Fisica Nucleare e Subnucleare III

verifiche sperimentali
del Modello Standard

predizioni del modello standard.

- esistenza delle correnti deboli neutre
- relazione tra gli accoppiamenti CC e NC
- proprietà dei bosoni vettori
- esistenza del bosone di Higgs

verifiche

- scattering di neutrino
- produzione diretta dei bosoni vettori
- ricerca del bosone di Higgs

Cinematica della diffusione di neutrino su bersaglio

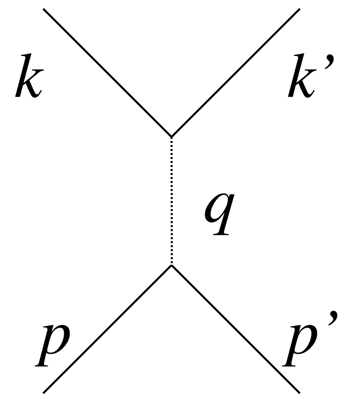
$$y = \frac{p \cdot q}{p \cdot k}$$

$$k \equiv \left(E_\nu, \vec{E}_\nu\right)$$

$$p \equiv \left(m, 0\right) \qquad p' = (E', \vec{p}\,')$$

$$q = k - k' = p' - p \equiv \left(\nu, \vec{q}\right)$$

$$\nu = E' - m \qquad \vec{q} = \vec{p}\,'$$



Nel laboratorio:

$$y = \frac{m\nu}{mE_\nu} = \frac{E' - m}{E_\nu} \approx \frac{E'}{E_\nu}$$

nel c.d.m.:

$$\left|p^*\right| = \left|k^*\right|$$

$$p^* \equiv \left(p^*, \vec{p}^{\,*}\right), k^* \equiv \left(p^*, -\vec{p}^{\,*}\right)$$

$$p^* \cdot k'^* = p^{*2} - p^{*2} \cos\vartheta^*$$

$$p^* \cdot k^* = 2p^{*2}$$

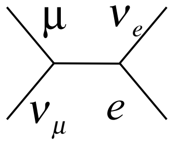
$$y = \frac{p^* \cdot \left(k^* - k'^*\right)}{p^* \cdot k^*} = \frac{1 - \cos\vartheta^*}{2} = \tfrac{1}{2}\left(1 - \cos\vartheta^*\right)$$

$$\left(1 - y\right)^2 = \tfrac{1}{4}\left(1 + \cos\vartheta^*\right)^2$$

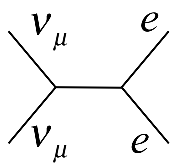
reazioni neutrino-elettrone

CC NC

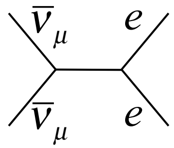
$$\nu_\mu e \to \nu_e \mu$$



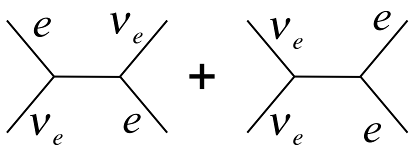
$$\nu_\mu e \to \nu_\mu e$$



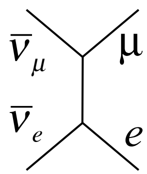
$$\bar{\nu}_\mu e \to \bar{\nu}_\mu e$$



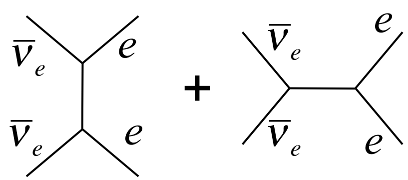
$$\nu_e e \to \nu_e e$$



$$\bar{\nu}_e e \to \bar{\nu}_\mu \mu$$



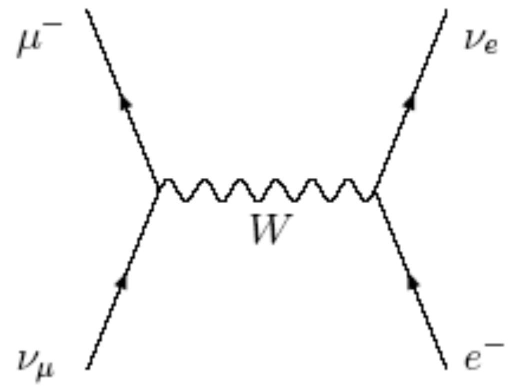
$$\bar{\nu}_e e \to \bar{\nu}_e e$$



correnti cariche ν-e^-

Le CC ν_μ e ν_e su elettrone sono paradigmatiche rispetto a tutti i processi neutrino-fermione:

Consideriamo $\nu_\mu e^- \to \nu_e \mu^-$



Il processo è in onda s

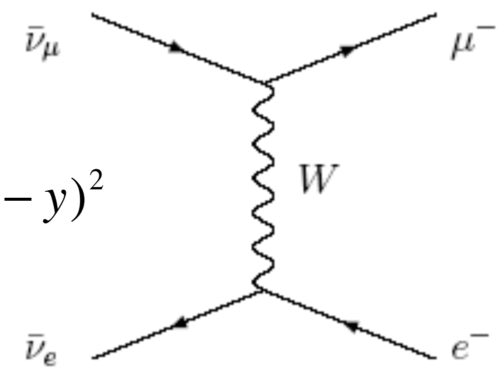
(partecipano solo e_L)

la distribuzione angolare è isotropica

la sezione d'urto totale è (per $s >> m_e^2$)

$$\sigma[\nu_\mu e^- \to \nu_e \mu^-] = \frac{G_F^2 s}{\pi}$$

Consideriamo ora $\bar{\nu}_e e^- \to \bar{\nu}_\mu \mu^-$



Lo spin totale è 1

la distribuzione angolare è $\sim (1 + \cos\theta)^2 \propto (1-y)^2$

la sezione d'urto totale è

$$\sigma[\bar{\nu}_e e^- \to \bar{\nu}_\mu \mu^-] = \frac{1}{3}\frac{G_F^2 s}{\pi}$$

calcolo numerico:

G=1.166 10^{-5} GeV^{-2}

$$\sigma = \frac{G^2 s}{\pi} = \frac{G^2\, 2mE_\nu}{\pi} = \frac{\left(1.166\cdot 10^{-5}\right)^2 2mE_\nu}{\pi} = \frac{\left(1.166\cdot 10^{-5}\right)^2 2mE_\nu}{\pi} = \frac{1.36\cdot 10^{-10} 2mE_\nu}{\pi}\,\mathrm{GeV}^{-2}$$

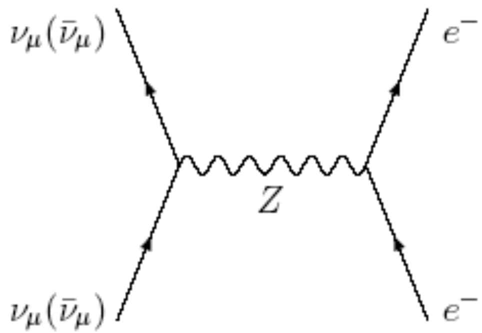
$$\sigma = \frac{G^2 s}{\pi} = \frac{1.36\cdot 10^{-10} 2mE_\nu}{\pi}\cdot\left(5.07\cdot 10^{15}\right)^{-2}\,\mathrm{m}^{-2} = \frac{5,29\cdot 10^{-38} 2mE_\nu}{\pi}\,\mathrm{cm}^{-2} \approx 1.7\cdot 10^{-38} 2mE_\nu \mathrm{cm}^2$$

$$= 1.7\cdot 10^{-41} E_\nu (\mathrm{GeV})\mathrm{cm}^2$$

correnti neutre ν_μ-e^-

le reazioni di corrente neutra sono

$$\nu_\mu e^- \rightarrow \nu_\mu e^-$$
$$\bar{\nu}_\mu e^- \rightarrow \bar{\nu}_\mu e^-$$



Qui dobbiamo considerare che lo Z interagisce sia con e_R che con e_L per cui ci sarà sia una componente
a spin totale 1 che una a spin zero

$$\bar{u}_e \gamma_\mu \left[\tfrac{1}{2}\left(1-\gamma^5\right) I_3 - Q \sin^2\vartheta_w\right] u_e = \bar{u}_{eL}\gamma_\mu \left[I_3 - Q\sin^2\vartheta_w\right] u_{eL} + \bar{u}_{eR}\gamma_\mu \left[-Q\sin^2\vartheta_w\right] u_{eR} =$$

$$= \bar{u}_{eL}\gamma_\mu \left(-\tfrac{1}{2} + \sin^2\vartheta_w\right) u_{eL} + \bar{u}_{eR}\gamma_\mu \sin^2\vartheta_w u_{eR}$$

per cui possiamo scrivere:

$$g_L^e = C_L^e = -\tfrac{1}{2} + \sin^2\vartheta_w = \tfrac{1}{2}\left(C_V^e + C_A^e\right) = \tfrac{1}{2}\left(g_V^e + g_A^e\right) = \tfrac{1}{4}(v_e + a_e)$$

$$g_R^e = C_R^e = \sin^2\vartheta_w = \tfrac{1}{2}\left(C_V^e - C_A^e\right) = \tfrac{1}{2}\left(g_V^e - g_A^e\right) = \tfrac{1}{4}(v_e - a_e)$$

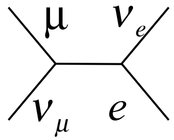
per cui misure di sez. d'urto individuano delle ellissi nel piano g_V, g_A:

$$\sigma\left[\nu_\mu e^- \rightarrow \nu_\mu e^-\right] = \frac{G_F^2 s}{\pi}\left[C_L^2 + \frac{1}{3}C_R^2\right] = \frac{G^2 s}{3\cdot 4\pi}\left(3\left(g_V + g_A\right)^2 + \left(g_V - g_A\right)^2\right) = \frac{G^2 s}{3\pi}\left(g_V^2 + g_A^2 + g_V g_A\right)$$

$$\sigma\left[\bar{\nu}_\mu e^- \rightarrow \bar{\nu}_\mu e^-\right] = \frac{G_F^2 s}{\pi}\left[\frac{1}{3}C_L^2 + C_R^2\right] = \frac{G^2 s}{3\cdot 4\pi}\left(\left(g_V + g_A\right)^2 + 3\left(g_V - g_A\right)^2\right) = \frac{G^2 s}{3\pi}\left(g_V^2 + g_A^2 - g_V g_A\right)$$

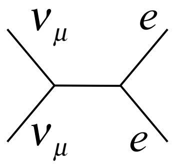
CC NC

$$\nu_\mu e \to \nu_e \mu$$



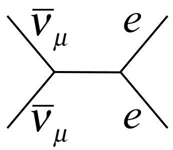
$$\sigma = \sigma_0 = \frac{G^2 s}{\pi}$$

$$\nu_\mu e \to \nu_\mu e$$



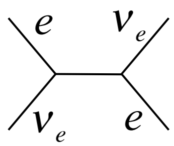
$$\sigma = \sigma_0\left(g_L^2 + \frac{1}{3} g_R^2\right) = \sigma_0\left(\left(\sin^2\vartheta_W - \frac{1}{2}\right)^2 + \frac{1}{3}\sin^4\vartheta_W\right)$$

$$\bar{\nu}_\mu e \to \bar{\nu}_\mu e$$



$$\sigma = \sigma_0\left(\frac{1}{3} g_L^2 + g_R^2\right) = \sigma_0\left(\frac{1}{3}\left(\sin^2\vartheta_W - \frac{1}{2}\right)^2 + \sin^4\vartheta_W\right)$$

$$\nu_e e \to \nu_e e$$



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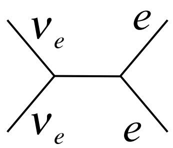
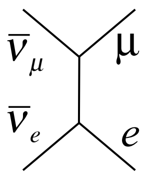


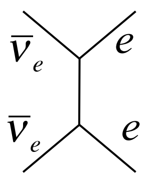
$$\sigma = \sigma_0\left((1 + g_L)^2 + \frac{1}{3} g_R^2\right) = \sigma_0\left(\left(\sin^2\vartheta_W + \frac{1}{2}\right)^2 + \frac{1}{3}\sin^4\vartheta_W\right)$$

$$\bar{\nu}_e e \to \bar{\nu}_\mu \mu$$



$$\sigma = \frac{1}{3}\sigma_0$$

$$\bar{\nu}_e e \to \bar{\nu}_e e$$



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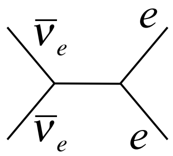


$$\sigma = \sigma_0\left(\frac{1}{3}(1 + g_L)^2 + g_R^2\right) = \sigma_0\left(\frac{1}{3}\left(\sin^2\vartheta_W + \frac{1}{2}\right)^2 + \sin^4\vartheta_W\right)$$

scoperta delle correnti neutre

(dionisi, cap. 6)

gargamelle 1973:

- la prima osservazione è una reazione antinuetrino mu su elettrone
- successivamente sono osservate correnti neutre su nucleoni, 1000 volte più abbondanti

Un calcolo di cinematica

Il p_t dell'elettrone dello stato finale si può calcolare tenendo conto che non dipende dal sistema di riferimento. Uguagliando quello del lab. a quello del c.d.m si ha:

$$E_e^2\vartheta^2 = \left(\frac{\sqrt{s}}{2}\right)^2 \sin^2\vartheta^* = \frac{mE_\nu}{2}\left(1-\cos^2\vartheta^*\right)$$

$$E_e\vartheta^2 = \frac{m}{2}\frac{E_\nu}{E_e}\left(1-(1-2y)^2\right) = \frac{m}{2}\frac{1}{y}\left(4y-4y^2\right) = 2m(1-y)$$

se $m=m_e$

$E_e\,\theta^2 \leq 1$ MeV, $E_e \sim 10$ GeV, $\theta^2 \sim 10^{-4}$, $\theta = 10$ mrad

misure sperimentali

Fine grained calorimeters per identificare gli elettroni
(il fondo è costituito dalle interazioni neutrino adrone $\sigma \propto s \propto 2mE_\nu$)
CHARM, E734 e soprattutto
CHARM II con 20 volte più statistica

Gli eventi $\nu_\mu e^-$ sono identificati dal piccolo angolo di rinculo dell'elettrone

In CHARM II tubi a streamer di 1 cm (già presenti in CHARM) letti anche da una striscia catodica ortogonale con misura del segnale con una risoluzione di 3 mm sul centroide della traccia

misura assoluta dei flussi per determinare le sez. d'urto

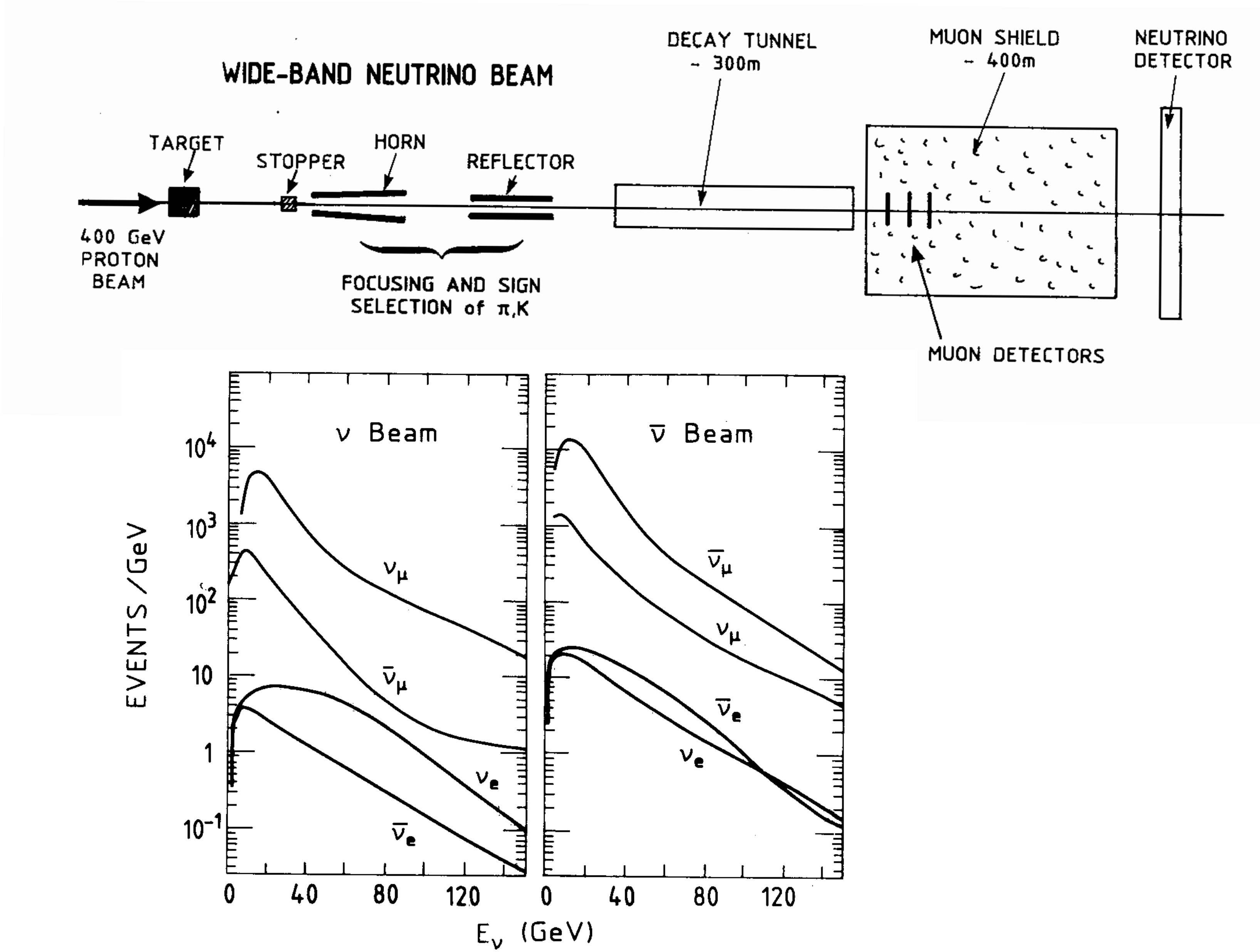
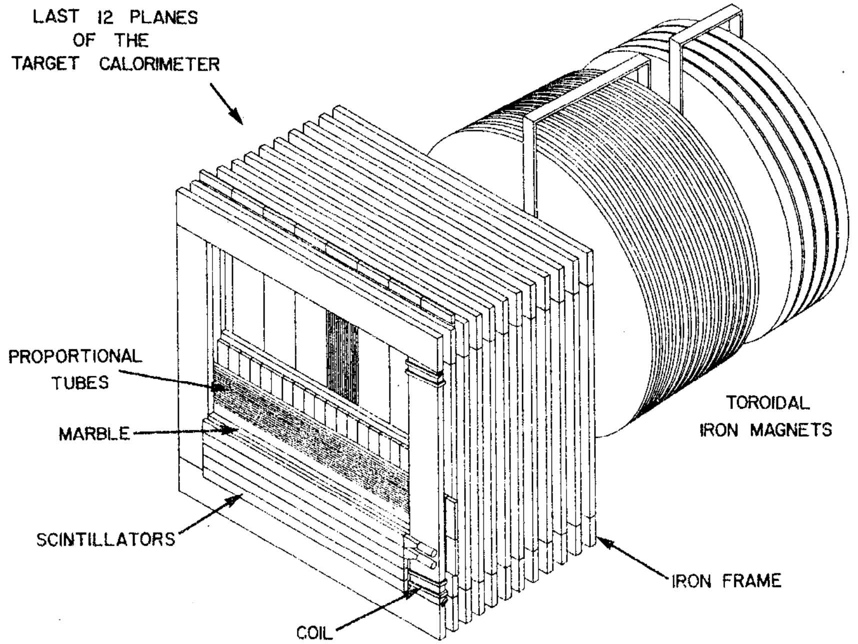
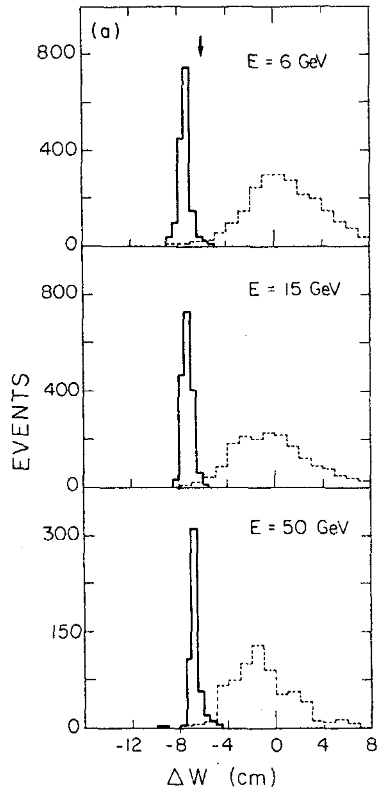

WIDE-BAND NEUTRINO BEAM
DECAY TUNNEL ~ 300m
MUON SHIELD ~ 400m
NEUTRINO DETECTOR
TARGET
STOPPER
HORN
REFLECTOR
400 GeV PROTON BEAM
FOCUSING AND SIGN SELECTION of π,K
MUON DETECTORS
ν Beam
ν̄ Beam
EVENTS / GeV
E_ν (GeV)
ν_μ
$\bar\nu_\mu$
ν_e
$\bar\nu_e$

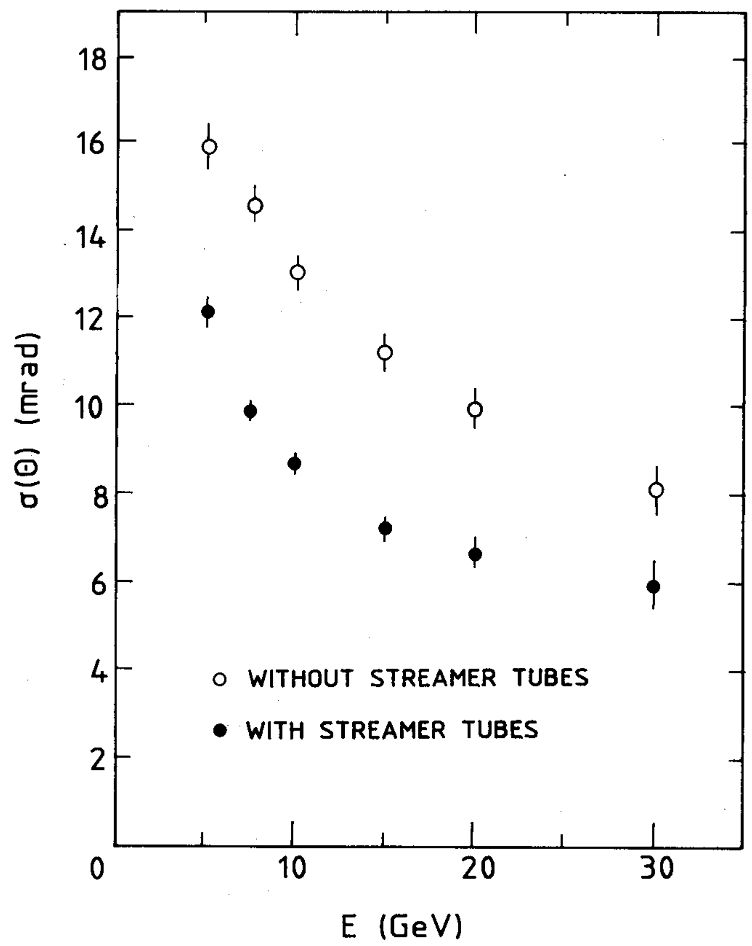
Fig. 13

CHARM I

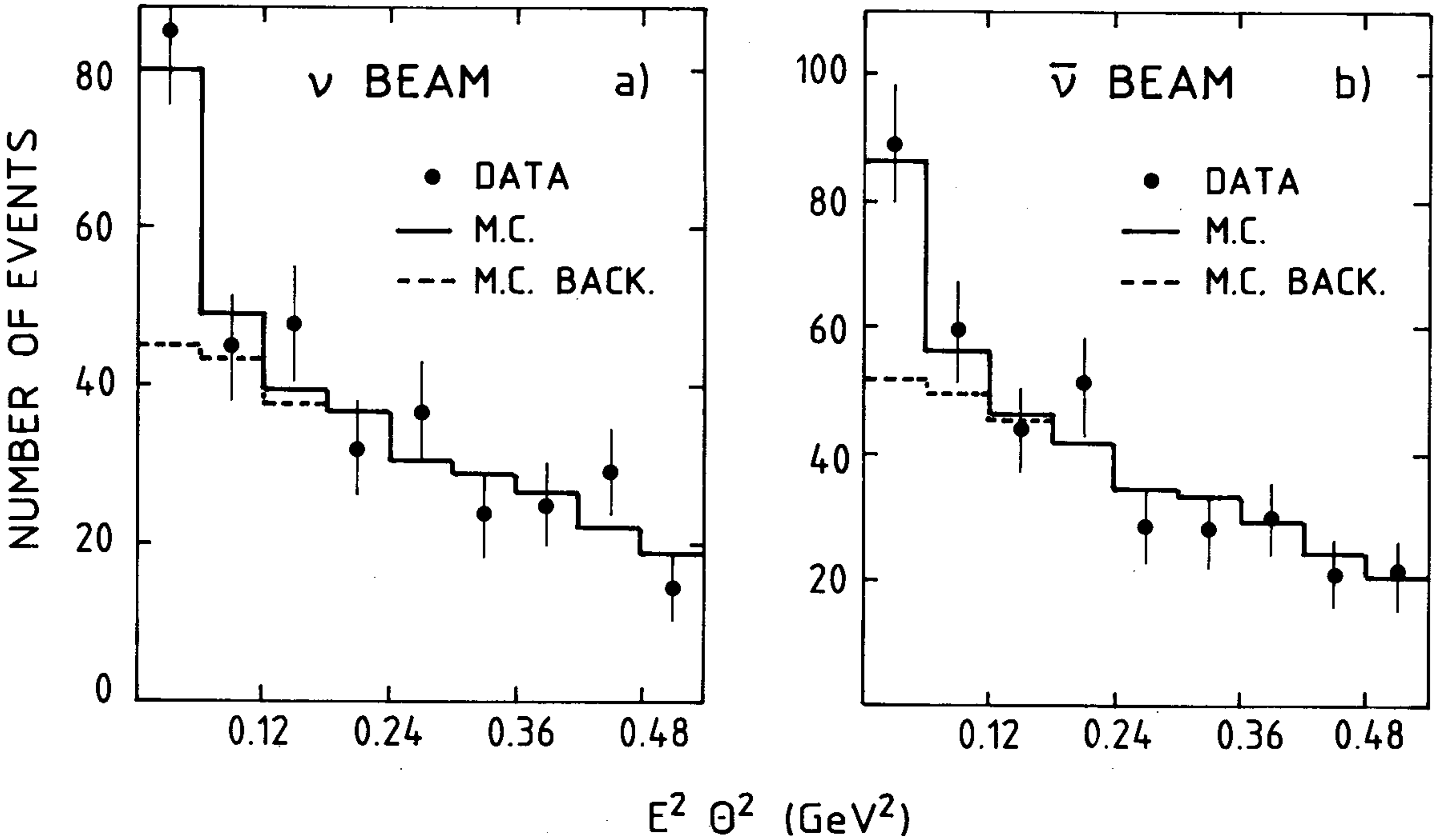

LAST 12 PLANES
OF THE
TARGET CALORIMETER
PROPORTIONAL
TUBES
MARBLE
SCINTILLATORS
COIL
TOROIDAL
IRON MAGNETS
IRON FRAME


(a)
E = 6 GeV
E = 15 GeV
E = 50 GeV
EVENTS
800
400
0
300
150
-12
-8
-4
0
4
8
ΔW (cm)

risoluzione angolare di CHARM



risultati



ν BEAM a)
$\bar{\nu}$ BEAM b)
DATA
M.C.
M.C. BACK.
NUMBER OF EVENTS
0
20
40
60
80
100
0.12
0.24
0.36
0.48
$E^2\ \Theta^2\ (GeV^2)$