

HELICITY

ONLY THIS CONTRIBUTES

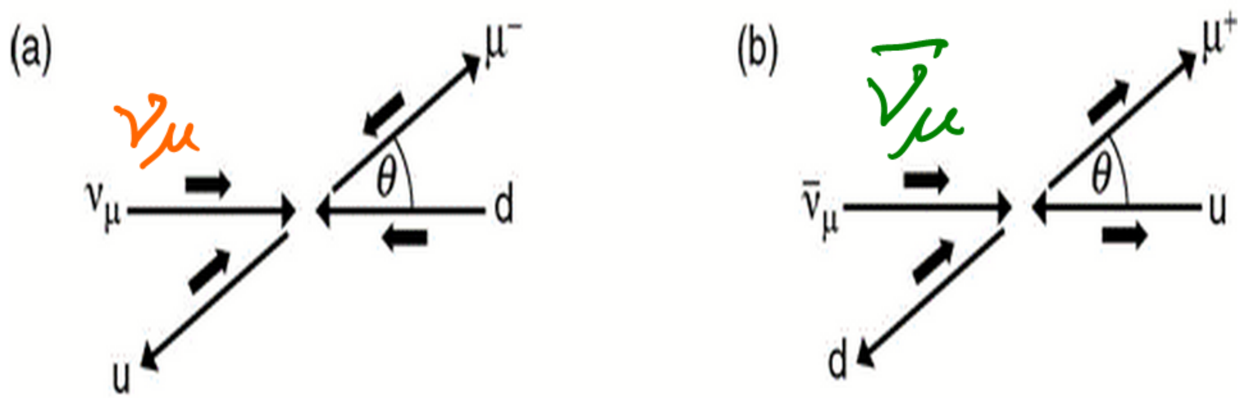
$E_\nu \gg m_q,\ m_\nu \qquad u_L \equiv u_\downarrow$

$$\mathcal{M}_{fi} = \frac{g_W^2}{2m_W^2}\, g_{\mu\nu}\left[\bar{u}_\downarrow(p_3)\gamma^\mu u_\downarrow(p_1)\right]\left[\bar{u}_\downarrow(p_4)\gamma^\nu u_\downarrow(p_2)\right]$$

$$= \frac{g_W^2}{2m_W^2}\cdot J_e \cdot J_q$$

LEPTON CURRENT

QUARK CURRENT.



CENTRE OF MASS

$$\nu_\mu d \to \mu^- u$$

$$(\theta_1 \phi_1) = (0, 0), \quad (\theta_2 \phi_2) = (\pi, \pi)$$

$$(\theta_3 \phi_3) = (\theta^*, 0), \quad (\theta_4, \phi_4) = (\pi - \theta^*, \pi)$$

LEFT HANDED SPINORS

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

$$u_\downarrow(p_4) = \sqrt{E}\begin{pmatrix} -c \\ -s \\ c \\ s \end{pmatrix}$$

AS USUAL, USE

$$\bar{\psi}\gamma^0\phi = \psi^\dagger\gamma^0\gamma^0\phi = \psi_1^*\phi_1 + \psi_2^*\phi_2 + \psi_3^*\phi_3 + \psi_4^*\phi_4$$

$$\bar{\psi}\gamma^1\phi = \psi^\dagger\gamma^0\gamma^1\phi = \psi_1^*\phi_4 + \psi_2^*\phi_3 + \psi_3^*\phi_2 + \psi_4^*\phi_1$$

$$\bar{\psi}\gamma^2\phi = \psi^\dagger\gamma^0\gamma^2\phi = -i(\psi_1^*\phi_4 - \psi_2^*\phi_3 + \psi_3^*\phi_2 - \psi_4^*\phi_1)$$

$$\bar{\psi}\gamma^3\phi = \psi^\dagger\gamma^0\gamma^3\phi = \psi_1^*\phi_3 - \psi_2^*\phi_4 + \psi_3^*\phi_1 - \psi_4^*\phi_2$$

$$j_\ell^\mu = \bar{u}_\downarrow(p_3)\gamma^\mu u_\downarrow(p_1) = 2E(c, s, -is, c)$$

$$j_q^\nu = \bar{u}_\downarrow(p_4)\gamma^\nu u_\downarrow(p_2) = 2E(c, -s, -is, -c)$$

$$\mathcal{M}_{fi} = \frac{g_W^2}{2m_W^2}\, j_\ell \cdot j_q = \frac{g_W^2}{2m_W^2} 4E^2(c^2+s^2+s^2+c^2)$$

$$\mathcal{M}_{fi} = \frac{g_W^2}{m_W^2} \cdot \hat{s} \longleftarrow \hat{s} = (2E)^2$$

q, ℓ IN LH $\rightarrow$ $S_z = 0$ $\rightarrow$ NO PREFERRED POLAR ANGLE

GENERALLY $$\frac{d\sigma}{d\Omega^*} = \frac{1}{64\pi^2 s} \cdot \frac{p_f^*}{p_i^*} \langle |M_{fi}|^2 \rangle$$

HERE $$\frac{d\sigma}{d\Omega^2} = \frac{1}{64\pi^2 \hat{s}} \cdot \langle |M_{fi}|^2 \rangle$$

IN QED $\rightarrow$ SPIN AVERAGE $\rightarrow$ $\frac{1}{4}$

HERE ν IS ALWAYS LH $\leftarrow$ PRODUCED IN WEAK

$\pi \rightarrow \mu \nu \hookrightarrow$ LH

SO ONLY HAVE TO AVERAGE OVER SPINS OF QUARK

$$\mathcal{M}_{fi} = \frac{g_W^2 \hat{s}}{m_W^2} \rightarrow \langle |M_{fi}|^2 \rangle = \frac{1}{2} \left(\frac{g_W^2}{m_W^2} \cdot \hat{s} \right)$$

$$\frac{d\sigma}{d\Omega^*} = \frac{1}{64\pi^2 \hat{s}} \cdot \langle |M_{fi}|^2 \rangle = \left(\frac{g_W^2}{8\sqrt{2}\,\pi m_W^2} \right)^2 \hat{s}$$

IF WE PUT $G_F = \sqrt{2}\, g_W^2 / 8 m_W^2$

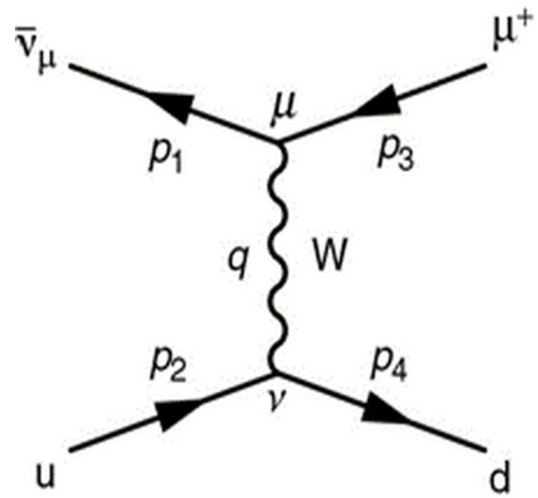
$$\frac{d\sigma^{\nu q}}{d\Omega^*} = \frac{G_F^2}{4\pi^2} \hat{s}$$

$\int$ OVER ISOTROPIC DISTRIBUTIONS $\rightarrow 4\pi$

$$\sigma_{\nu q} = \frac{G_F^2 \hat{s}}{4\pi^2}$$

ANTI-NEUTRINO QUARK SCATTERING

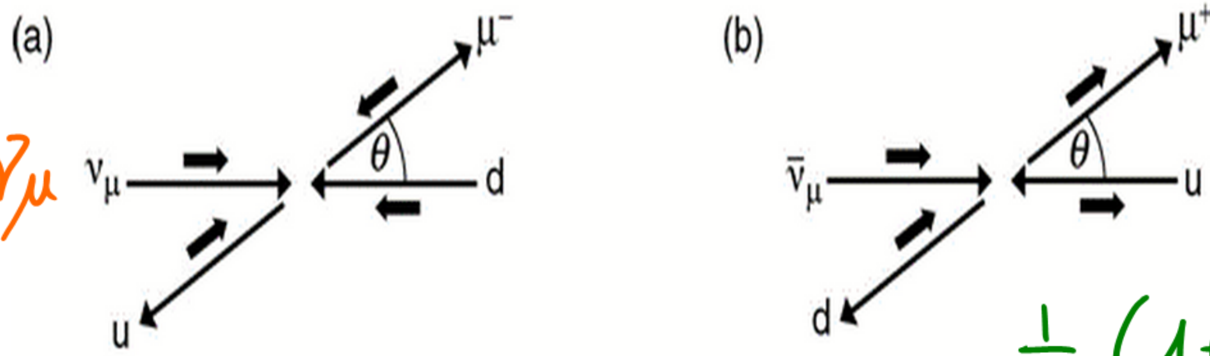
$\bar{\nu}$ → $\bar{\nu}_\mu u \to \mu^+ d$ → CONSERVE CHARGE



$$\mathcal{M}_{fi} = \frac{g_w^2}{2m_W^2} g_{\mu\nu} \left[\bar{v}(p_1) \gamma^\mu \frac{1}{2}(1-\gamma^5) v(p_3) \right] \left[\bar{u}(p_4) \gamma^\nu \frac{1}{2}(1-\gamma^5) u(p_2) \right]$$

AS BEFORE $\mathcal{M}_{\bar{\nu}q} = \frac{1}{2}(1+\cos\theta^*) \frac{g_W^2}{m_W^2} \cdot \hat{s}$

ν_μ



$\bar{\nu}_\mu$

ISOTROPIC

$S_z = 0$

$\frac{1}{2}(1+\cos\theta^*)$

$S_z = 1$

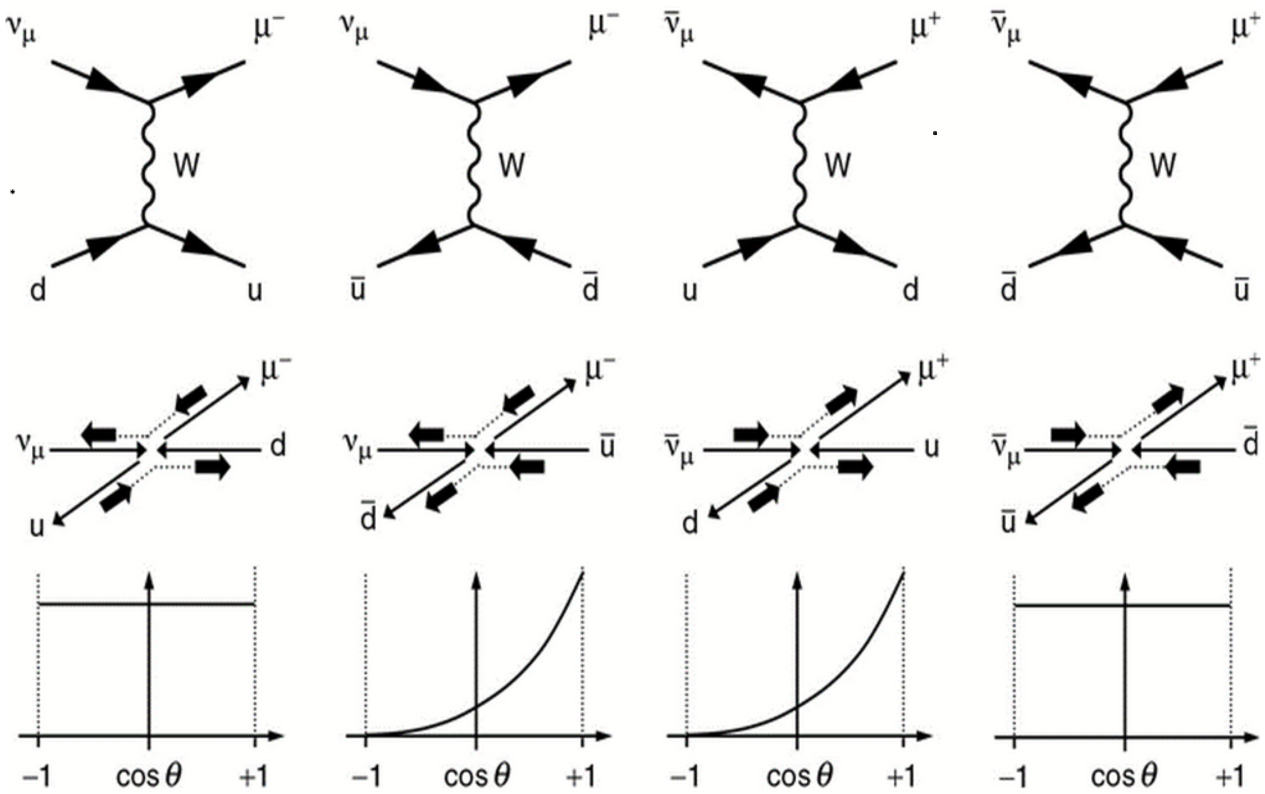
$$\frac{d\sigma^{\bar{\nu}q}}{d\Omega^*} = \frac{1}{4}(1+\cos\theta^*)^2 \frac{d\sigma_{\nu q}}{d\Omega^*} = \frac{G_F^2}{16\pi^2}(1+\cos\theta^*)^2\,\hat{s}$$

$$\int (1+\cos\theta^*)^2\, d\Omega^* = \int_0^{2\pi} d\phi^* \int_{-1}^{+1}(1+x^2)\,dx = 16\pi/3$$

$$\sigma_{\bar{\nu}q} = \frac{G_F^2\,\hat{s}}{3\pi}$$

$$\frac{\sigma_{\bar{\nu}q}}{\sigma_{\nu q}} = 1/3$$

NEUTRINO-NUCLEON DIFFERENTIAL CROSS SECTIONS



$\nu_\mu d \rightarrow \mu^- u$

$\nu_\mu \bar{u} \rightarrow \mu^- \bar{d}$

$\bar{\nu}_\mu u \rightarrow \mu^+ d$

$\bar{\nu}_\mu \bar{d} \rightarrow \mu^+ u$

CHARGE CONSERVATION

$\nu \leftrightarrow \mu^-$ $\qquad$ $\bar{\nu} \leftrightarrow \mu^+$

FOR EACH OF THESE FOUR PROCESSES $\rightarrow$ ONE HELICITY COMBINATION

BY LOOKING AT SPIN STATES

$$\frac{d\sigma_{\bar{\nu}\bar{d}}}{d\Omega^*} = \frac{d\sigma_{\nu d}}{d\Omega^*} = \frac{G_F^2 \hat{s}}{4\pi^2} \; ; \quad \frac{d\sigma_{\nu\bar{u}}}{d\Omega^*} = \frac{d\sigma_{\bar{\nu}u}}{d\Omega^*} = \frac{G_F^2}{16\pi^2} \hat{s} \left(1+\cos\theta^*\right)^2$$

$$d\Omega^* = d\phi^* \, d(\cos\theta^*) \longrightarrow \int d\phi^*$$

$$\frac{d\sigma_{\bar{\nu}\bar{d}}}{d(\cos\theta^*)} = \frac{d\sigma_{\nu d}}{d(\cos\theta^*)} = \frac{G_F^2 \hat{s}}{2\pi}$$

$$\frac{d\sigma_{\bar{\nu}u}}{d(\cos\theta^*)} = \frac{d\sigma_{\nu\bar{u}}}{d(\cos\theta^*)} = \frac{G_F^2 \hat{s}}{8\pi} \left(1+\cos\theta^*\right)^2$$

CAN EXPRESS THESE CMS DIFFERENTIAL σ IN TERMS OF LORENTZ INVARIANTS

$$y = \frac{p_2 \cdot q}{p_2 \cdot p_1} \longrightarrow \frac{E_\mu}{E_\nu} \longrightarrow \text{MEASURED IN LAB}$$

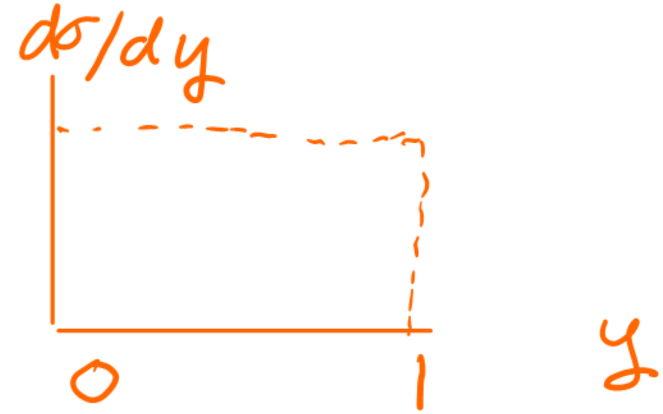
ELASTIC νq IN CMS:-

$$p_1 = (E, 0, 0, E), \quad p_2 = (E, 0, 0, -E), \quad p_3 = (E, 0, E\sin\theta^*, E\cos\theta^*)$$

$$y = \frac{p_2 \cdot q}{p_2 \cdot p_1} = \frac{p_2 (p_1 - p_3)}{p_2 \cdot p_1} = \frac{1}{2}(1 - \cos\theta^*)$$

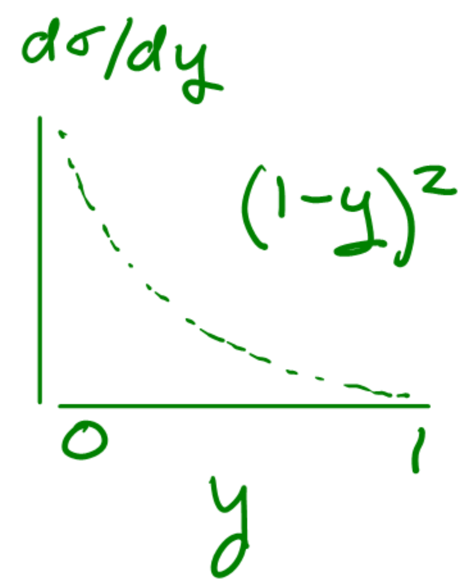
$$\frac{dy}{d(\cos\theta^*)} = \left| \frac{d(\cos\theta^*)}{dy} \right| \frac{d\sigma}{d(\cos\theta^*)} = 2 \cdot \frac{d\sigma}{d(\cos\theta^*)}$$

$$\frac{d\sigma_{\nu q}}{dy} = \frac{d\sigma_{\bar{\nu}\bar{q}}}{dy} = \frac{G_F^2\,\hat{s}}{\pi}$$

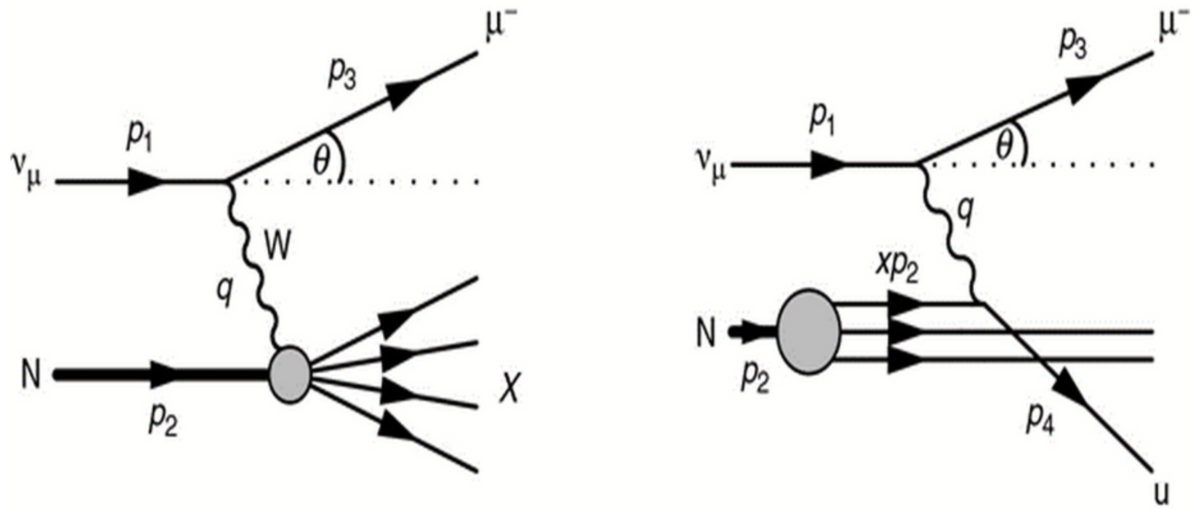


$\bar{\nu}$ $\qquad (1-y) = \frac{1}{2}(1+\cos\theta^*)$

$$\frac{d\sigma_{\bar{\nu} q}}{dy} = \frac{d\sigma_{\nu\bar{q}}}{dy} = \frac{G_F^2}{\pi}(1-y^2)\,\hat{s}$$



NEUTRINO DEEP INELASTIC SCATTERING



NEGLECT $s\bar{s}$ SEA

$$\nu_\mu p \longrightarrow \nu_\mu d \to \mu^- u + \nu_\mu \bar{u} \to \mu^- \bar{d}$$

$$\frac{d\sigma^{\nu p}}{d\hat{y}} = \frac{G_F^2 \hat{s}}{\pi} \left[d(x) + (1-\hat{y})^2 \bar{u}(x) \right] dx$$

$\hat{y}, \hat{s} \to \nu q$ CMS

NUMBER d QUARKS IN RANGE $x \to x + dx$ IS $d(x)dx$

$$\hat{s} = (p_1 + x p_2)^2 \approx 2x\, p_1 \cdot p_2 = x S$$

$$\hat{y} = \frac{x P_q \cdot q}{x p_2 \cdot p_1} = y$$

$$\frac{d^2\sigma^{\nu p}}{dx\,dy} = \frac{G_F^2}{\pi} s \cdot x \left[\overset{\text{VALENCE}}{d(x)} + (1-y)^2 \overset{\text{SEA}}{\bar{u}(x)} \right]$$

FOR $\bar{\nu}$ $\quad \bar{\nu} p \to$

$$\bar{\nu} u \to \mu^+ \bar{d}$$

$$\bar{\nu} \bar{d} \to \mu^+ \bar{u}$$

$$\frac{d^2\sigma^{\bar{\nu} p}}{dx\,dy} = \frac{G_F^2}{\pi} s x \left[(1-y)^2 \underset{\text{VALENCE}}{u(x)} + \overset{\text{SEA}}{\bar{d}(x)} \right]$$

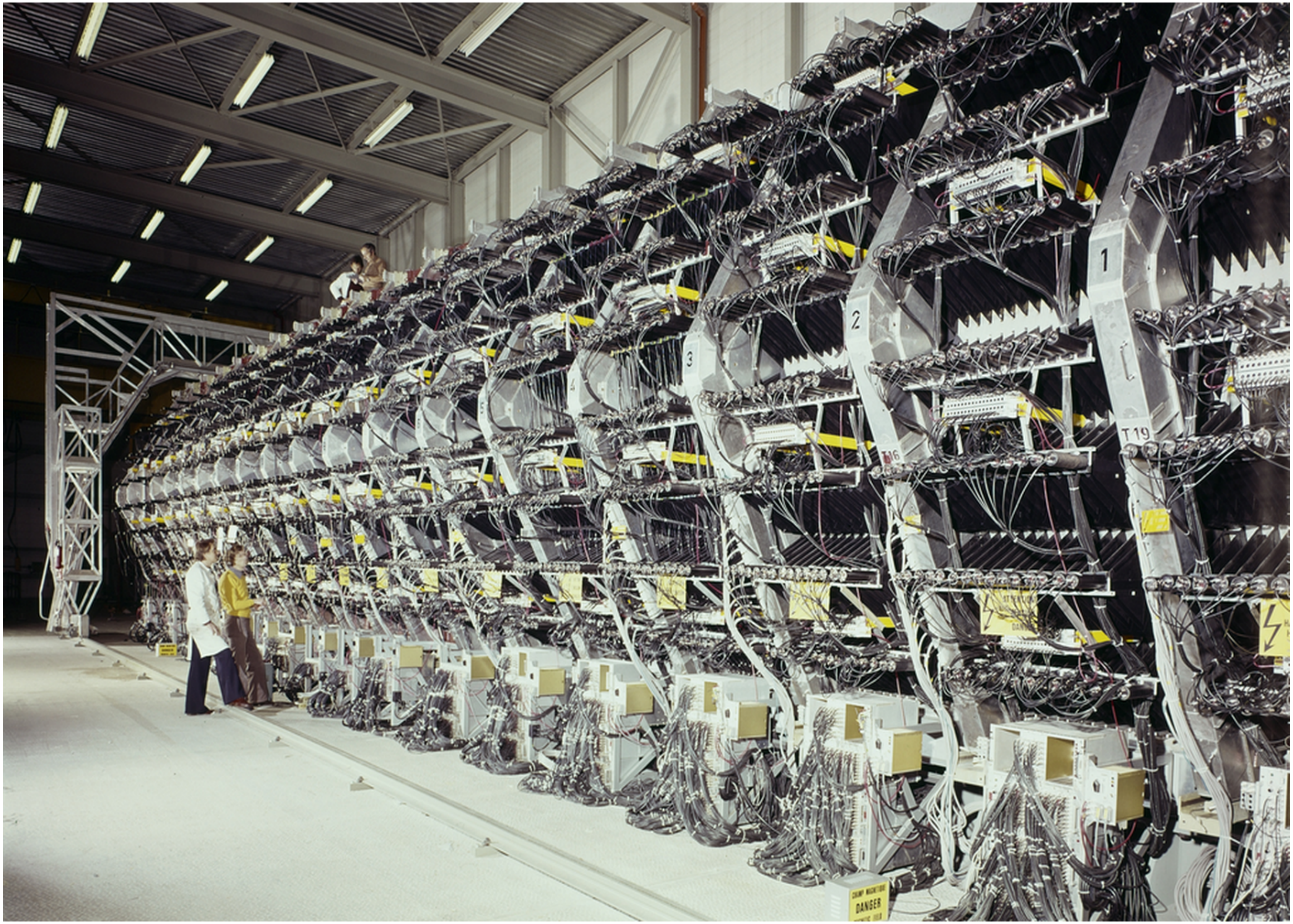
IN ep WE HAD PROTON TARGET — LIQUID HYDROGEN

$\sigma_{\nu p}$ IS SO SMALL THAT WE NEED A VERY MASSIVE TARGET $\rightarrow$ DENSE, LARGE $\rightarrow$ Fe $\rightarrow$ n + p IN NUCLEUS

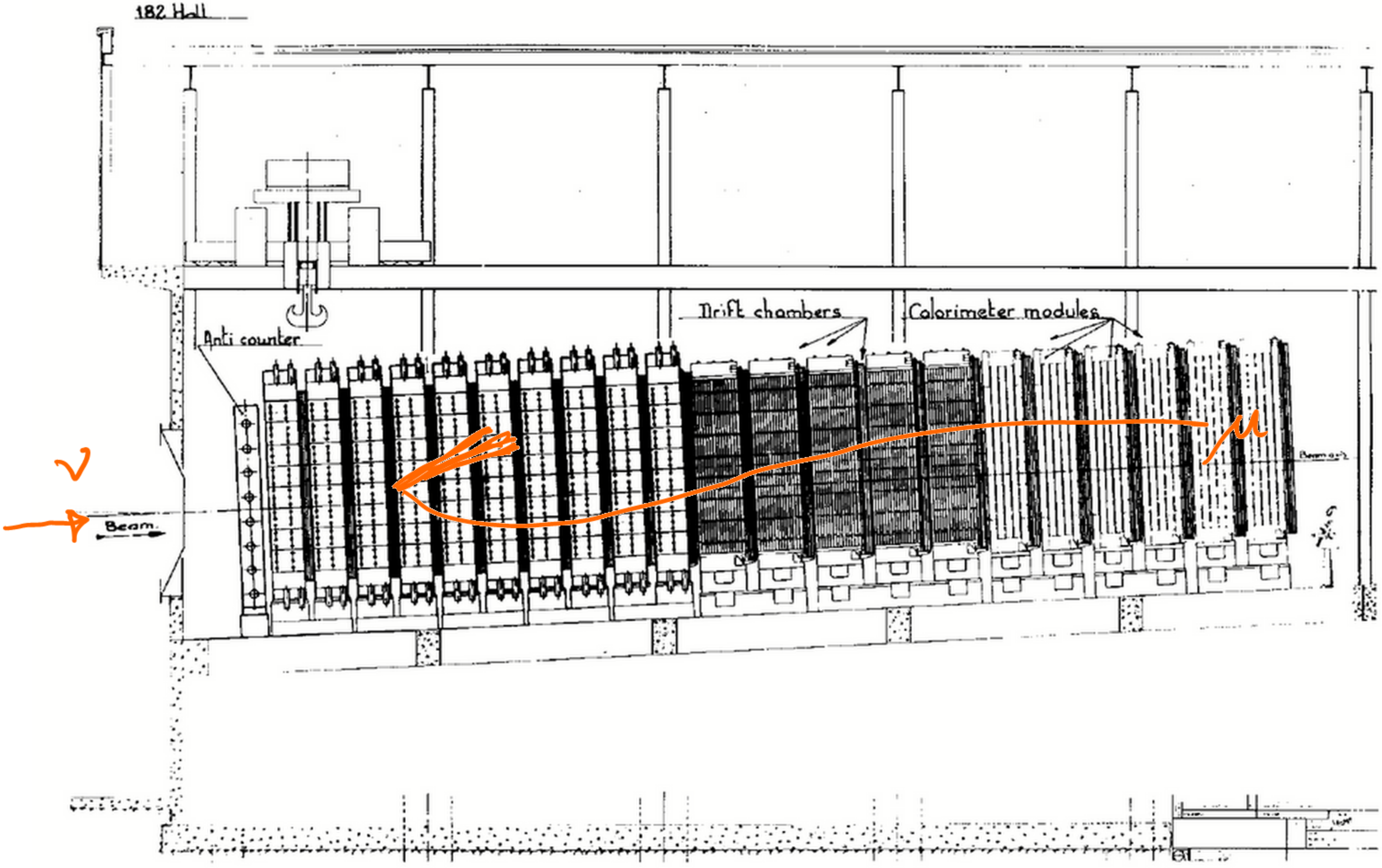
ISOSPIN $\rightarrow$ $d^n(x) = u(x)$

$$\frac{d^2\sigma^{\nu n}}{dx\,dy} = \frac{G_F^2}{\pi} s \cdot x \left[u(x) + (1-y)^2 \bar{d}(x) \right]$$

$$\frac{d^2\sigma^{\bar{\nu} n}}{dx\,dy} = \frac{G_F^2}{\pi} s \cdot x \left[(1-y)^2 d(x) + \bar{u}(x) \right]$$



1250 TONNES OF STEEL



182 Hall
Anti counter
Drift chambers
Colorimeter modules
Beam
Beam axis
ν
μ

THE DETECTOR $\equiv$ TARGET

STEEL $\;{}^{26}Fe_{56}$ $\rightarrow$ PROTONS $\approx$ NEUTRONS

$\rightarrow$ ISOSCALAR TARGET.

$$\frac{d^2\sigma^{\nu N}}{dx\,dy} = \frac{1}{2}\left(\frac{d^2\sigma^{\nu p}}{dx\,dy} + \frac{d^2\sigma^{\nu n}}{dx\,dy}\right)$$

$$\frac{d^2\sigma^{\nu N}}{dx\,dy} = \frac{G_F^2 m_N}{\pi} E_\nu x \left[\underbrace{d(x)+u(x)}_{\text{VALENCE}} + (1-y)^2 \underbrace{\left[\bar{u}(x)+\bar{d}(x)\right]}_{\text{SEA}}\right]$$

$\int dx \rightarrow \int$ OVER STRUCK QUARK
FRACTION OF PROTON MOMENTUM

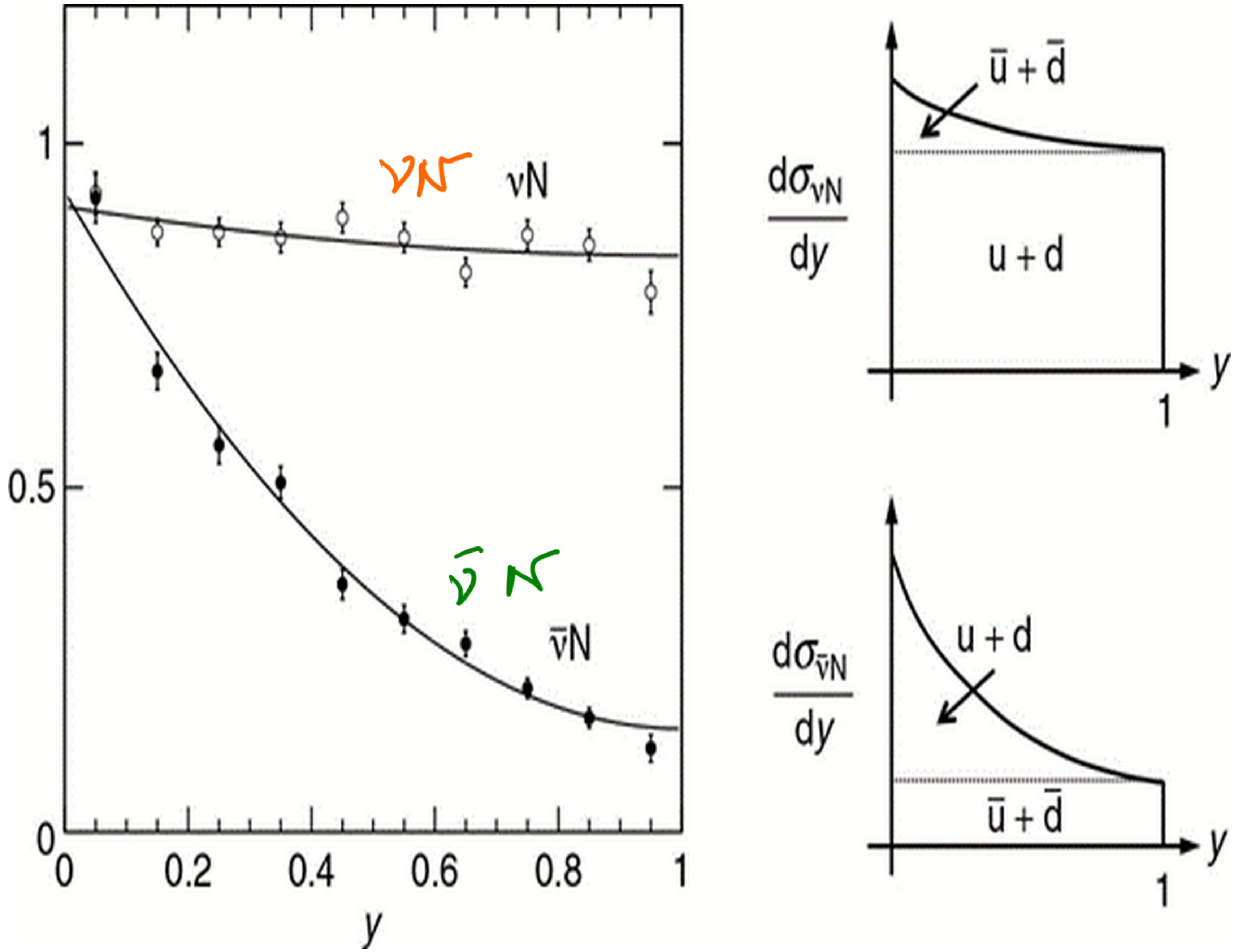
$$\frac{d\sigma^{\nu N}}{dy} = \frac{G_F^2 m_N}{\pi} E_\nu \left[f_q + (1-y)^2 f_{\bar{q}} \right]$$

$$f_q = \int_0^1 x\left[u(x) + d(x)\right] dx \qquad f_{\bar{q}} = \int_0^1 x\left[\bar{u}(x) + \bar{d}(x)\right] dx$$

IN SAME WAY

$$\frac{d^2\sigma^{\bar{\nu} N}}{dx\,dy} = \frac{G_F^2 m_N}{\pi} E_\nu x \left[\underbrace{(1-y)^2 \left\{ u(x) + d(x) \right\}}_{\text{VALENCE}} + \underbrace{\bar{u}(x) + \bar{d}(x)}_{\text{SEA}} \right]$$

$$\frac{d\sigma^{\bar{\nu} N}}{dy} = \frac{G_F^2 m_n}{\pi} E_x \left[(1-y)^2 f_q + f_{\bar{q}} \right]$$



νN
νN
ν̄ N
ν̄N
0
0.5
1
0
0.2
0.4
0.6
0.8
1
y
dσ_νN / dy
ū + d̄
u + d
y
1
dσ_ν̄N / dy
u + d
ū + d̄
y
1

TO GET σ = TOTAL CROSS SECTION $\sigma = \int \frac{d\sigma}{dy} \cdot dy$

$$\sigma^{\nu N} = \frac{G_F^2 m_N E_\nu}{\pi}\left[f_q + \frac{1}{3} f_{\bar{q}}\right]$$

$$\sigma^{\bar{\nu} N} = \frac{G_F^2 m_N E_\nu}{\pi}\left[\frac{1}{3} f_q + f_{\bar{q}}\right]$$

$$\frac{\sigma^{\nu N}}{\sigma^{\bar{\nu} N}} = \frac{3f_q + f_{\bar{q}}}{f_q + 3f_{\bar{q}}} \longrightarrow 3$$

FOR VALENCE QUARKS

$\downarrow$ NO $\bar{q}$

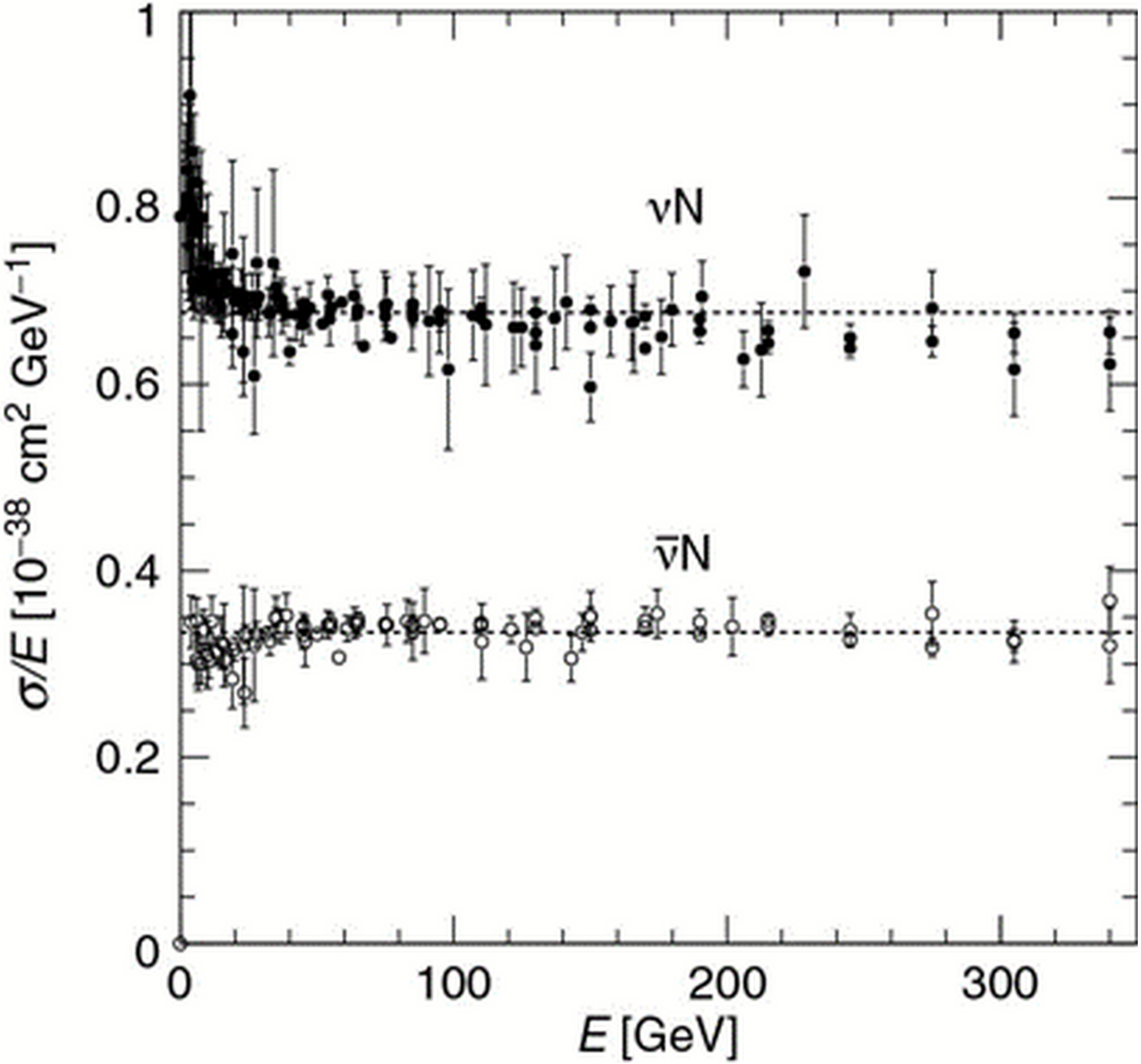
$$\sigma^{\nu N}/E_\nu = 0.677 \pm 0.014 \times 10^{-38}\,\mathrm{cm}^2\,\mathrm{GeV}^{-1}$$

$$\sigma^{\bar{\nu} N}/E_\nu = 0.334 \pm 0.008 \times 10^{-38}\,\mathrm{cm}^2\,\mathrm{GeV}^{-1}$$

$$\frac{\sigma^{\nu N}}{\sigma^{\bar{\nu} N}} = 1.984 \pm 0.012$$

$f_q = 0.41 \leftarrow$ VALENCE

$f_{\bar{q}} = 0.08 \leftarrow$ SEA



νN
ν̄N
1
0.8
0.6
0.4
0.2
0
100
200
300
σ/E [10⁻³⁸ cm² GeV⁻¹]
E [GeV]

STRUCTURE FUNCTIONS IN νN

$e^{\pm} p$ DEEP INELASTIC

$$\frac{d^2\sigma^{ep}}{dx\,dy} = \frac{4\pi\alpha^2 s}{Q^4}\left[(1-y)F_2(x,Q^2) + y^2 x F_1(x,Q^2)\right]$$

THIS CONSERVES PARITY → VIOLATED IN νN

$$\frac{d^2\sigma^{\nu p}}{dx\,dy} = \frac{G_F^2 s}{2\pi}\left[(1-y)F_2^{\nu p}(x,Q^2) + y^2 x F_1^{\nu p}(x,Q^2) + y\left(1-\frac{y}{2}\right)x F_3^{\nu p}(x,Q^2)\right]$$

$$\frac{d^2\sigma^{\bar{\nu} p}}{dx\,dy} = \frac{G_F^2}{2\pi}\left[(1-y)F_2^{\bar{\nu} p}(x,Q^2) + y^2 x F_1(x,Q^2) \mp y\left(1-\frac{y}{2}\right)x F_3^{\bar{\nu} p}(x,Q^2)\right.$$

COMPARE POWERS

$$\frac{d^2\sigma^{\nu p}}{dx\,dy} = \frac{G_F^2}{\pi} s x\left[d(x) + (1-y)^2\bar{u}(x)\right]$$

$$F_2^{\nu p} = 2x F_1^{\nu p} = 2x\left[d(x) + \bar{u}(x)\right]$$

$$x F_3^{\nu p} = 2x\left[d(x) - \bar{u}(x)\right]$$

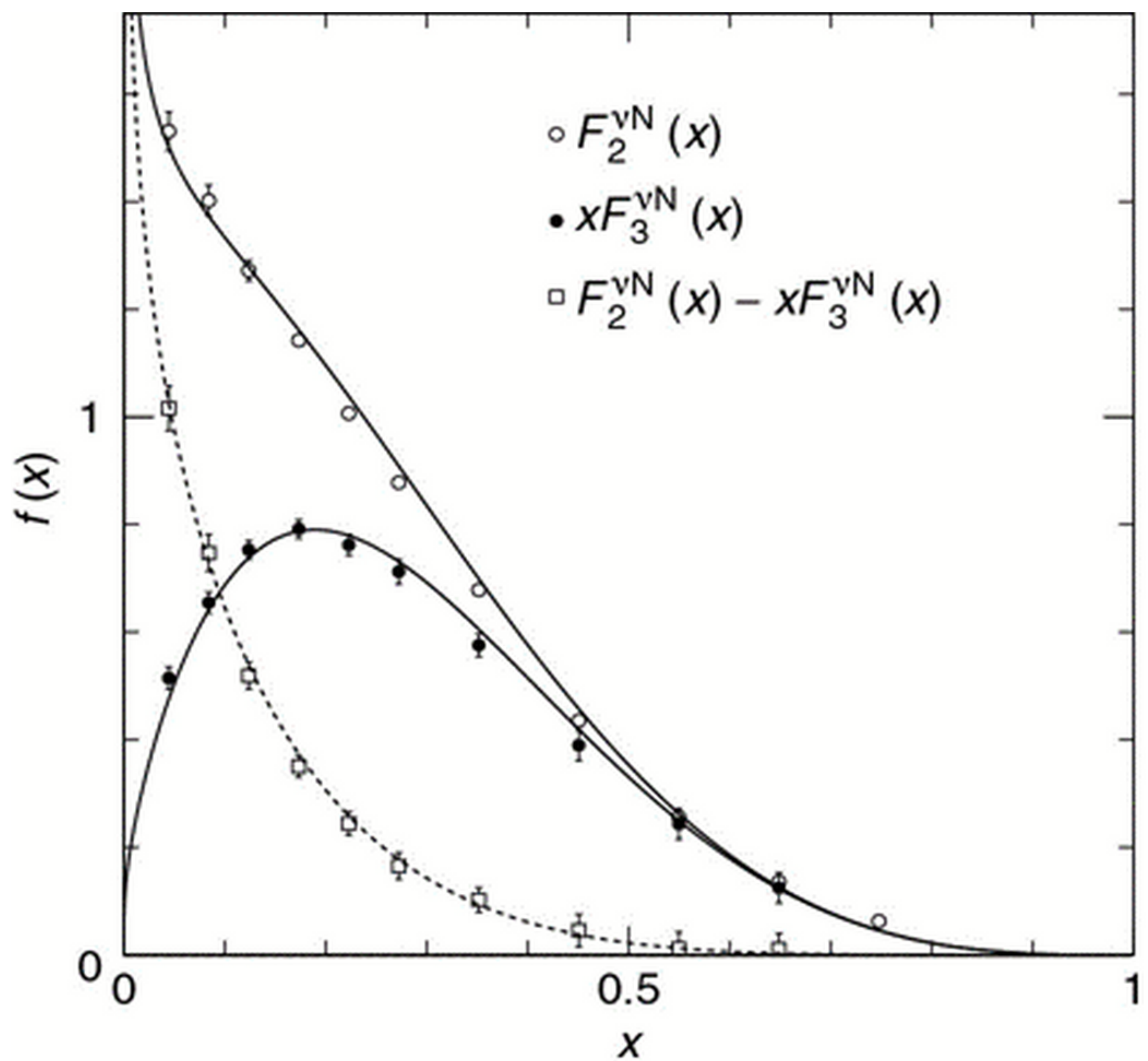
FOR νN

$$F_2^{\nu N} = 2x F_1^{\nu N} = \frac{1}{2}\left(F_2^{\nu p} + F_2^{\nu n}\right) = x\left[u(x) + d(x) + \bar{u}(x) + \bar{d}(x)\right]$$

$$x F_3^{\nu N}(x) = \frac{1}{2}\left(x F_3^{\nu p} + x F_3^{\nu n}\right) = x\left[u(x) + d(x) - \bar{u}(x) - \bar{d}(x)\right]$$

PARTON MODEL $F_2^{\nu N} = 2x F_1^{\nu N}$

$$\frac{d^2\sigma^{\nu N}}{dx\,dy} = \frac{G_F^2 s}{2\pi}\left[\left(1 - y + \frac{y^2}{2}\right) F_2^{\nu N}(x, Q^2) + y\left(1 - \frac{y}{2}\right) x F_3^{\nu N}(x, Q^2)\right]$$



EXTRACT F_3 BY MEASURING y-DIST AT A VALUE of x

$$F_2^{\nu N}(x) - xF_3^{\nu N}(x) = 2x\underbrace{\left[\bar{u}(x) + \bar{d}(x)\right]}_{\text{ANTIQUARK CONTENT}}$$

IN THE $q\bar{q}$ SEA, EQUAL NUMBERS $u(x)$ & $\bar{u}(x)$

SO $u(x) - \bar{u}(x) \rightarrow$ VALENCE u QUARKS

$$F_3^{\nu N}(x) = u_v + d_v \rightarrow \text{VALENCE}$$

$$\int F_3^{\nu N}(x)\,dx = \int_0^1 u_v(x) + d_v(x)\,dx = 3$$

NUMBER OF VALENCE QUARKS