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UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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SMR.762 - 26

SUMMER SCHOOL IN HIGH ENERGY PHYSICS AND COSMOLOGY

13 June - 29 July 1994

NEUTRINO PHYSICS

KLAUS WINTER
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Geneva
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Please note: These are preliminary notes intended for internal distribution only.

NEUTRINO PHYSICS

KLAUS WINTER

CERN

(1) $\nu_\mu e$ Scattering

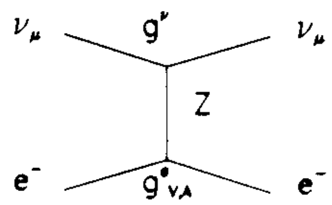
(2) g_A^e, g_V^e

(3) FLAVOUR UNIVERSALITY OF ν - Z^0 COUPLING

(4) CONSTRAINTS ON ADDITIONAL Z BOSONS

(5) NEUTRINO OSCILLATION

Muon-Neutrino Electron Scattering



$$\frac{d\sigma(\nu_\mu e)}{dy} = \frac{G_F^2 \, s \, (g^\nu)^2}{\pi}\left((g_V+g_A)^2 + (g_V-g_A)^2(1-y)^2\right)$$

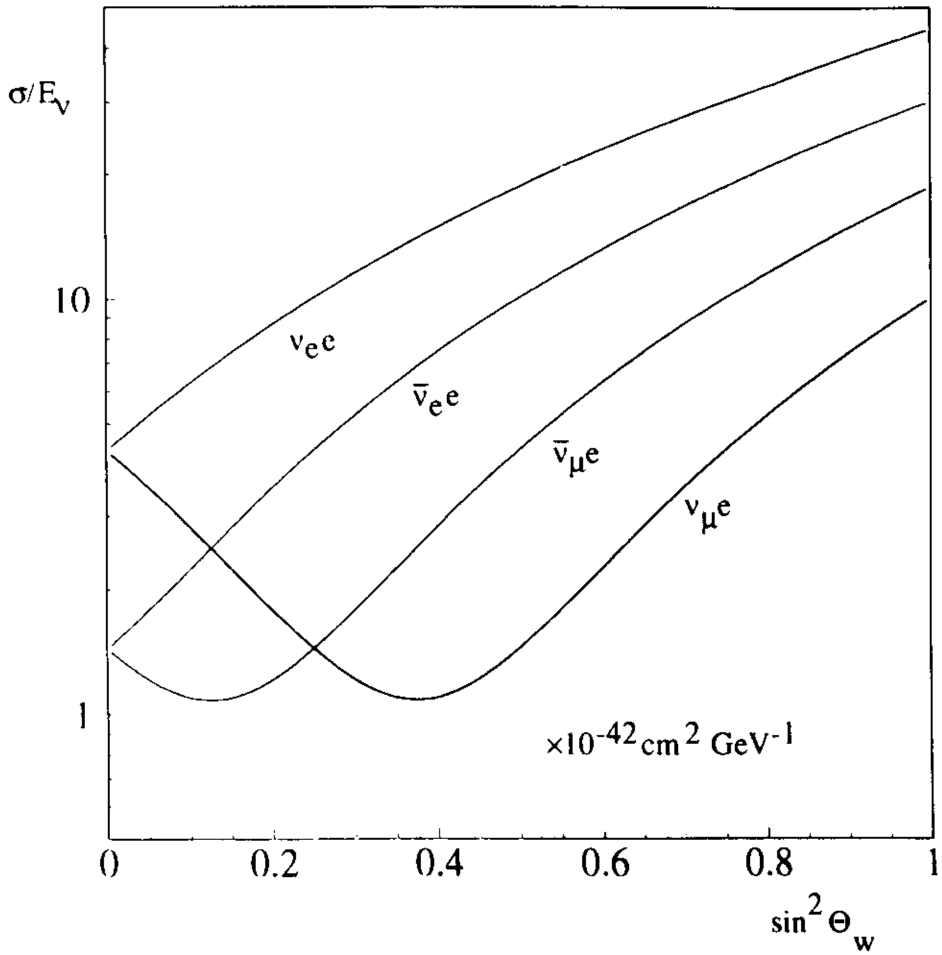
$$\frac{d\sigma(\bar{\nu}_\mu e)}{dy} = \frac{G_F^2 \, s \, (g^\nu)^2}{\pi}\left((g_V-g_A)^2 + (g_V+g_A)^2(1-y)^2\right)$$

Standard Model:

$g^\nu = 0.5$

$g_V = \rho(-0.5 + 2\sin^2\Theta_W)$

$g_A = -0.5\,\rho$



The CHARM II Collaboration

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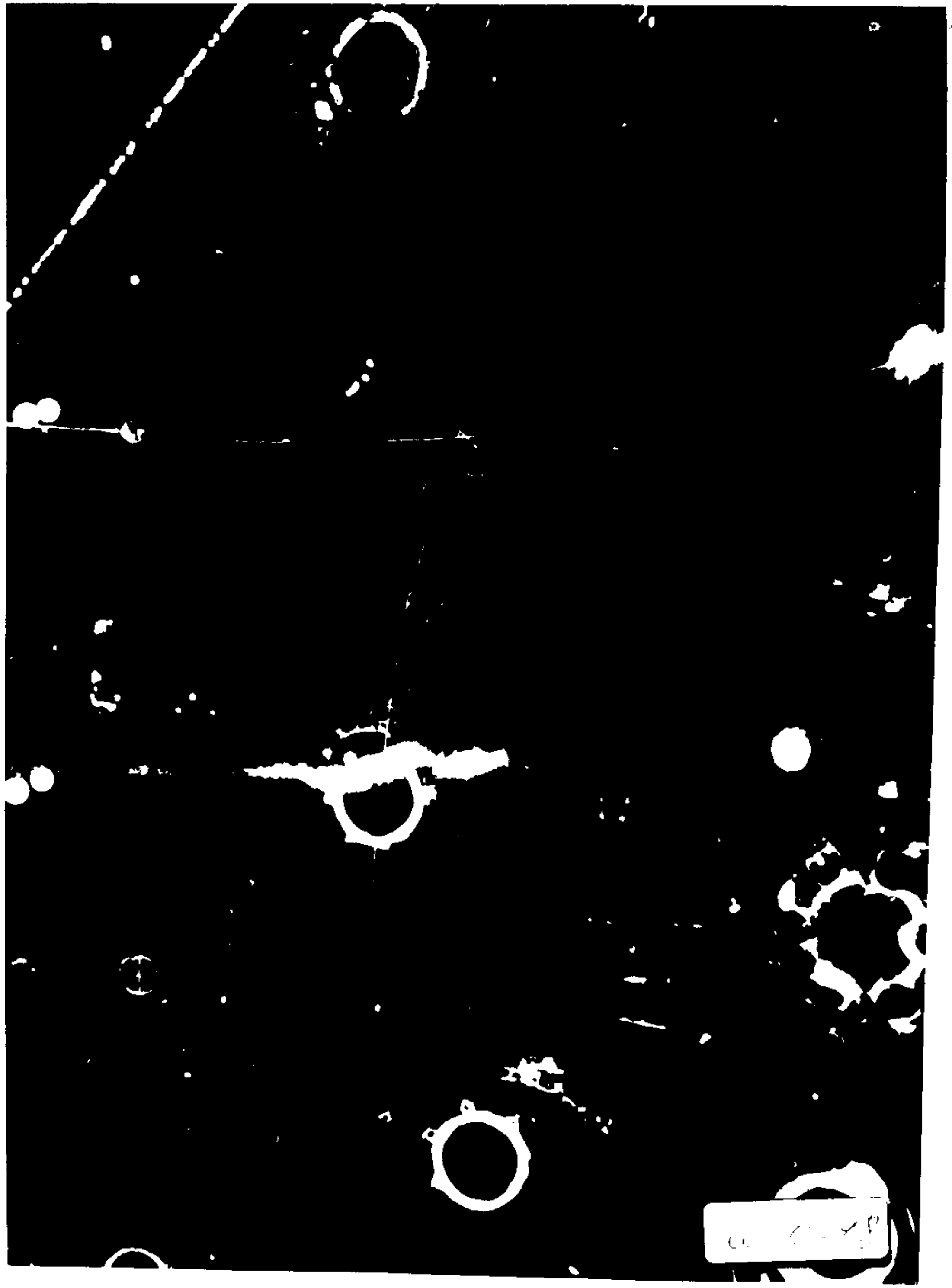
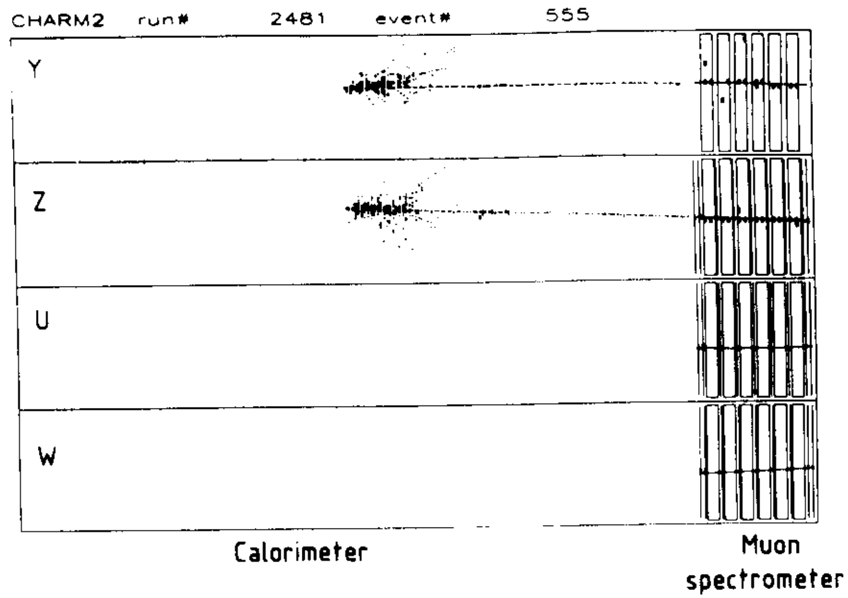
Muon-Neutrino Electron Scattering Experiments

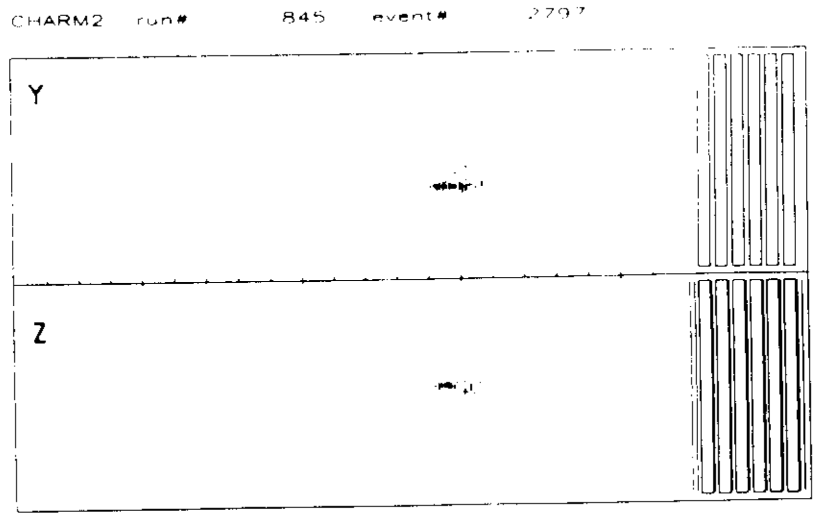
Experiment	Events: Neutrino	Antineutrino
Discovery:		
$\bar{\nu}_\mu e$ by Gargamelle (PS)	1	3
Confirmation and first measurements:		
Aachen-Padova(PS)	11	8
Gargamelle (SPS)	9	3
VMWOF (FNAL)	40	-
15-foot BNL-Columbia (FNAL)	22	-
Quantitative test of the Standard Model:		
CHARM (SPS)	83	116
BNL E734 (AGS)	160	97
CHARM II (SPS)	2677	2753



CHARM-II

- 600 tons glass calorimeter
- plastic streamer tubes

a)


b)


$$\sigma(\theta) = \frac{17\ \mathrm{mrad}}{\sqrt{E}}$$

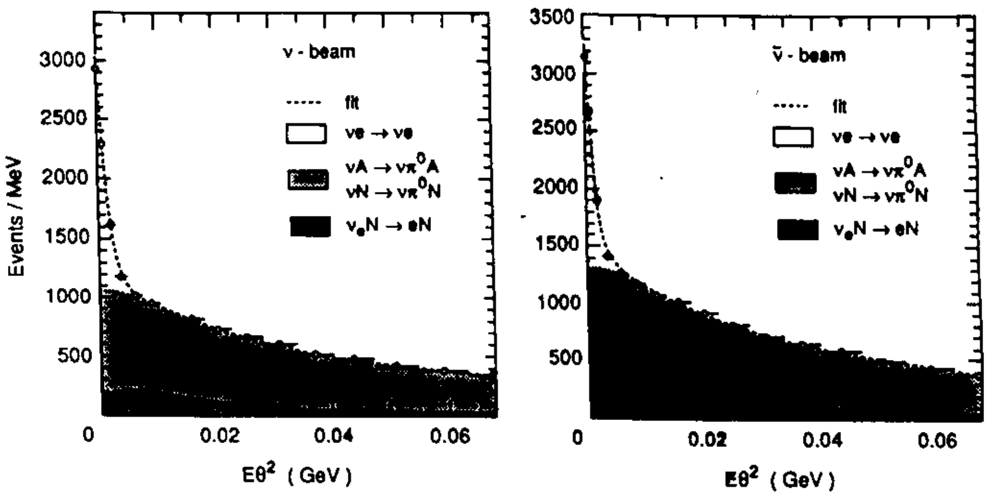


Figure 1 : Experimental data and the result of the best fit; data are shown as circles and the fit results are displayed as a dashed line. Only the projections in $E_e\theta_e^2$ of the 2-dim. distributions are shown. The different background components are added on top of each other. The bin size varies with the experimental resolution.

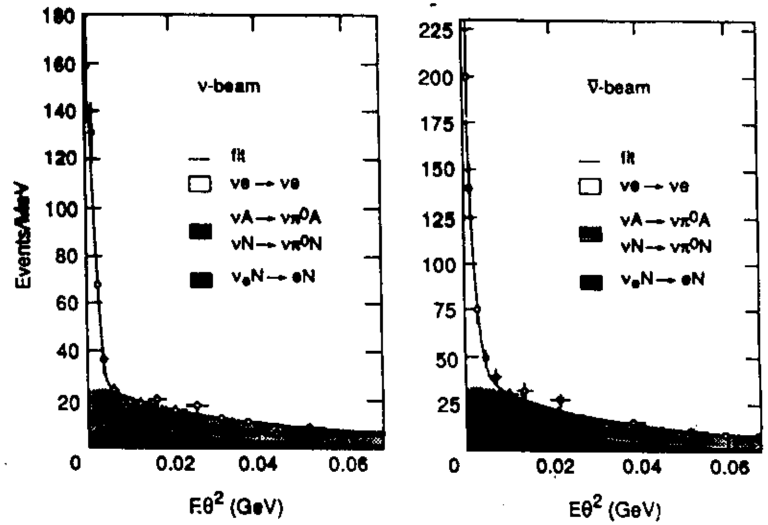


Figure 2 : Experimental data and the result of the best fit for the sample of events with energy loss information weighted with the electron probability. The signal to background ratio is improved by a factor 3.5 with respect to the total sample shown in figure 1. The bin size varies with the experimental resolution.

Differential Neutrino Electron Cross-Sections

- $(E, E\Theta^2)$ **distribution is sensitive to** $d\sigma/dy$
- **apply regularized unfolding method of V.Blobel**
- **no model dependent assumptions on y-distribution**
- **subtract background and** $\nu_e e$
- $\sin^2\Theta$ **fitted from shape alone**

  $\sin^2\Theta^{\nu e} = 0.212 \pm 0.027 \pm 0.006$
- **demonstrates that both left-, and right-handed electrons couple to the Z-boson**

  $g^2_R/g^2_L = 0.60 \pm 0.19_{stat.}$
- **result independent of** ρ **, of absolute and relative normalization**

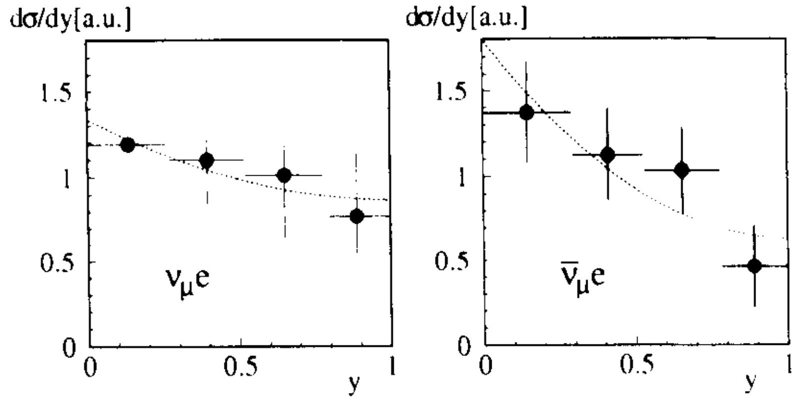
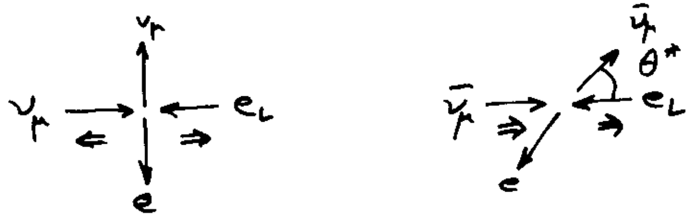


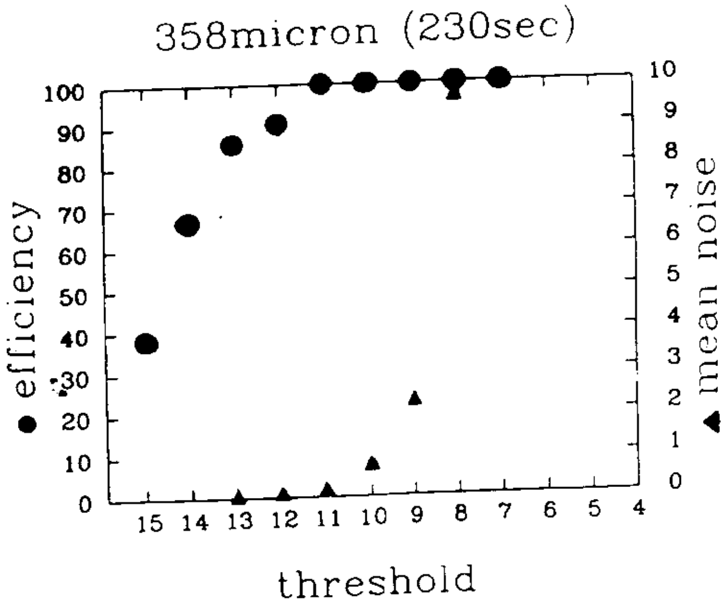
Figure 1: Unfolded differential cross $d\sigma/dy$ sections for $\nu_\mu e$ scattering (left), and $\bar{\nu}_\mu e$ scattering (right) in arbitrary units. The line overlaid corresponds to the prediction of the Standard Model for a value of the electroweak mixing angle of $\sin^2\Theta_W = 0.212$.

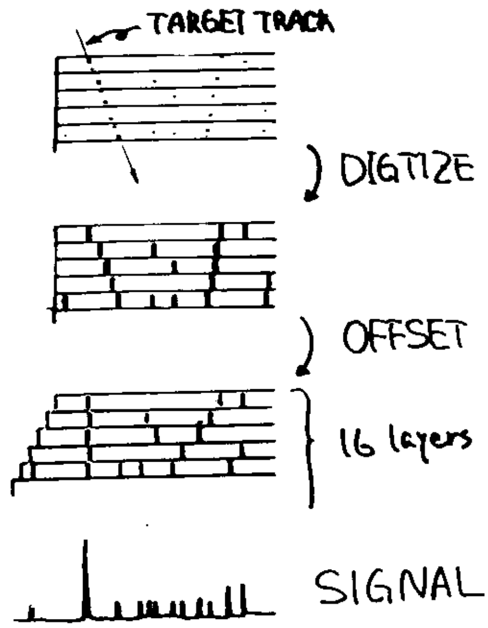


$$y = \frac{E_e}{E_\nu} = \frac{1}{2}(1 - \cos\theta^*)$$

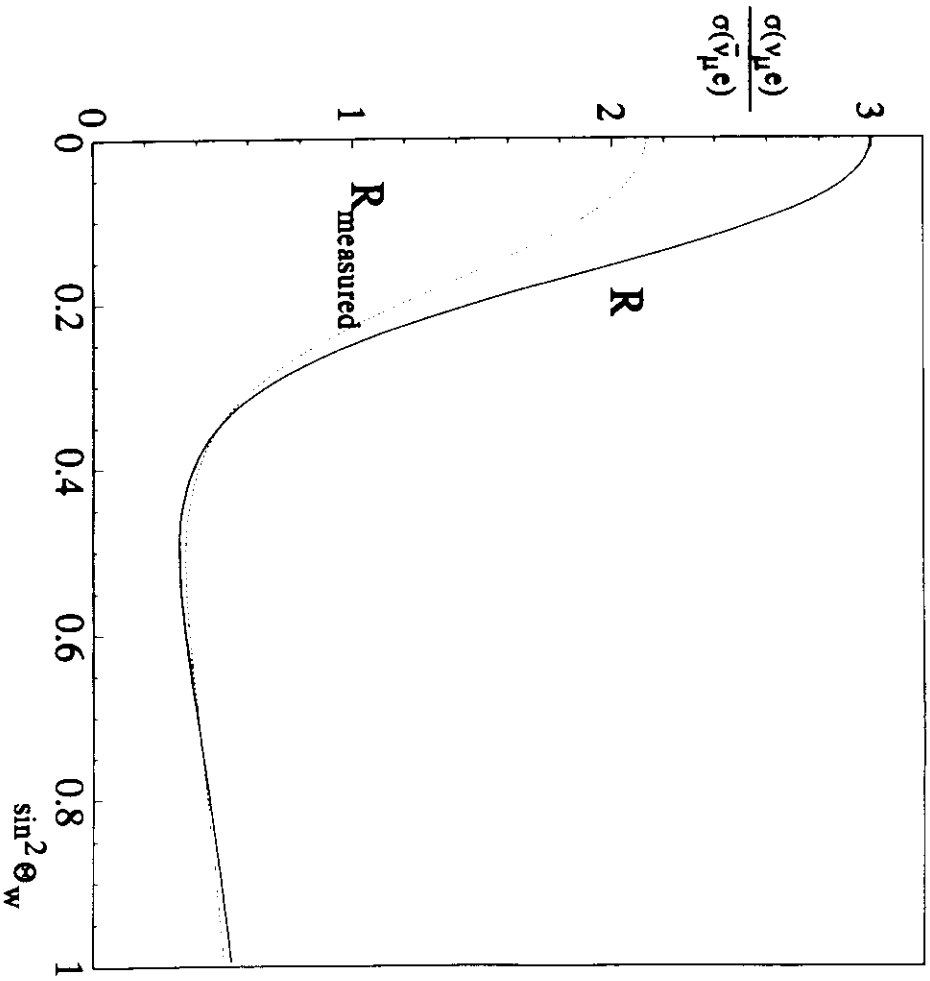
AUTOMATIC SCANNING

OF CHANGEABLE SHEETS





19 MICROSCOPES IN JAPAN + KOREA
1 MICROSC. IN ANKARA
1 MICROSC. IN BARI
1 MICROSC. IN ROME + 1 IN MOSCOW



Electroweak mixing angle

$$R = \frac{\sigma(\nu_\mu e^- \rightarrow \nu_\mu e^-)}{\sigma(\bar{\nu}_\mu e^- \rightarrow \bar{\nu}_\mu e^-)} = 3\frac{(1 - 4\sin^2\Theta_w + (16/3)\sin^4\Theta_w)}{(1 - 4\sin^2\Theta_w + 16 \quad \sin^4\Theta_w)}$$

- **relative flux normalization by four methods (inclusive, quasielastic, muon fluxes, pizero production)**
- **fit in the range** $E = 3-24$ GeV, $E\Theta^2 = 0-72$ MeV
- ρ cancels in the ratio
- **final result from the full data sample 1987-91**

$$\sin^2\Theta^{\nu e} = 0.2324 \pm 0.0062_{stat.} \pm 0.0059_{syst.}$$

↓ 0.0058 with E_{first}

GUT

$$\sin^2\theta_W(M^2_{GUT}) = \frac{3}{8}$$

IN SU(5)

$$\sin^2\theta_W(M^2_W) = 0.215 \pm 0.003$$

IN SS+SM

$$\sin^2\theta_W(M^2_W) = 0.235 \pm 0.003$$

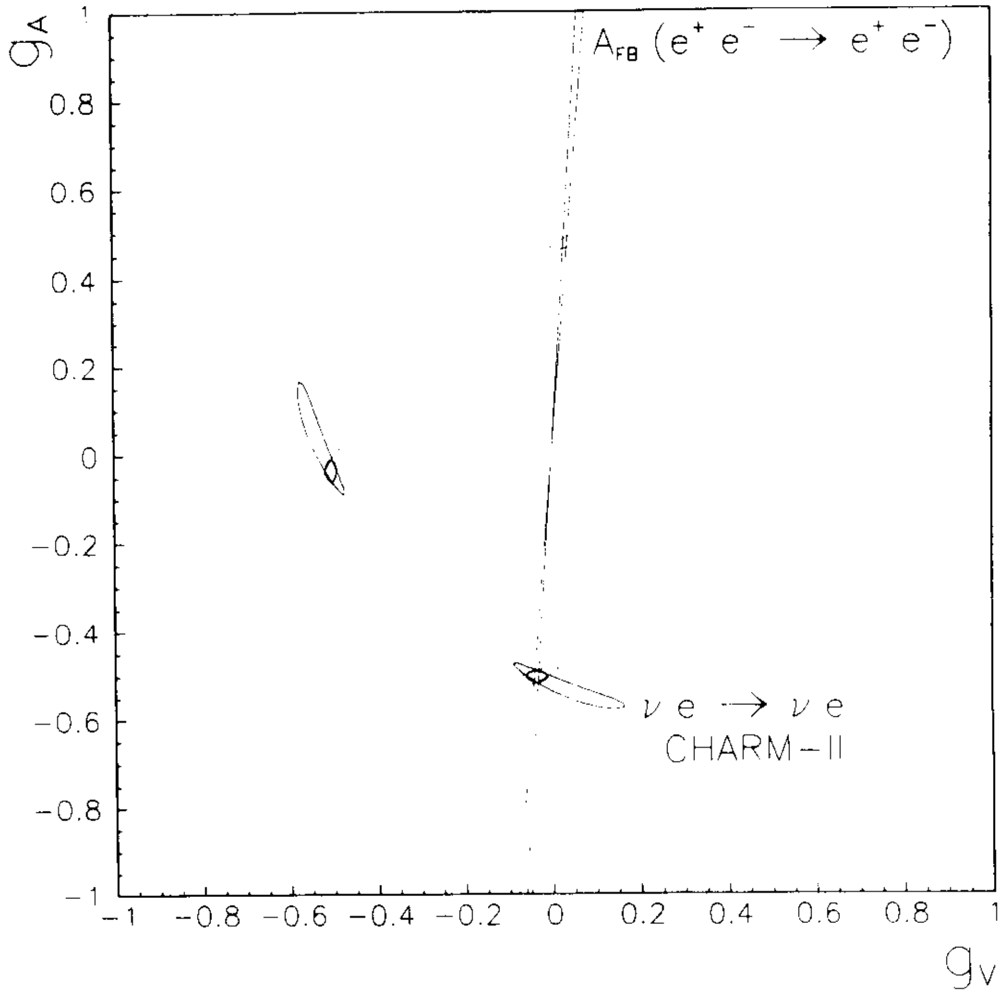
Coupling constants

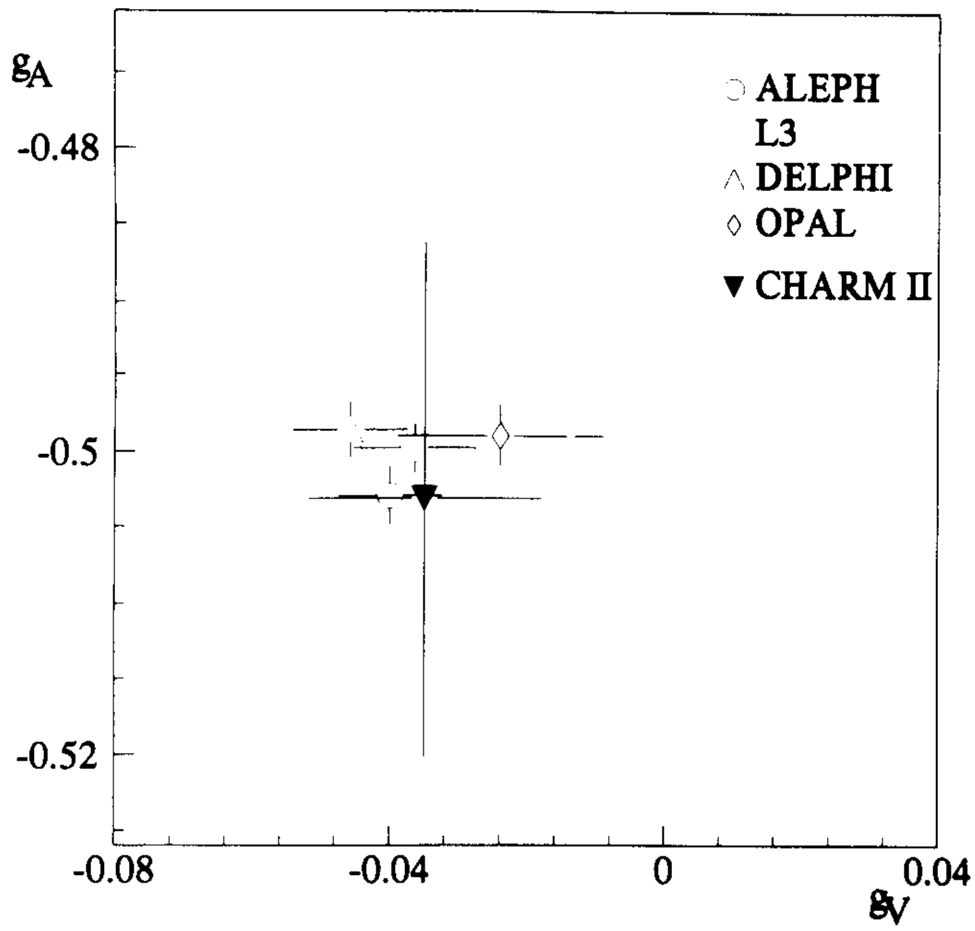
- Include absolute neutrino fluxes from minimum bias (NC+CC) and CC-events
- correct for absolute experimental selection efficiencies
- full data sample from 1987-91 runs
- results:

$$g_V^{\nu e} = -0.035 \pm 0.012_{stat} \pm 0.012_{syst}$$
$$g_A^{\nu e} = -0.503 \pm 0.006_{stat} \pm 0.016_{syst}$$

ρ, $\sin^2\Theta$ nearly uncorrelated

$$\sin^2\Theta^{\nu e} = 0.232 \pm 0.006_{stat} \pm 0.006_{syst}$$
$$\rho^{\nu e} = 1.006 \pm 0.012_{stat} \pm 0.031_{syst}$$





Neutrino magnetic moment

- **Electromagnetic interaction**

$$d\sigma / dy = \mu_\nu^2 \, \pi \, r_0 \, (1-y)/y$$

- **Include in the fit'**
- **CHARM-II result:**

$$\mu_\nu < 3.0 \; 10^{-9} \, \mu_{Bohr} \quad (90\% \text{ C.L.})$$

- **P.D.G.:**

$$\mu_\nu < 0.7 \; 10^{-9} \, \mu_{Bohr} \quad (90\% \text{ C.L.})$$

Anomalous neutrino charge radius

- **Vertex diagram change vector coupling constant**

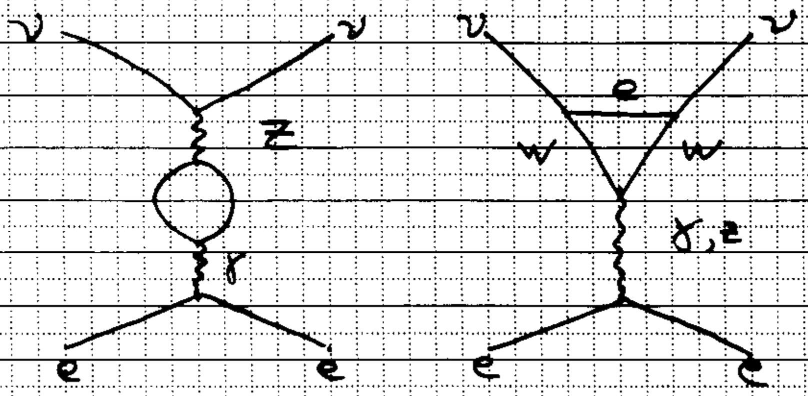
$$g_V = -0.5 + 2\,(\sin^2\Theta + \delta)$$

$$\delta = (\sqrt{2}\pi\alpha \, \langle r^2 \rangle)/(3G_F)$$

- From CHARM-II+LEP

$$|\langle r^2_{anom} \rangle| \leq 6.0 \; 10^{-33} \text{ cm}^2 \; (90\% \text{ C.L.})$$

Z-γ mixing   vertex



$+\frac{\bar{\alpha}}{3\pi}\cdot 7$ $-\frac{\bar{\alpha}}{3\pi}\cdot 6$

Vertex contribution is cancelled by γZ contribution.

$\nu_\mu e$ $Q^2 \sim 0.01\ GeV^2$

e^+e^- $Q^2 \sim 10^4\ GeV^2$

Muon neutrino neutral current coupling

– Neglecting box diagrams, γZ–mixing, neutrino charge radius, $O(\alpha/\pi)$(Novikov, Okun, Vysotsky, PL298, 453)

$$g_V^{\nu e}(0.01\ GeV^2) = 2\, g^\nu(m_Z^2)\, g_V^e(m_Z^2)$$

$$g_A^{\nu e}(0.01\ GeV^2) = 2\, g^\nu(m_Z^2)\, g_A^e(m_Z^2)$$

– one cannot extract $g(\nu_\mu)$ from LEP data

- CHARM-II results does not imply neutrino flavor universality

- using LEP result:

$$g_A^e(LEP) = -0.50084 \pm 0.00095$$

$$g_V^e(LEP) = -0.0382 \pm 0.0032$$

$$2g^\nu = 1.004 \pm 0.033$$

- to be compered with LEP result from the invisible width:

$$2g^\nu = 0.9999 \pm 0.0043$$

– it confirms lepton universality in neutrino sector

Number of light neutrinos from LEP

$N_\nu = 2.980 \pm 0.027$

obtained from $N_\nu = 2\,\Gamma_0\,\Gamma_{inv} / (2\,g^\nu)^2$

assuming neutrino flavor universality and

standard model couplings $2g^\nu = 1$.

$\Gamma_0 = \sqrt{2}\,G_F\,m_Z^3/48\pi$

– Assume N_ν=3 and

CHARM $g(\nu_e)/g(\nu_\mu) = 1.05^{+0.15}_{-0.18}$

LAMPF $2g(\nu_e) = 0.92 \pm 0.28$

$2g(\nu_\tau) = 0.98 \pm 0.15$

– Assume $2g(\nu_\tau)=2g(\nu_e)=2g(\nu_\mu)= 1.004 \pm 0.033$

$N_\nu = 2.98 \pm 0.20$

Additional Z bosons

- **Left-Right extension of the Standard Model**

  Symmetry group $SU(2)_L \times SU(2)_R \times U(1)_{LR}$

- **Left-Right Symmetric Model :'**

$g_L = g_R$

$\tan^2\Theta = (M_0^2 - M_Z^2)/(M_{Z1}^2 - M_0^2)$

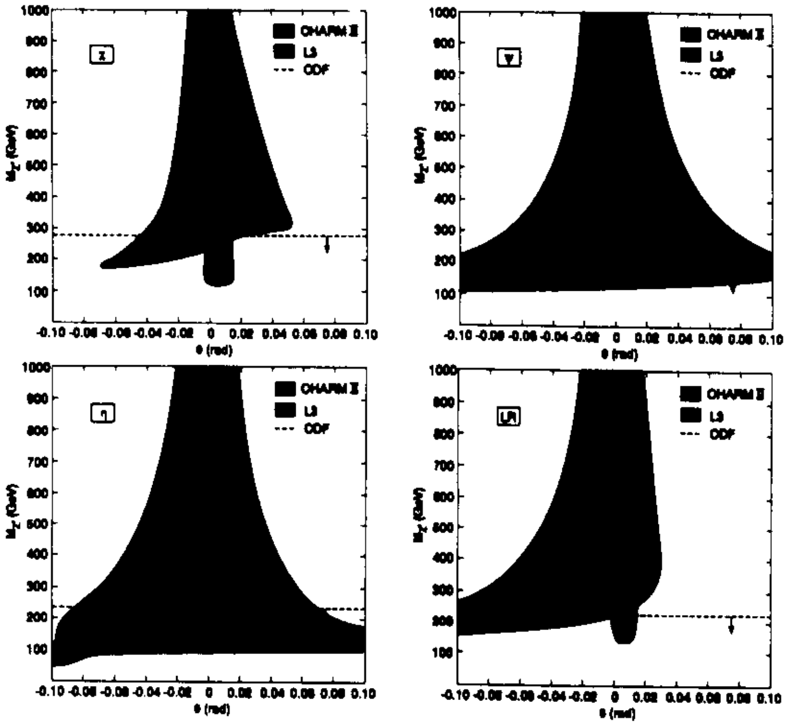
For Θ=0 and m_t = 150 GeV

CHARM–II	M_{Z-LR} > 253 GeV at 95 % C.L.
L3	130 GeV
CDF	230–310 GeV

Clone of standard Z with normal couplings Z

CHARM–II	M_Z > 398 GeV at 95 % C.L.
CDF	412 GeV

Z' Limits from CHARM II



Summary of CHARM-II results

NC/CC	$\sin^2\vartheta_w = 0.237 \pm 0.014$
	$\rho = 0.987 \pm 0.042$
y−distribution	$\sin^2\vartheta^{\nu e} = 0.212 \pm 0.028$
	$g_R^2/g_L^2 = 0.60 \pm 0.19$
$\sigma(\nu_\mu e)$	$g_V = -0.035 \pm 0.012_{stat.} \pm 0.012_{syst.}$
	$g_A = -0.503 \pm 0.006_{stat.} \pm 0.016_{syst.}$
$\nu_\mu e/\bar{\nu}_\mu e$	$\sin^2\vartheta^{\nu e} = 0.2324 \pm 0.0062_{stat.} \pm 0.0059_{syst.}$
$\nu_\mu Z$ coupling	$2g(\nu_\mu) = 1.004 \pm 0.033$
Magnetic moment	$\mu_\nu < 3.0\ 10^{-9}\ \mu_{Bohr}$ (90 % C.L.)
Charge radius	$<r^2> < 6.0\ 10^{-33}\ cm^2$ (90 % C.L.)
New Z	$M_{Z-LR} < 253$ GeV (95 % C.L.)
	$M_{Z1} < 398$ GeV (95 % C.L.)

NEUTRINO OSCILLATION
EXPERIMENTS AT CERN

KLAUS WINTER

- DO HEAVY ISOSINGLET ν_H EXIST IN NATURE ? CHARM II

- SEARCH FOR $\nu_\mu - \nu_\tau$ OSCILLATION
  - CHARM II
  - CHORUS
  - NOMAD
  - LONG FLIGHT PATH PROJECT

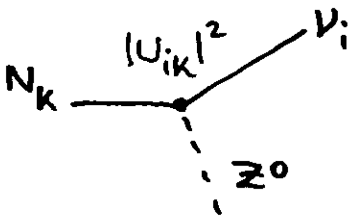
(1) WHICH ν STATES EXIST IN NATURE?

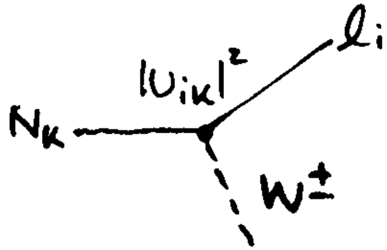
* 3 FAMILIES OF ISODOUBLET ν's

* DO HEAVY ISOSINGLET ν_H EXIST?

W GAUGEFIELD OF SU(2) DOES NOT COUPLE TO ν_H

EXCEPT THROUGH MIXING TO ISODOUBLET NEUTRINOS





KINEMATICAL FIT

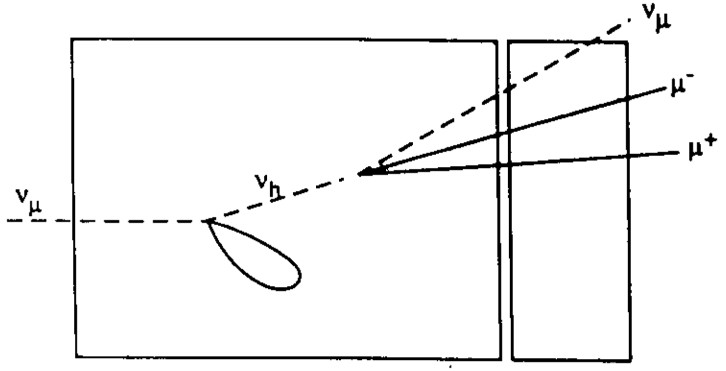
UNMEASURED QUANTITIES : 6

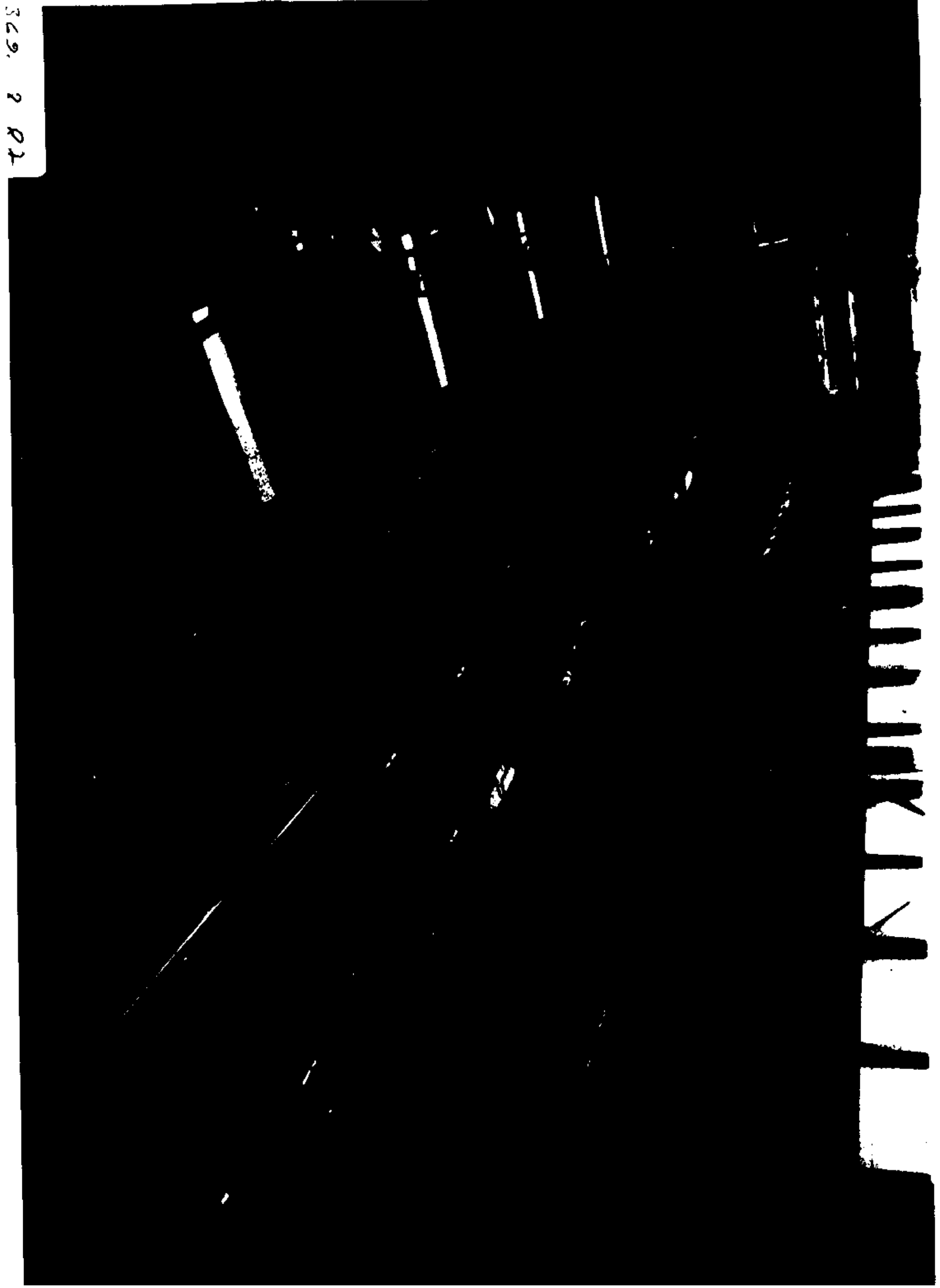
CONSTRAINING EQUATIONS : 8

(3)

(2)

(1)


ν_μ
μ^-
μ^+
ν_h
ν_μ



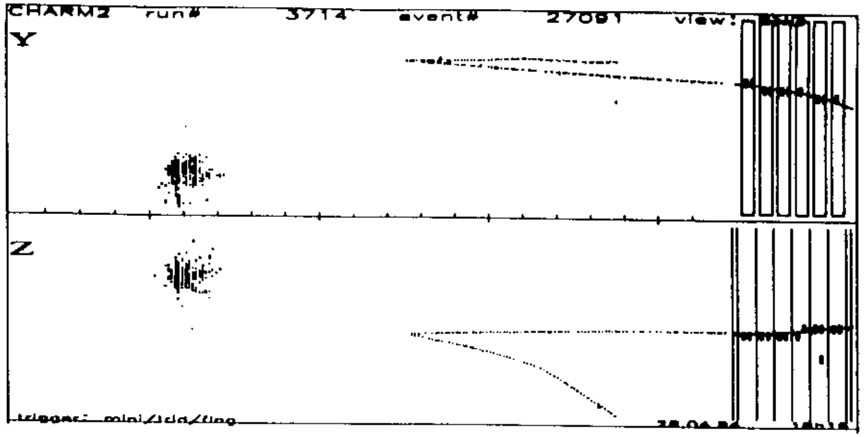


Abbildung 6.3: Darstellung eines Ereignisses mit zwei Myonen, von denen eines den Detektor seitlich verläßt

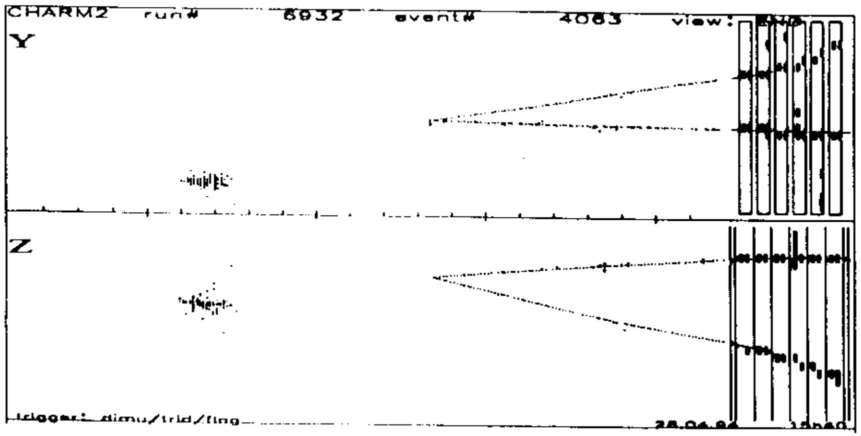


Abbildung 6.4: Darstellung eines Ereignisses mit zwei im Spektrometer vermessenen Myonen

NEW SEARCH FOR ν_H IN CHARMII (SIBYLLE PETRAK)

$$\nu_\mu N \rightarrow \nu_H X \quad , \quad \nu_H \rightarrow \mu^- \mu^+ \nu_\mu$$

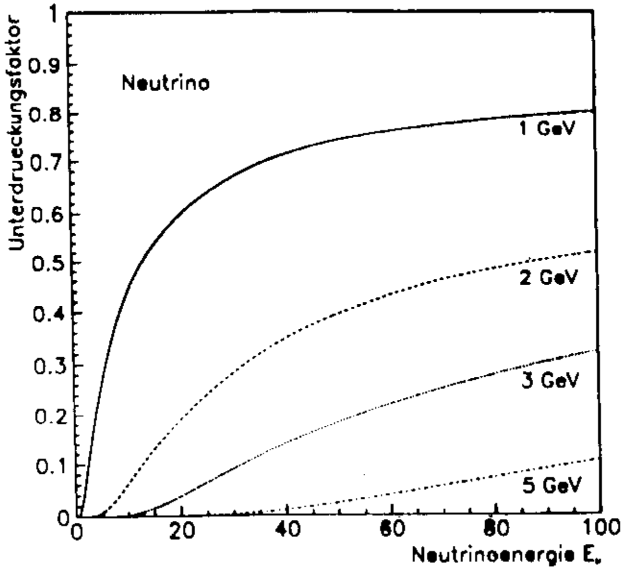
$2 \cdot 10^7$ $\nu + \bar{\nu}$ NC EVENTS

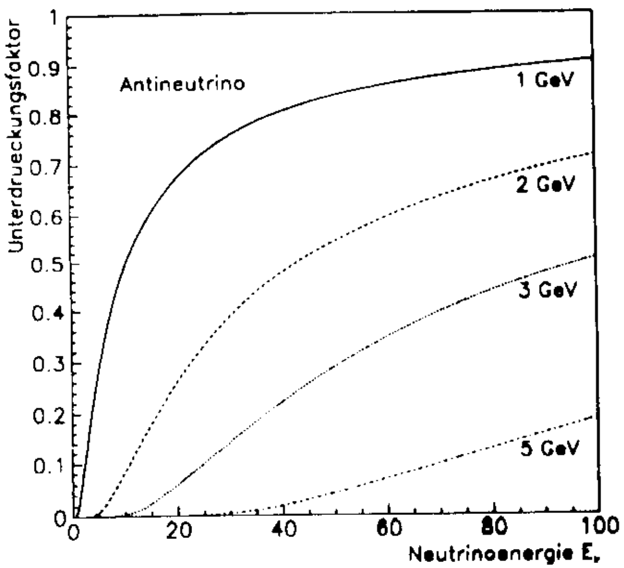
$|U|^2 = 10^{-4}$
$m_{\nu_H} = 2\,GeV$

TOPOLOGY	EVTS	MC
TRIDENT CAND.	38504	5.1
NC + 2 TRACKS	121	4.6
NC + 2μ	11 (10±4) OVERLAYS	4.3
ALL KINEM	10	3.7
KINEM. FIT	0	3.0

SENSITIVITY

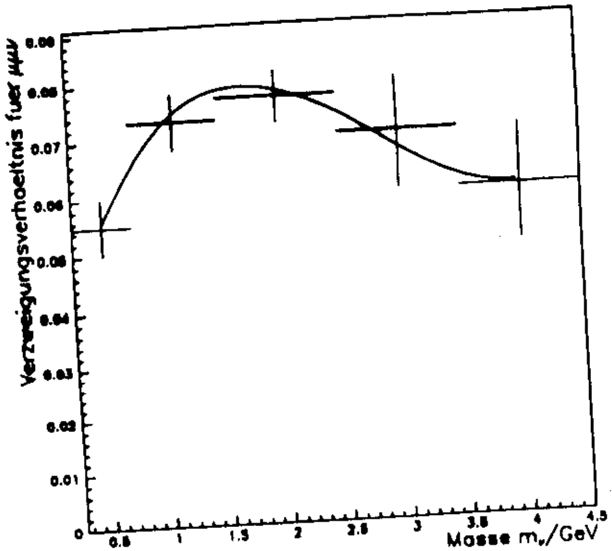
CREATION OF ν_h





BR

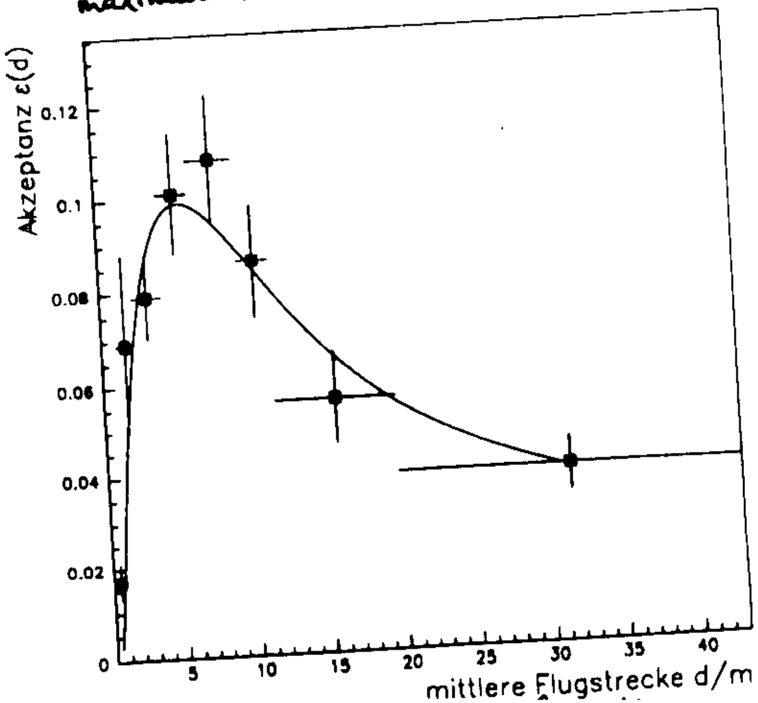
DECAY OF ν_h



m_{ν_H}

minimal distance 1,5 m
maximal distance 30 m

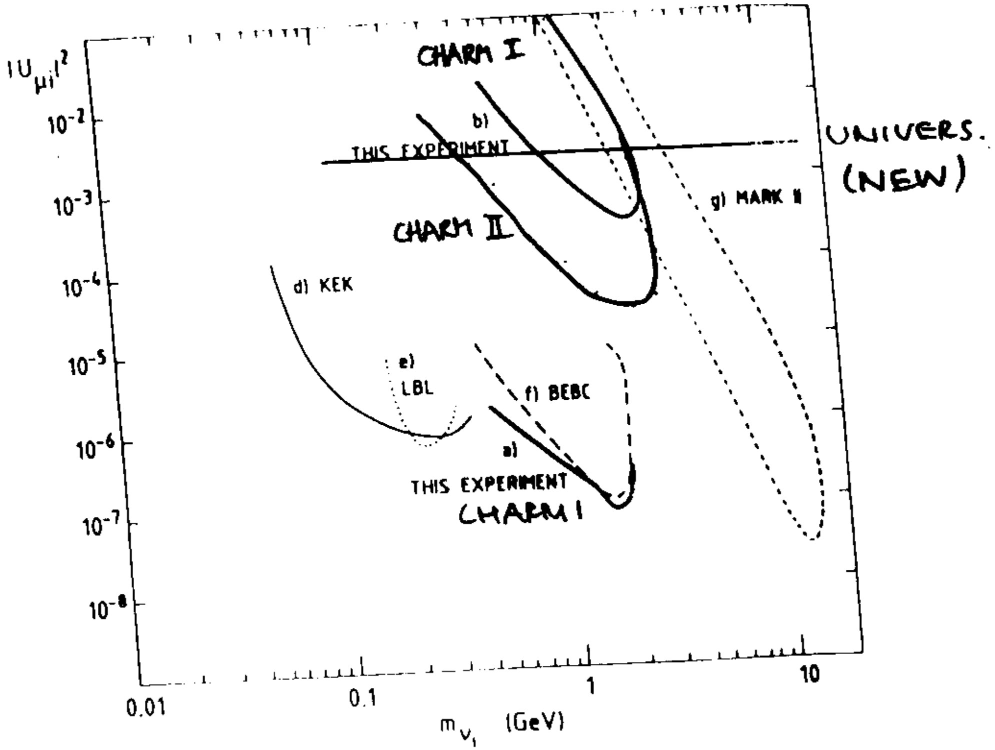
ε

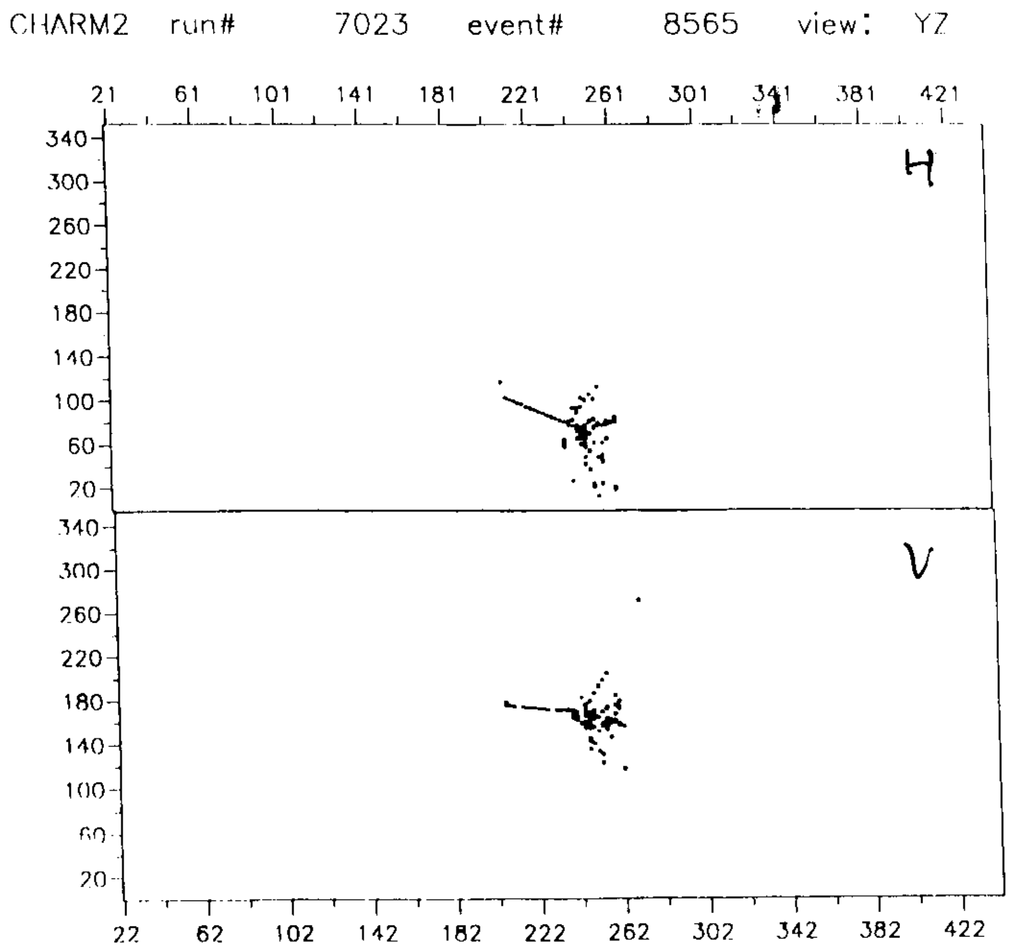


CHARM II SEARCH FOR

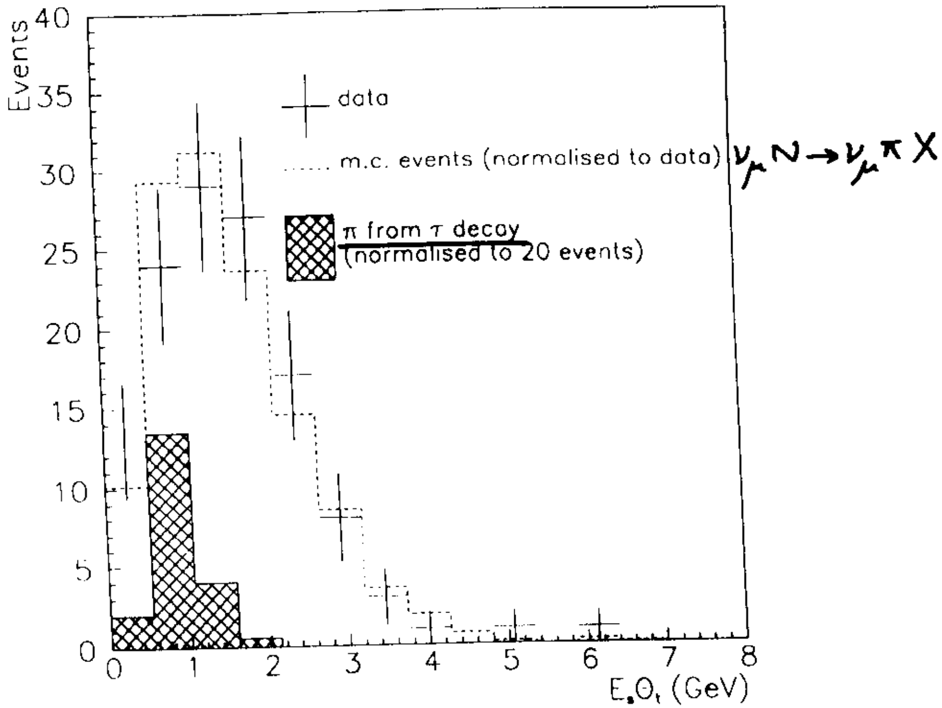
$$\overset{(-)}{\nu}_{\tau} N \to \tau^{\pm} N' , \quad \tau^{\pm} \to \pi^{\pm} \nu_{\tau}$$

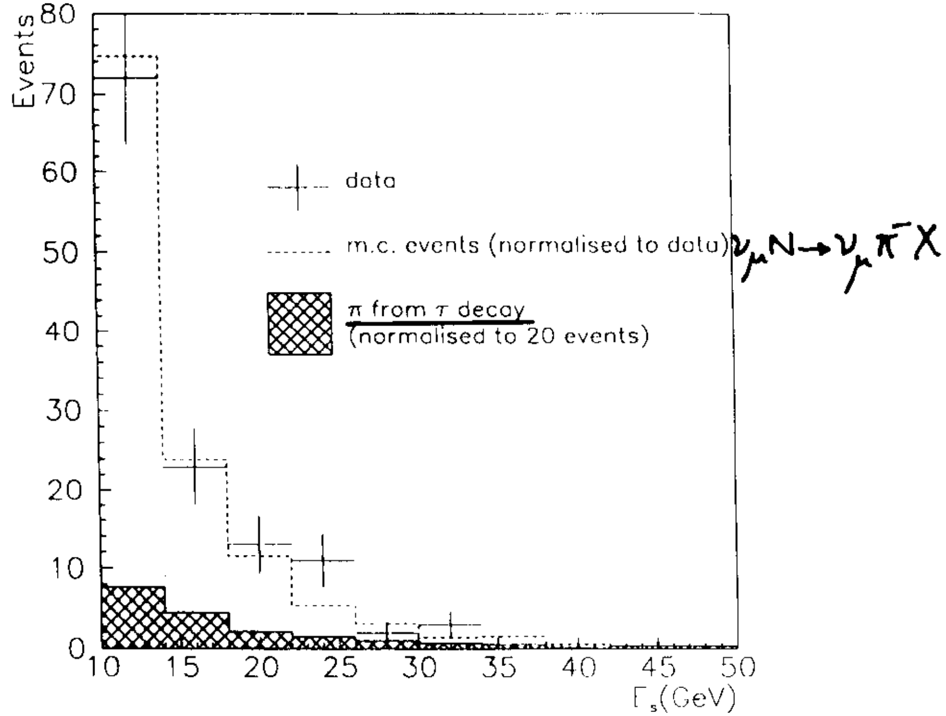
BACKGROUND $\overset{(-)}{\nu}_{\mu} N \to \overset{(-)}{\nu}_{\mu} \pi^{\pm} N'$

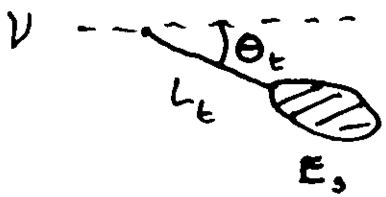




124 CANDIDATES



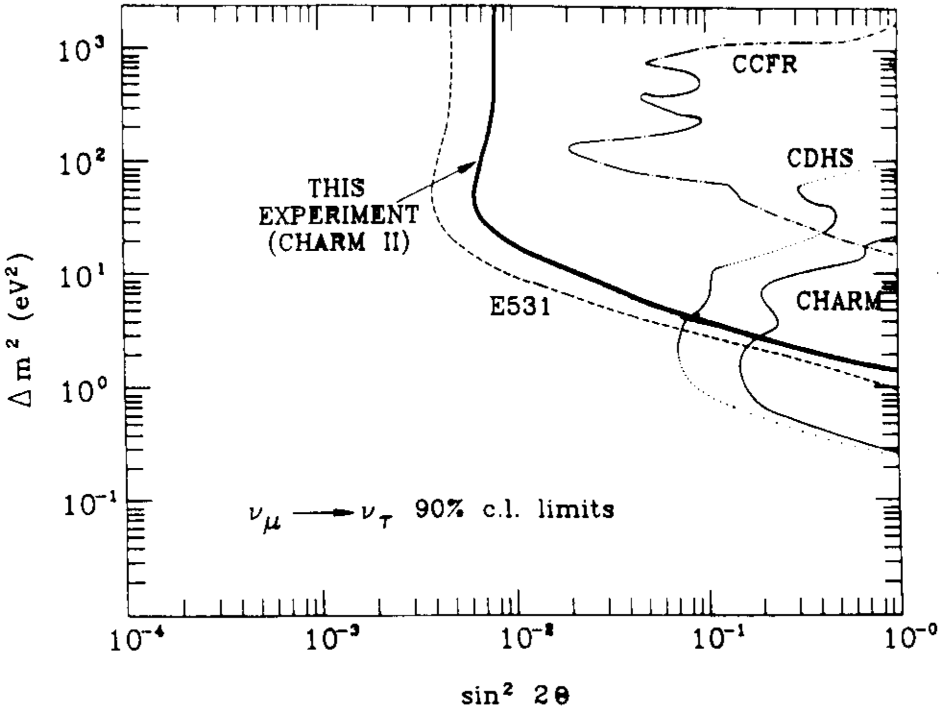




$E_s \geq 10$ GeV

$L_t \geq 15$ PLANES

$N_{ADD} \leq 3$ / 8 PLANES



$\phi(\nu_\tau)/\phi(\nu_\mu) < 10^{-7}$

FOR 450 GeV PROTONS + HORN FOCUSSED ν BEAM

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-PPE/93-131
July 20, 1993

A NEW SEARCH FOR $\nu_\mu - \nu_\tau$ OSCILLATION

CHORUS Collaboration

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K. Nakazawa: Gifu University, Gifu, Japan
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D. Favart, G. Gregoire, X. Lauwerys, V. Lemaitre, L. Michel: Université Catholique de
Louvain, Louvain-la-Neuve
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D. Frekers, H. von Heynitz : Münster University, Münster
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TECHNION, HAIFA, ISRAEL

Abstract

This report is describing the status of the construction of the WA95-CHORUS detector. It supersedes the text of the proposal CERN-SPSC/90-42 SPSC P254 which was approved by the CERN Research Board in September 1991.

SEARCH FOR $\nu_\mu - \nu_\tau$ OSCILLATION

— FROM SOLAR ν EXPERIMENTS

$m_{\nu_\mu} \sim 3 \cdot 10^{-3}\, eV$

$m_{\nu_\tau} \sim m_{\nu_\mu} \left(\frac{m_t}{m_c} \right)^2 \sim 30\, eV$

— FROM DARK MATTER

$\rho_\nu \sim 0.3 - 0.95$

$m_{\nu_\tau} \sim 3 - 100\, eV$

— DETECT $\nu_\tau N \to \tau^- X$

IN ν_μ BEAM

$\Delta m^2_{\mu\tau} \gtrsim \frac{E_\nu\,(GeV)}{l\ (km)} \gtrsim 25\, eV^2$

DIRECT M_ν MEASUREMENTS

$\bar{\nu}_e$	$H^3 \to He^3 e^- \bar{\nu}_e$	4.5 eV	1)
ν_μ	$\pi^+ \to \mu^+ \nu_\mu$	160 keV	2)
ν_τ	$\tau \to 5\pi\, \nu_\tau$	29 MeV	3)

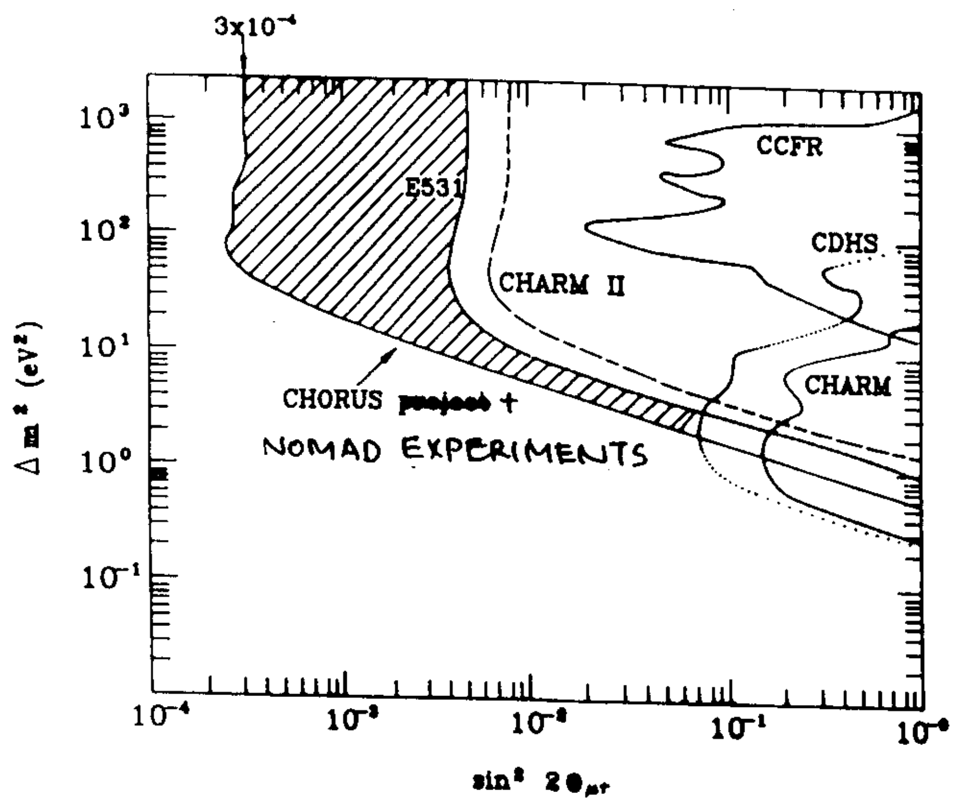
1) TROITK LOBASHEV et al.

2) PAUL SCHERRER INST

3) ARGUS – BEPC – CLEO

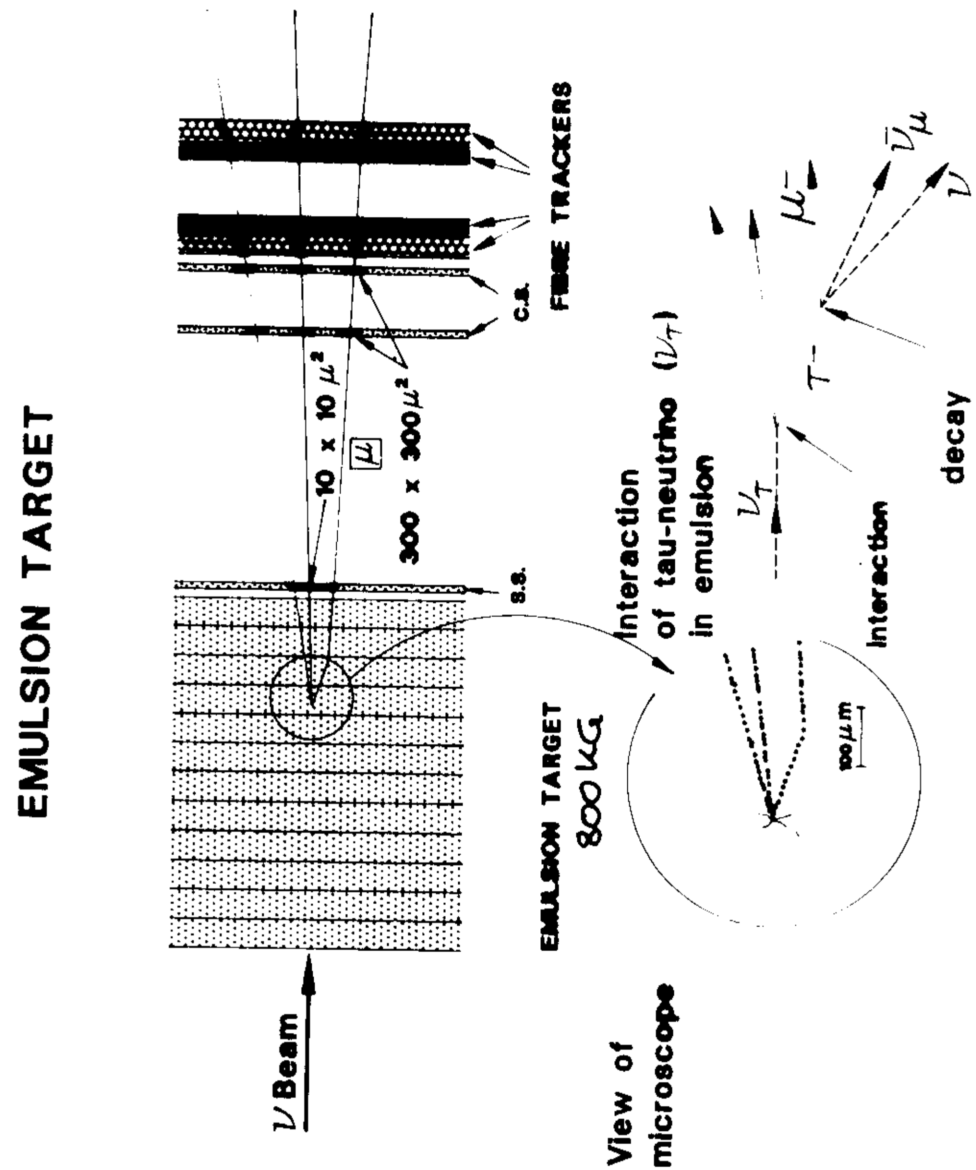
$$P(\nu_\mu \to \nu_\tau) = \sin^2 2\theta \cdot \sin^2\left(\frac{1.27 \cdot \Delta m^2 \cdot L}{E}\right)$$

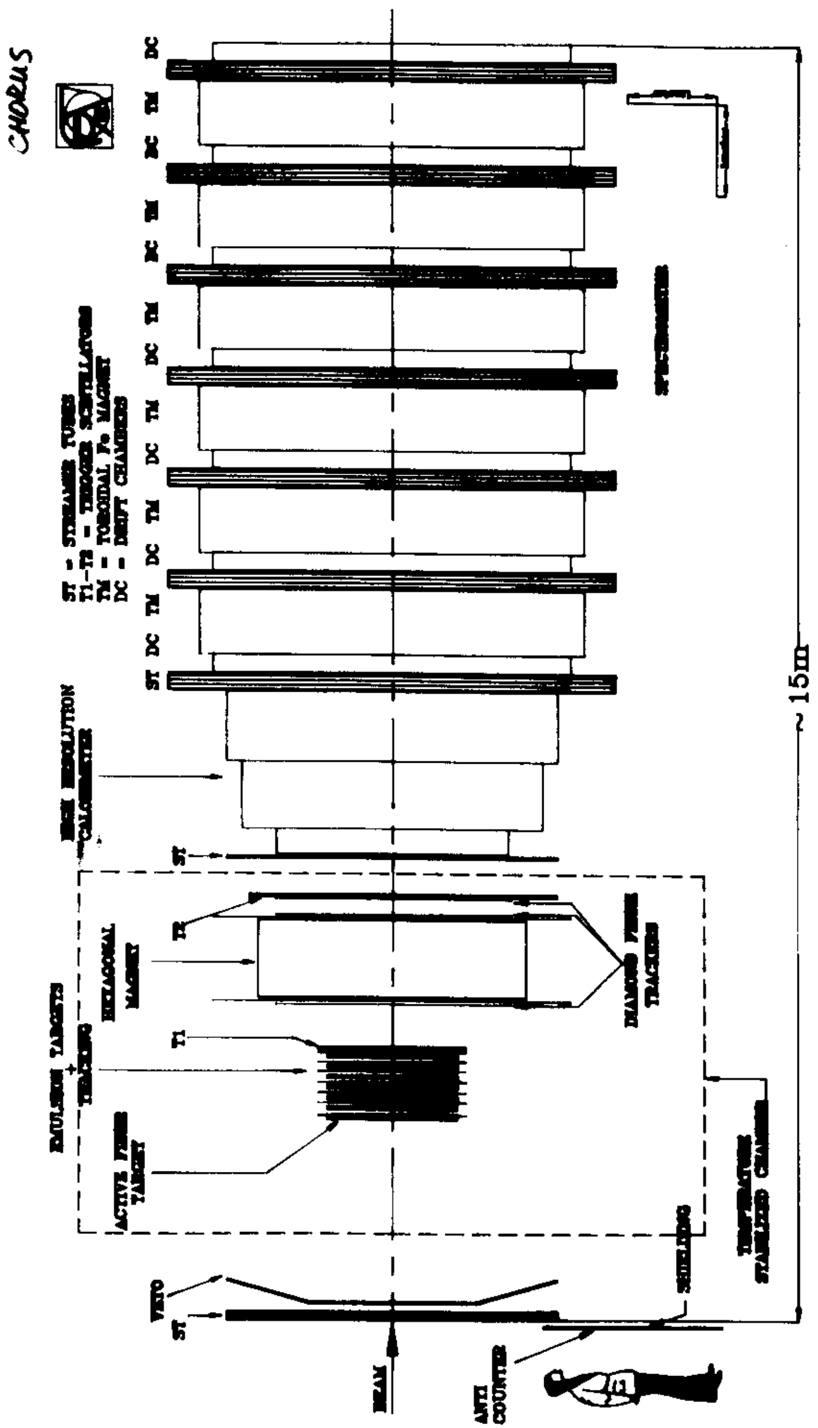
$$\left(\Delta m^2 \gg \frac{E}{L}\right) \sim \sin^2 2\theta \cdot \frac{1}{2}$$

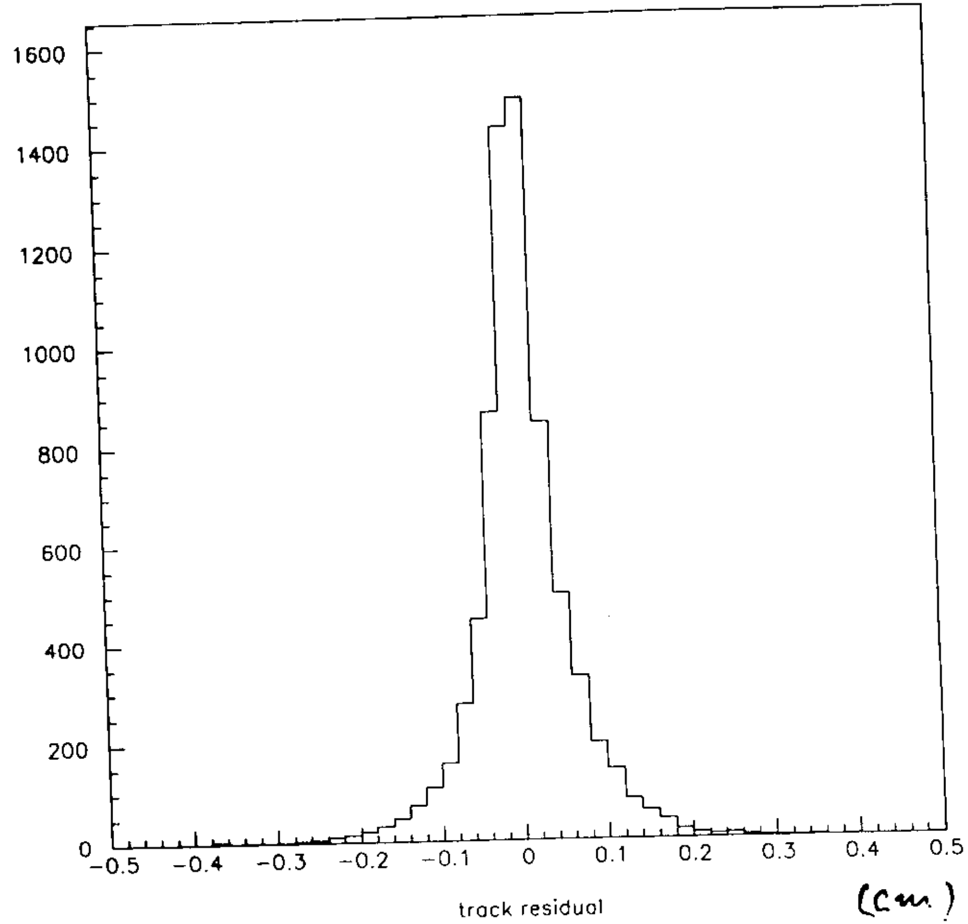


450 GeV PROTONS

- FIX $E \sim 25$ GeV, $L \sim 600$ m
- $\phi(\nu_\tau) / \phi(\nu_\mu) < 10^{-7}$



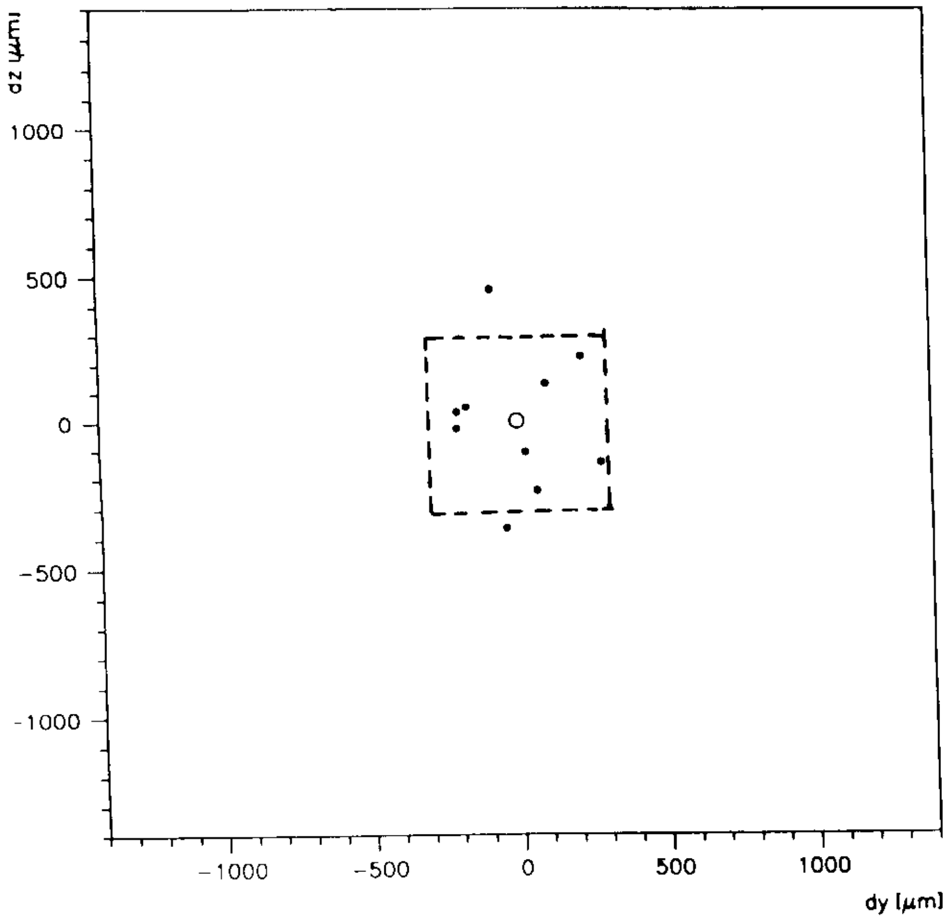




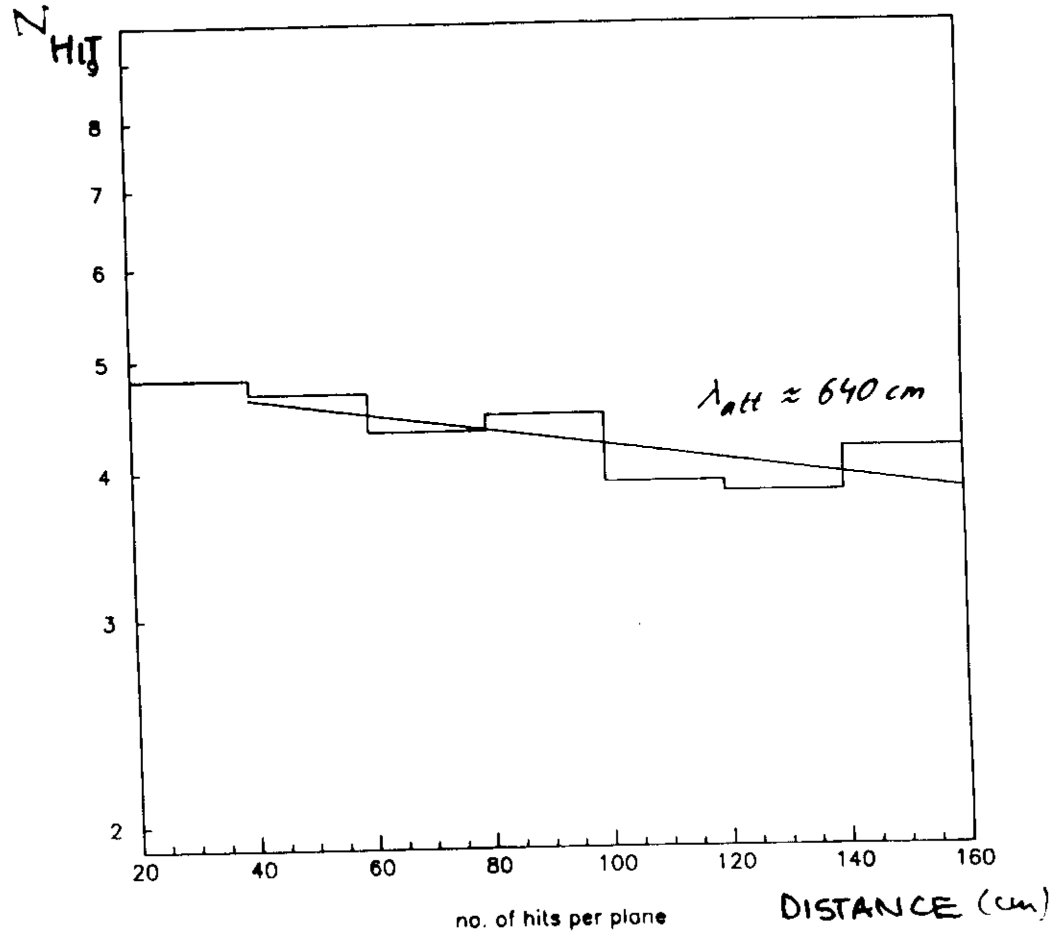
$\sigma = 340\,\mu$ / HIT

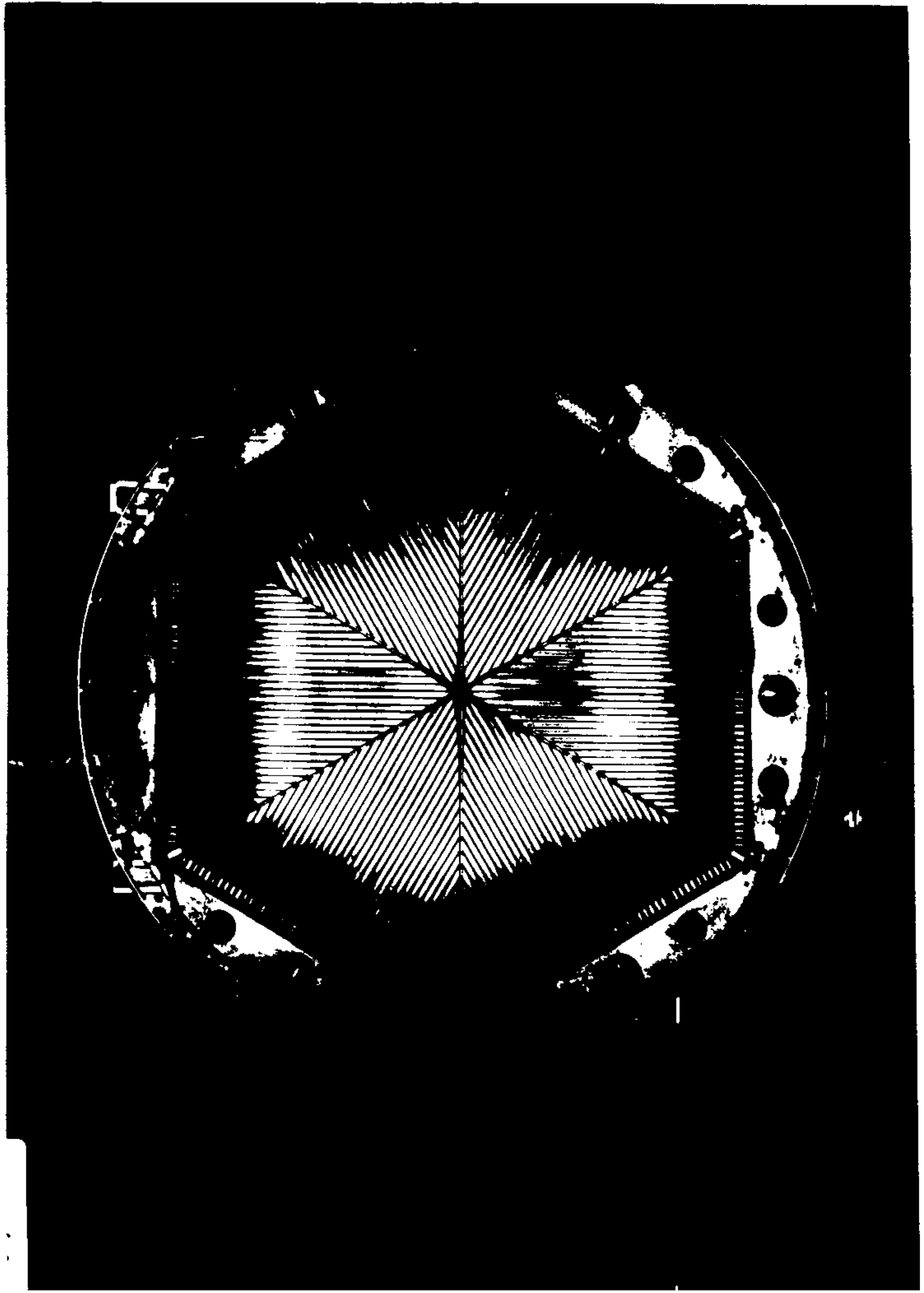
$\sigma_{TRACK} \sim 100\,\mu$ $\sigma_{\theta} \sim 3$ mrad

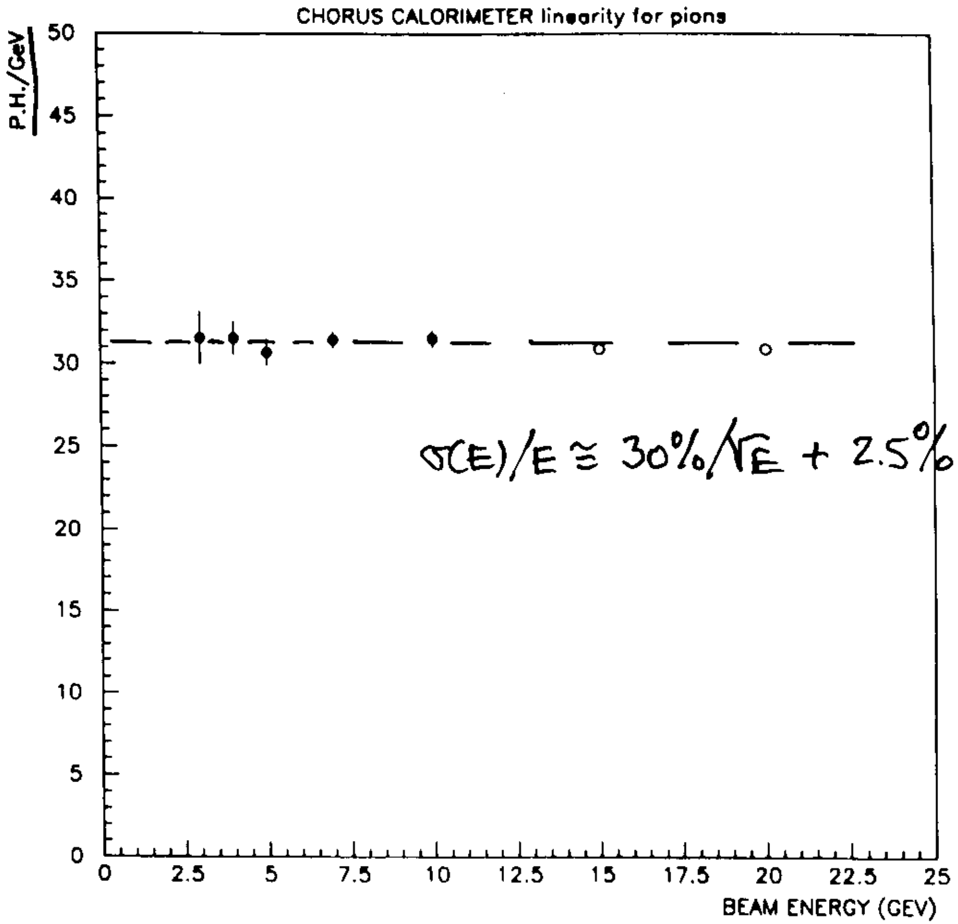
TRACK PREDICTIONS IN EMULSION INTERFACE

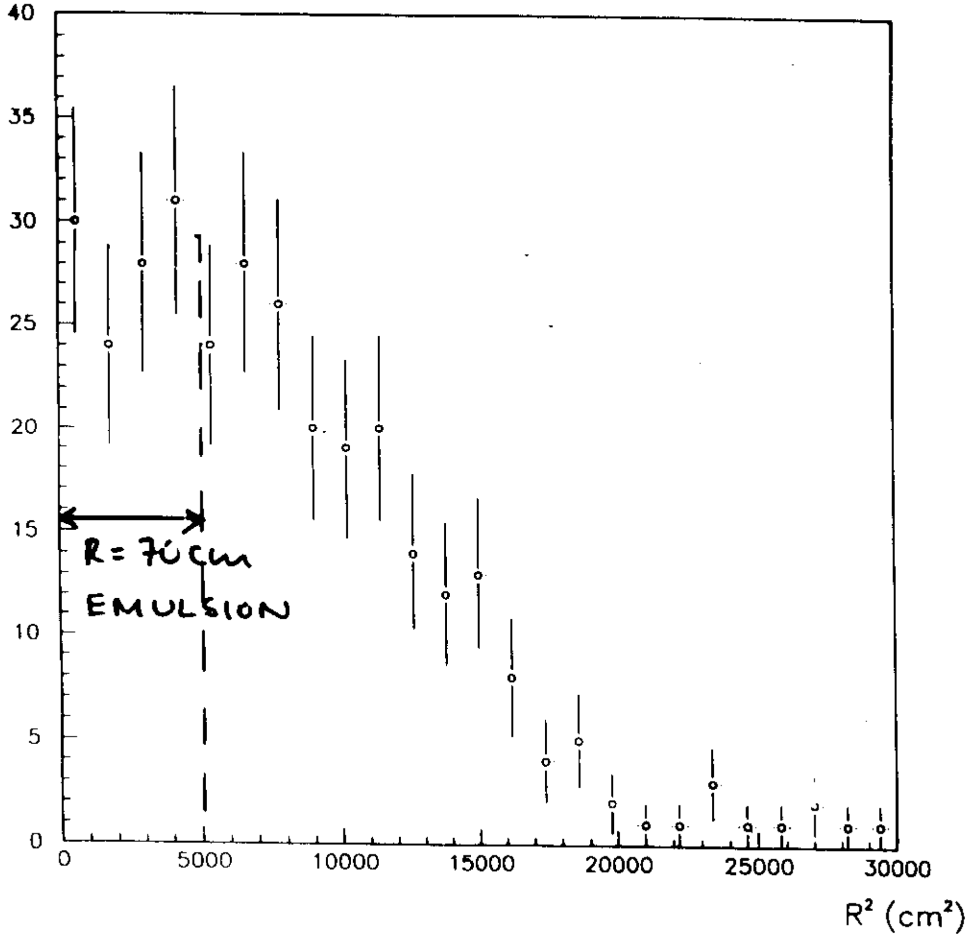


HITS PER PLANE OF FIBERS

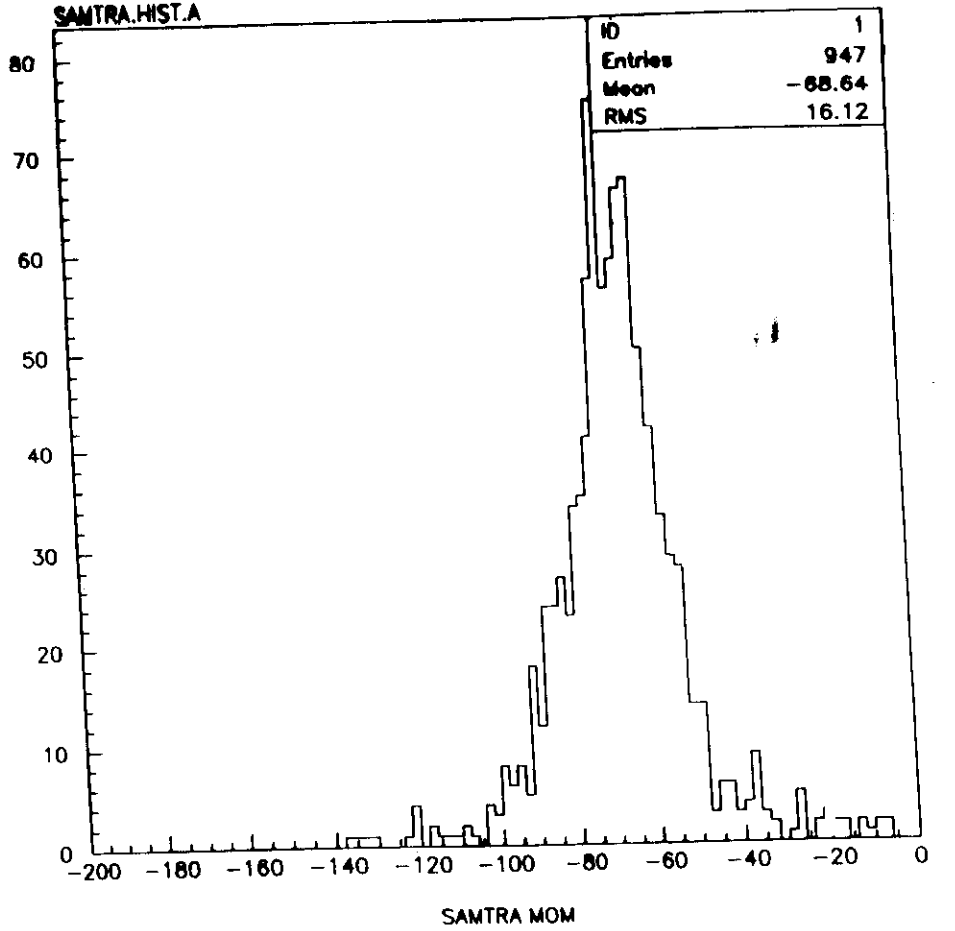





CHORUS CALORIMETER linearity for pions
P.H./GeV
50
45
40
35
30
25
20
15
10
5
0
0
2.5
5
7.5
10
12.5
15
17.5
20
22.5
25
BEAM ENERGY (GEV)
σ(E)/E ≅ 30%/√E + 2.5%



μ SPECTROMETER CALIBRATION



EMULSION TARGET

4 STACKS OF 36 SHEETS $2 \times 350 \mu$

800 kg   INSTALLED <u>5 MAY 1994</u>

PREPARATION IN 2 MONTHS AT CERN
8 PERSONS 6 DAYS / WEEK

PROCESSING AT CERN
C.S. EVERY 20 DAYS
FIRST CHANGE 25 MAY

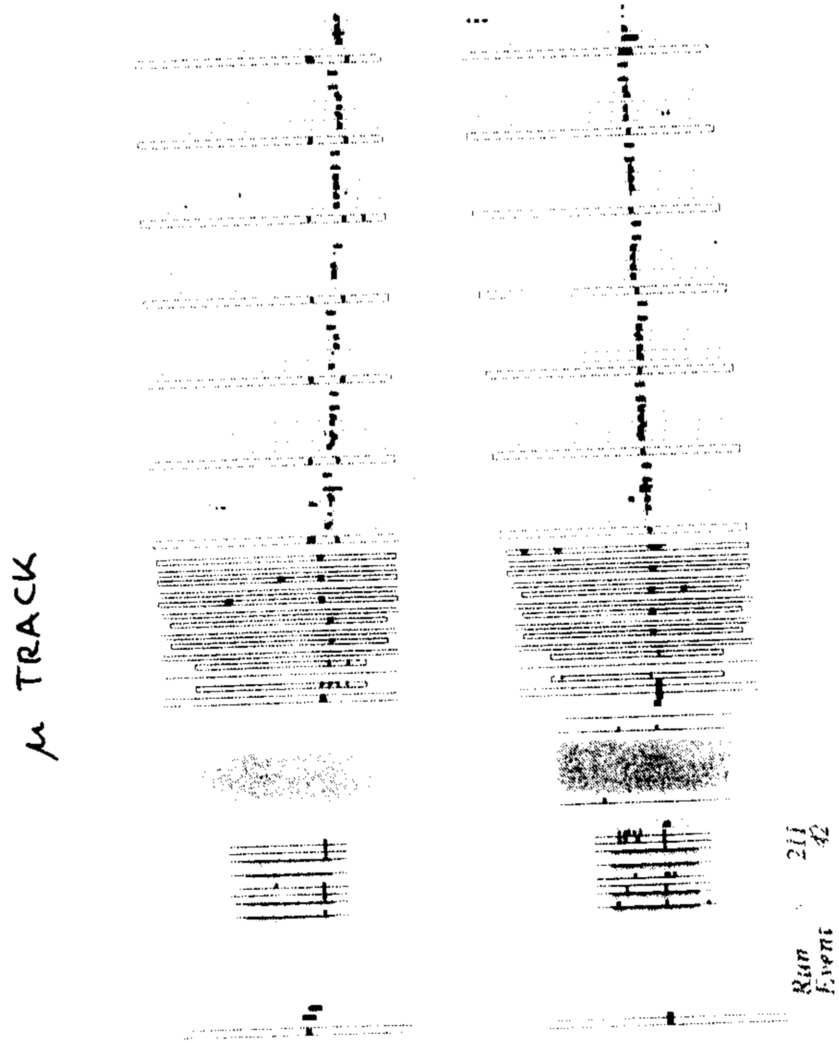
* PROTONS ON TARGET UP TO 30 MAY

$\sim 10^{18}$ p

SENSITIVITY $\sim$ E531

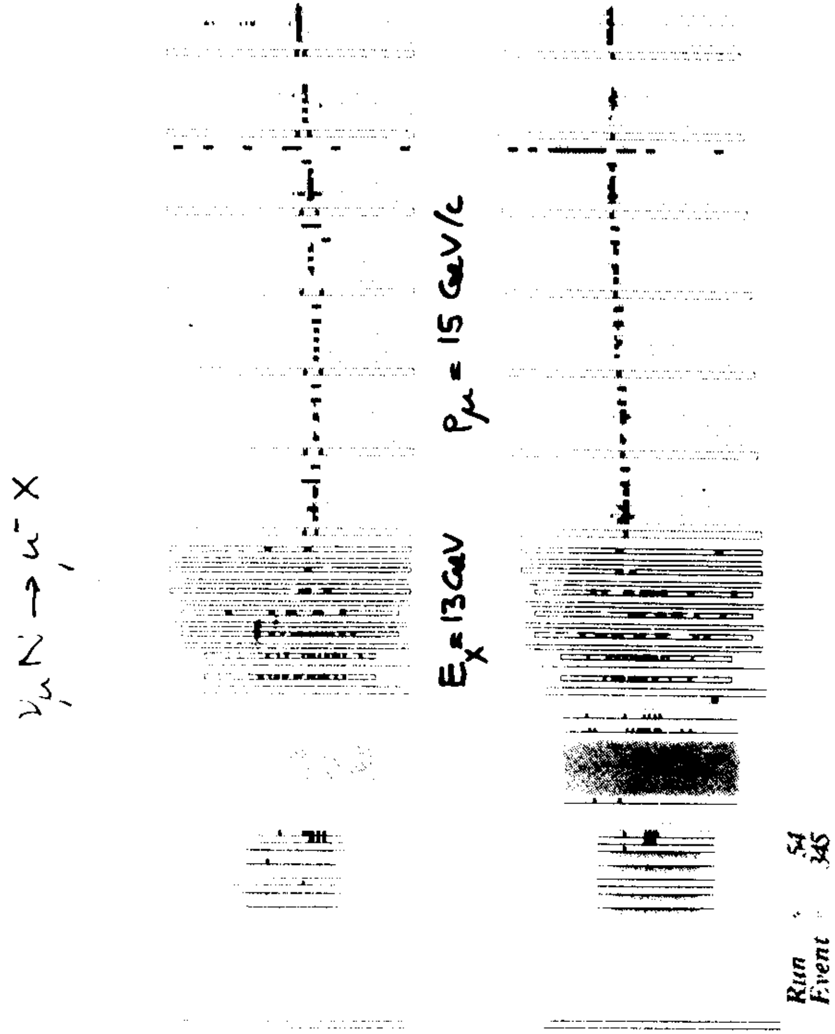
$\sin^2 2\theta < 5 \cdot 10^{-3}$

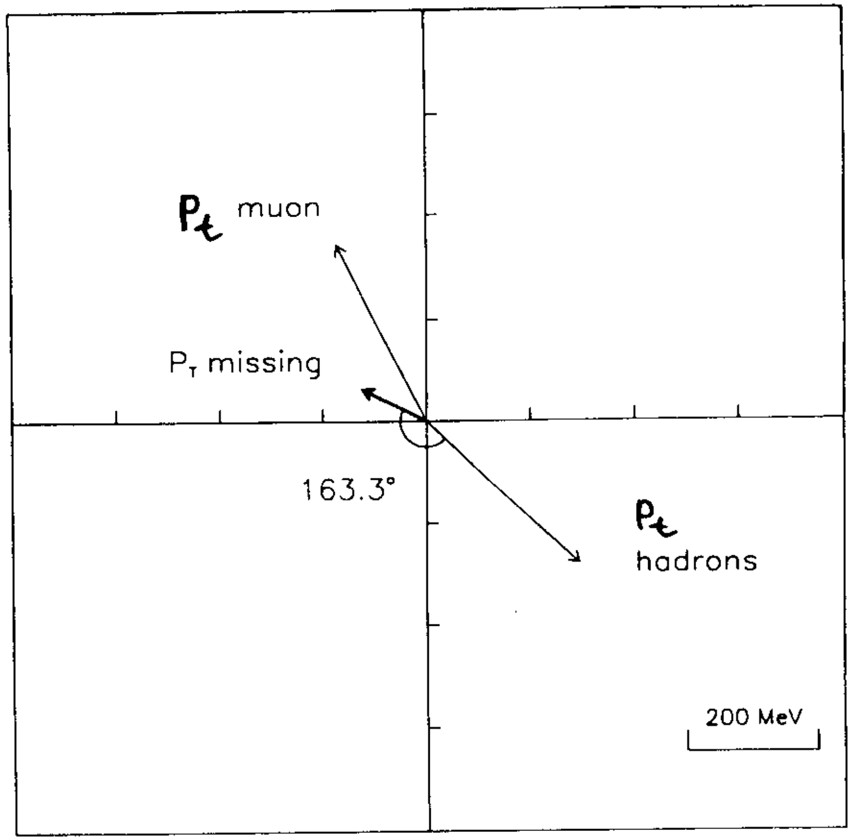
FOR $\Delta m^2 \sim 500 \text{ eV}^2$



EVENT SELECTION BY KINEMATICS

94/05/20 18.51



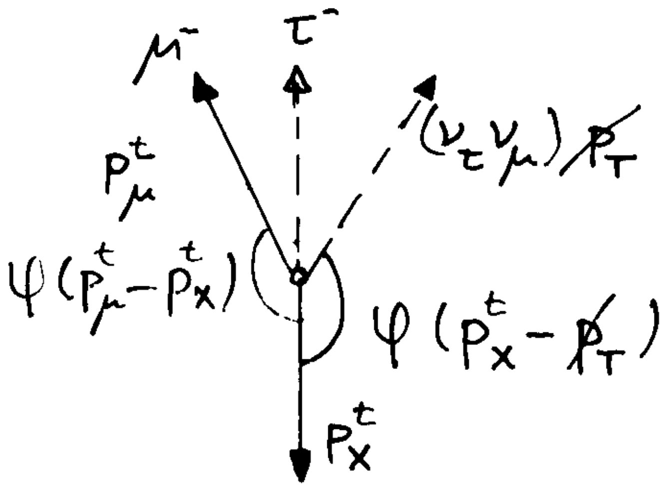


$\nu_\mu N \to \mu^- X$

KINEMATICAL SELECTION OF EVENTS

$\nu_\tau N \rightarrow (\tau^- \rightarrow \mu^-) X$ OR $(\tau^- \rightarrow \pi^-) X$

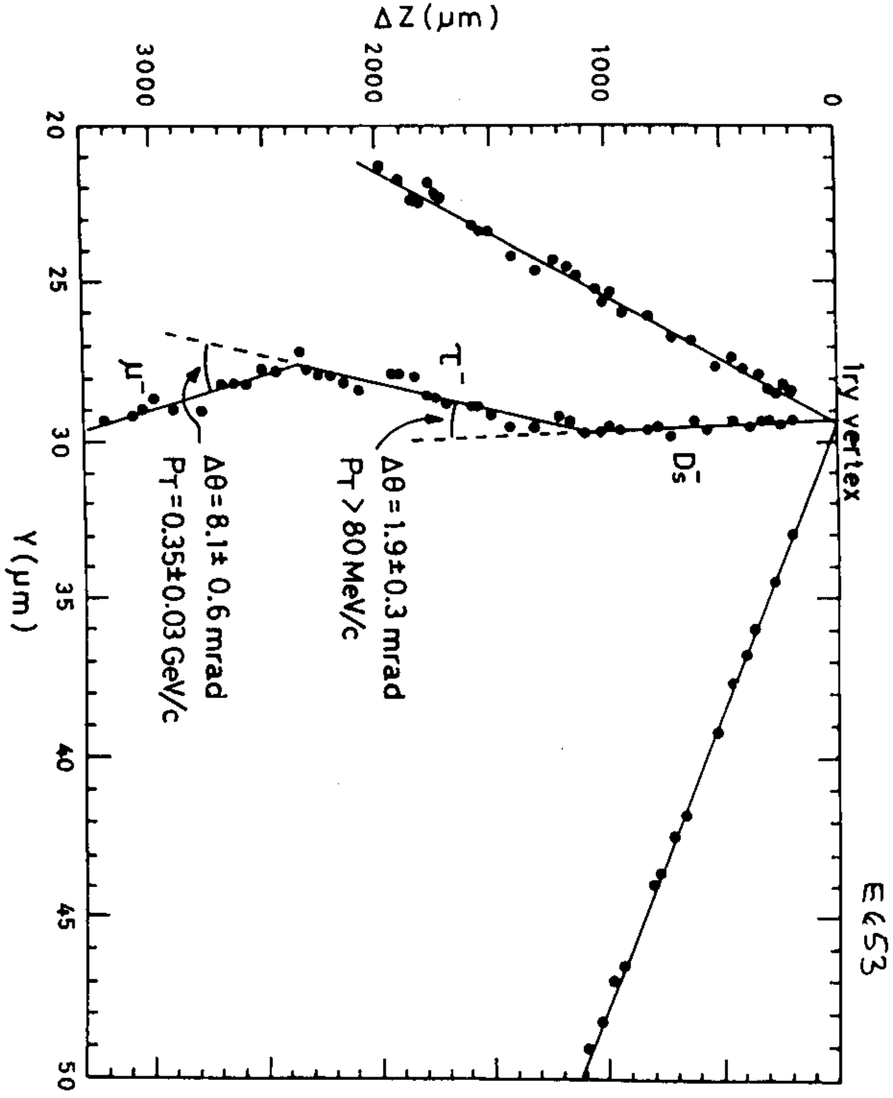
CHECK KINEMATICS

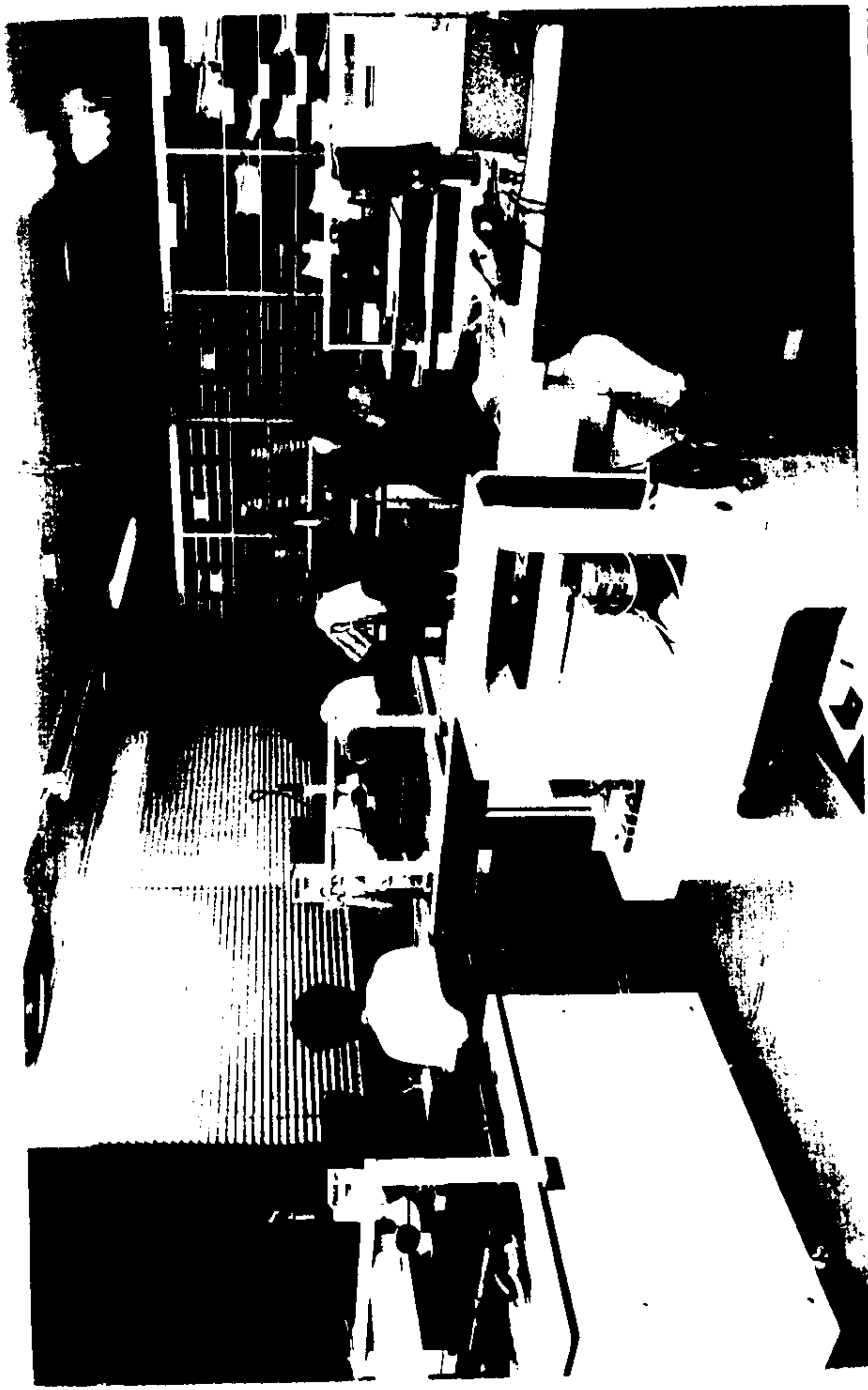


HADRON JET X

MEASURE DIRECTION OF τ TRACK

DEDUCE E_{ν_τ} FROM p_T BALANCE





準自動解析装置群

Table 1

Efficiency of τ^- detection

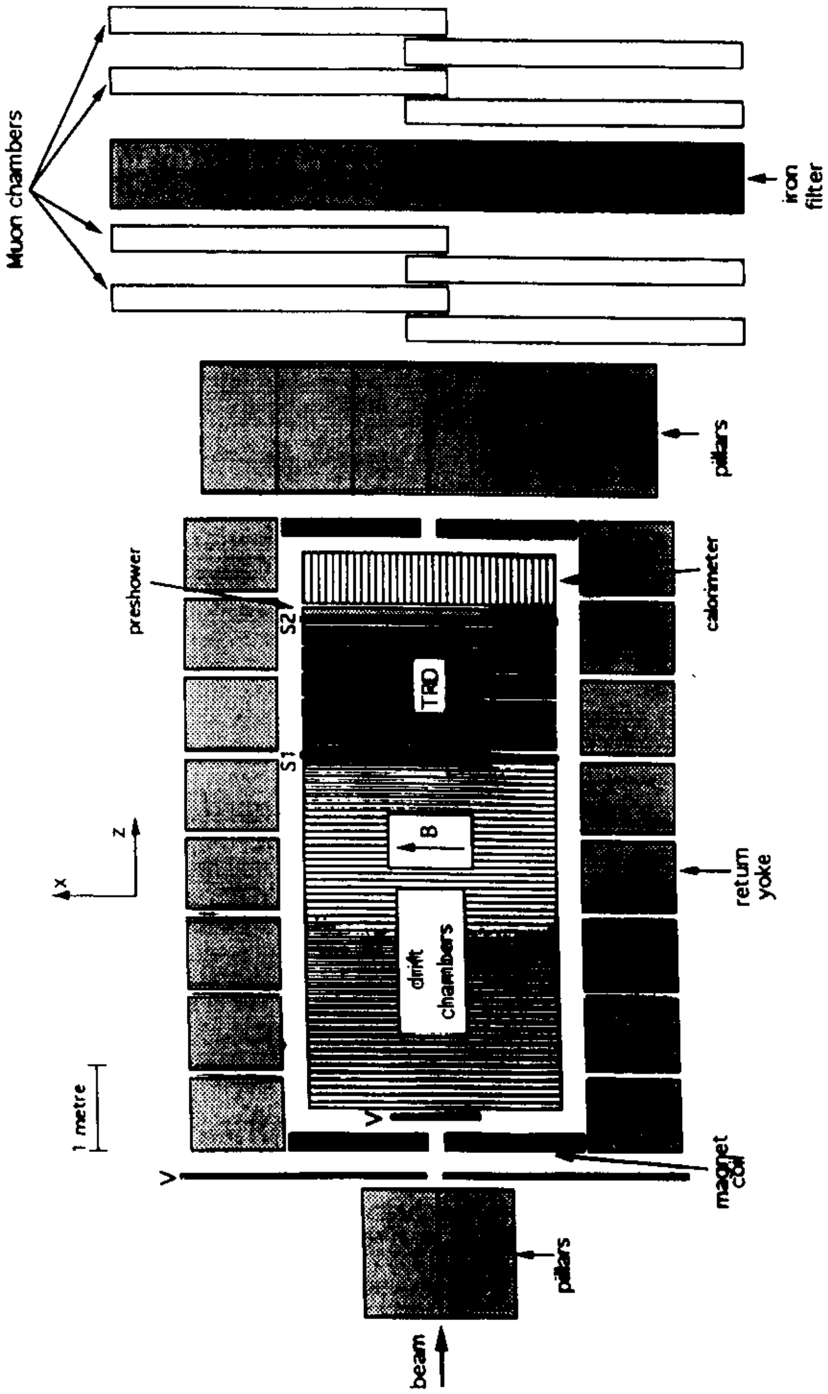
Experiment	τ^- Decay mode	Branching ratio (BR)	Efficiency (ε)	N_τ *	Background	Background after vertex out
CHORUS	$\mu^-\bar{\nu}_\mu\nu_\tau$	0.178	0.098	23	0.27	
	$h^-(n\pi^o)\nu_\tau$	0.50	0.046	29	0.72	
	$\pi^-\pi^+\pi^-(n\pi^o)\nu_\tau$	0.138	0.065	12	0.71	
	ε total = BR · ε		0.0494	64	1.70	0.4

* The number of events corresponds to $\sin^2 2\theta = 5\cdot10^{-3}$ and $\Delta m^2 \geq 40 eV^2$ and a run of 2,4·10[19] protons on target.

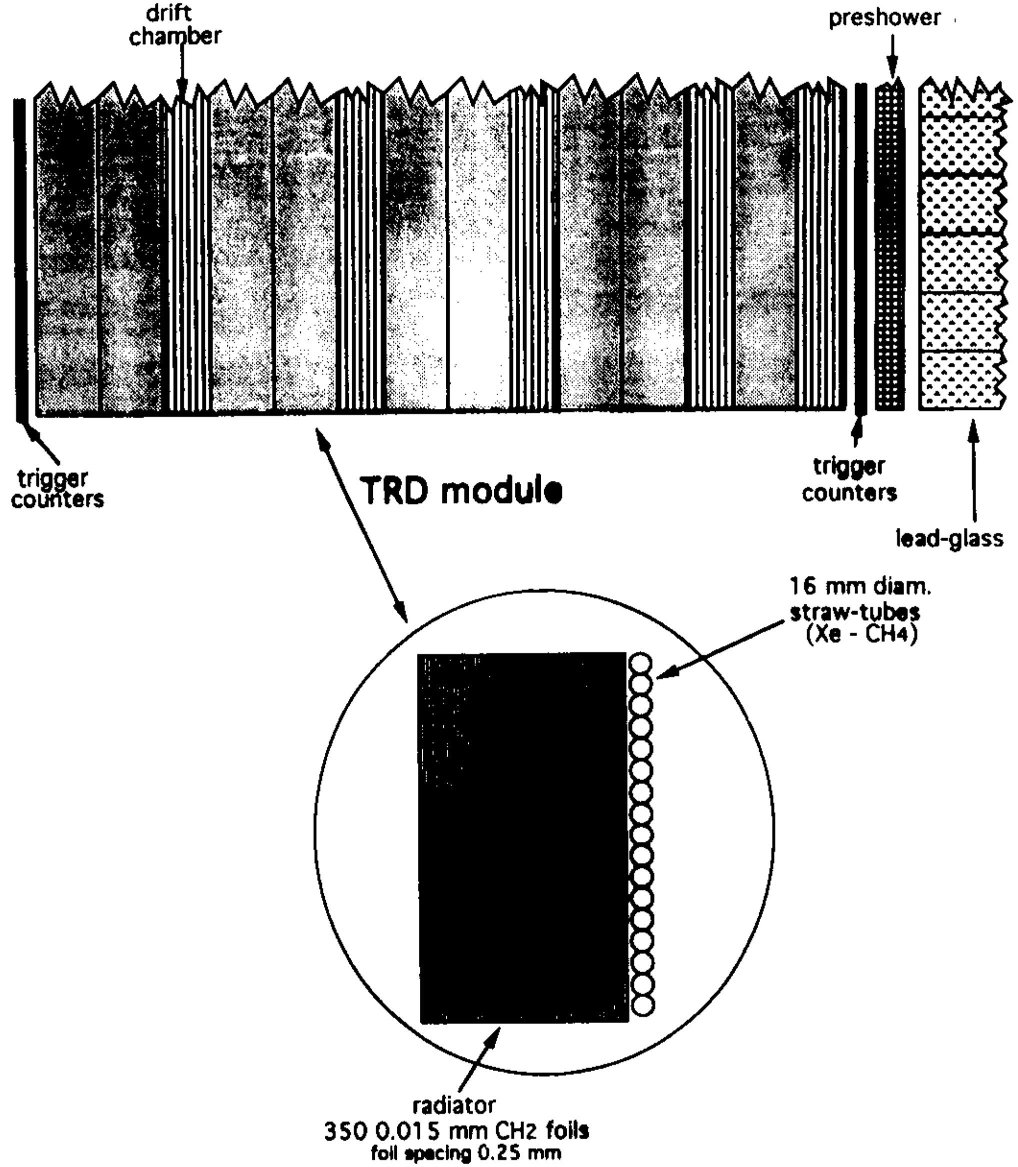
ANALYSIS OF 1 STACK AFTER 1 y

⇨ $N_{\tau*} = 8$

NOMAD

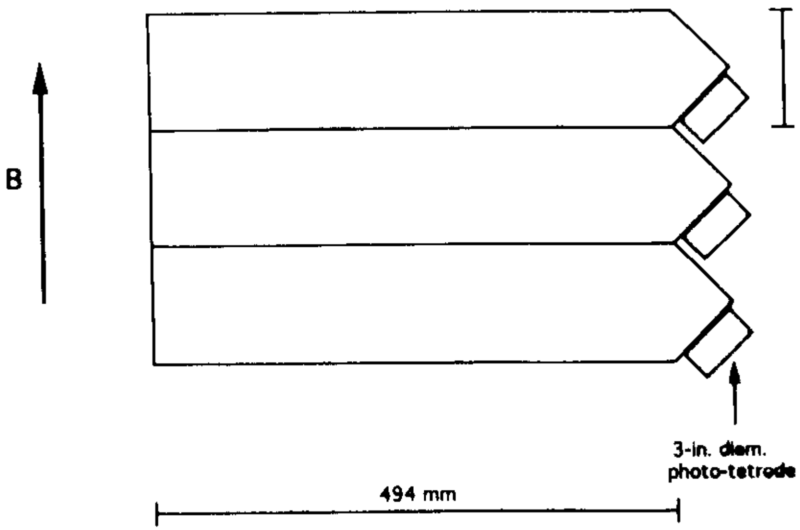


Muon chambers
iron filter
pillars
preshower
calorimeter
S2
TRD
S1
B
z
x
return yoke
drift chambers
1 metre
magnet coil
pillars
beam



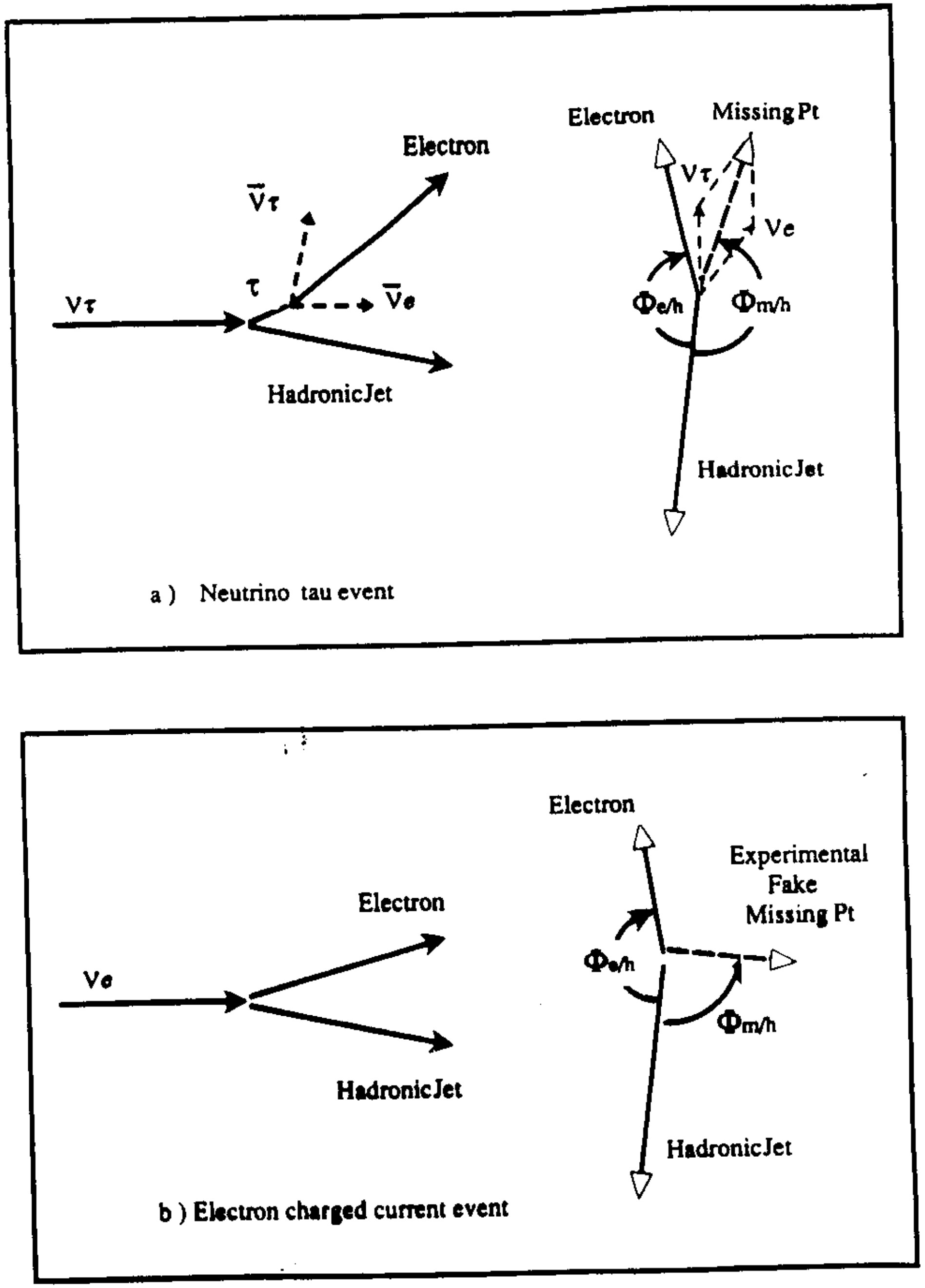
drift chamber
preshower
trigger counters
TRD module
trigger counters
lead-glass
16 mm diam. straw-tubes (Xe - CH4)
radiator
350 0.015 mm CH2 foils
foil spacing 0.25 mm

Pb - GLASS CALORIMETER



MEASURED RESOLUTION

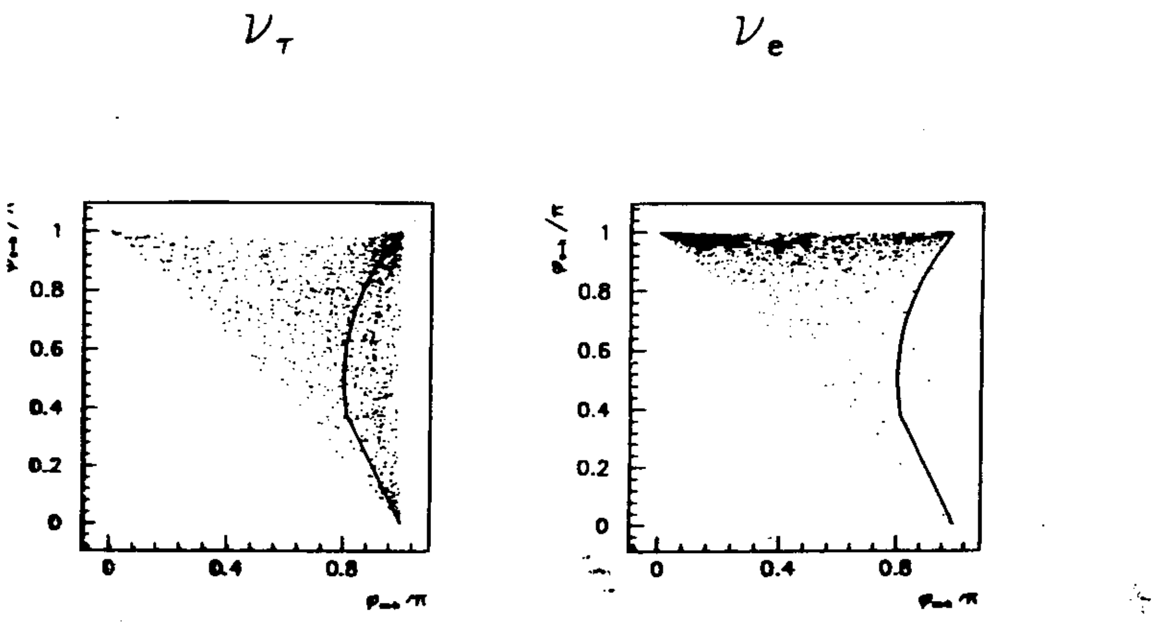
$\sigma(E)/E \sim 3\%/\sqrt{E} + 1\%$



a) Neutrino tau event

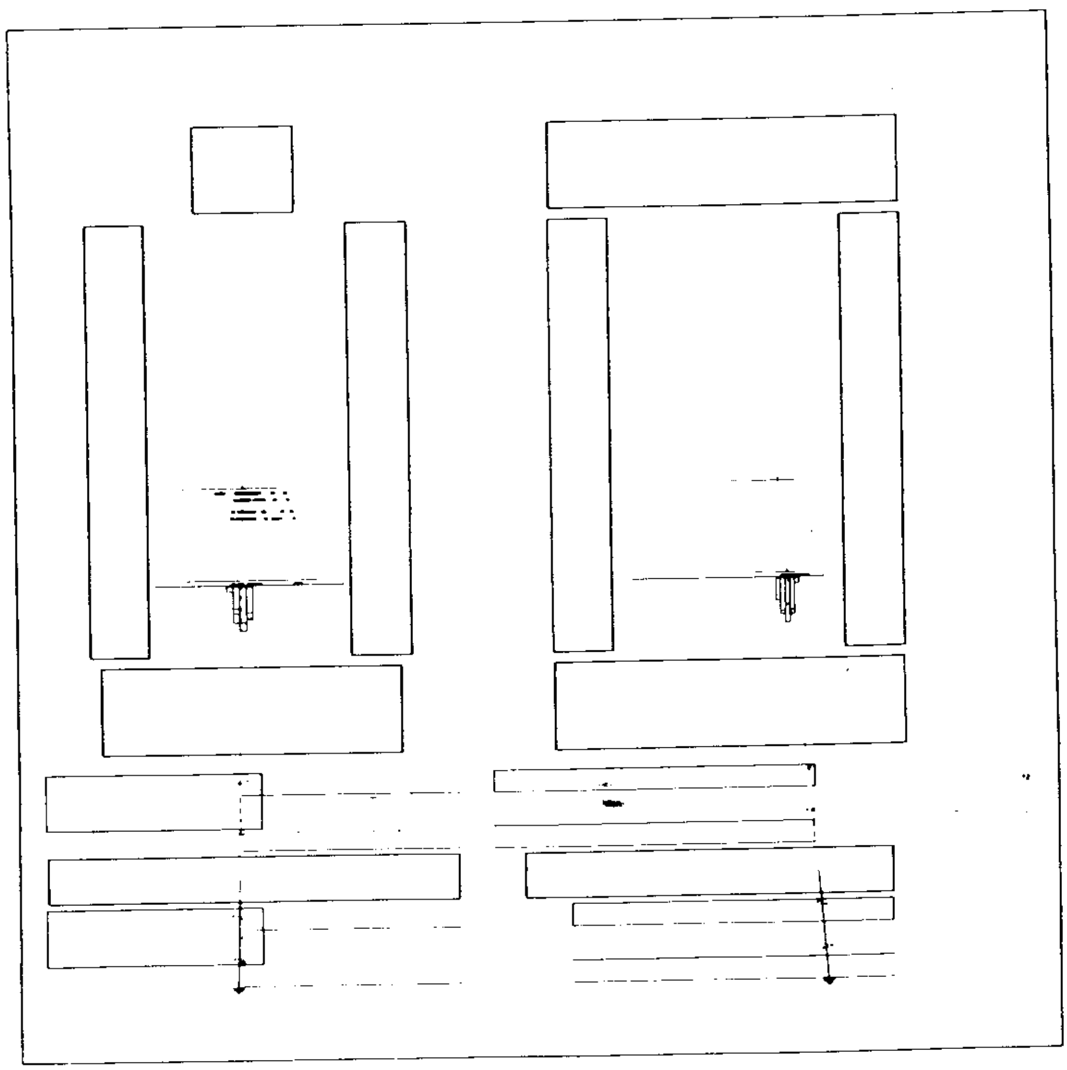
b) Electron charged current event

Fig. 10



$\varphi_{e\text{-}h}$ versus $\varphi_{m\text{-}h}$

Fig. 11



NOMAD

NOMAD STATUS

15 APRIL 1994 — JULY 94

TRIGGER + VETO — INSTALLED + TESTED

DRIFTCHAMBER MODULES — 2/11 (4/11)

TRANSITION RADIATION MODULES — 4/9 (9/9)

DRIFTCH IN TR RADIATION REGION — 2/5 (5/5)

PRE SHOWER — INST. + TESTED

Pb GLASS CALORIMETER — CALIBRATED

MUON CHAMBERS — INST. + TESTED

END OF CONSTRUCTION OF DRIFTCH.

15 FEB. 1995

Experiment	τ^- Decay mode	Branching ratio (BR)	Efficiency (ε)	N_τ *	Background	Background after vertex cut
CHORUS	$\mu^-\bar{\nu}_\mu\nu_\tau$	0.178	0.098	23	0.27	
	$h^-(n\pi^0)\nu_\tau$	0.50	0.046	29	0.72	
	$\pi^-\pi^+\pi^-(n\pi^0)\nu_\tau$	0.138	0.065	12	0.71	
	ε total = BR · ε		0.0494	64	1.70	0.4
NOMAD	$\nu_\tau e^-\bar{\nu}_e$	0.178	0.135	39	4.6	
	$\nu_\tau\mu^-+\bar{\nu}_\mu$	0.178	0.039	11	2.2	
	$\nu_\tau\pi^-\pi^-\pi^++n\pi^0$	0.138	0.077	18	< 0.2	
	$\nu_\tau\pi^-$	0.11	0.014	3	< 0.2	
	$\nu_\tau\rho^-$	0.23	0.020	7	<0.2	
	ε total		0.0477	78	6.8	6.8

* The number of events corresponds to $\sin^2 2\theta = 5\cdot10^{-3}$ and $\Delta m^2 \geq 40eV^2$ and a run of $2.4\cdot10^{19}$

TWO SCENARIOS

(1) DISCOVERY OF $\nu_\mu - \nu_\tau$ OSCILLATION

IF $\sin^2 2\theta_{\mu\tau} \geq 5 \cdot 10^{-4}$ $\Delta m^2 > 50\, eV^2$

⇨ MEASURE $\Delta m^2 \sim m^2_{\nu_\tau} \sim (20\, eV)^2$?

⇨ $\left(\frac{E}{L}\right) \times 10$ → NEW EXPERIMENT

(2) IF NO EVENTS FOUND ABOVE BCKGR

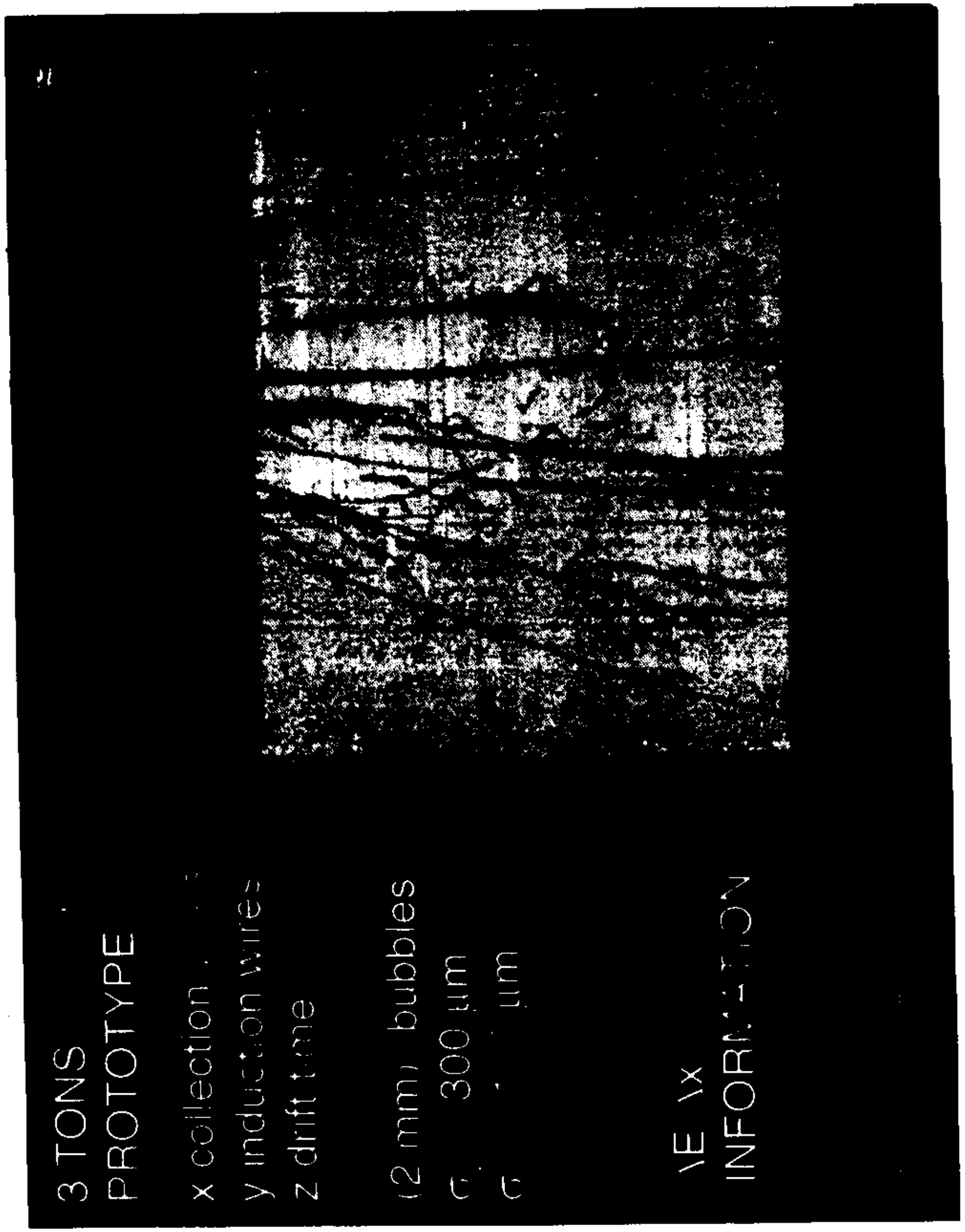
$\sin^2 2\theta_{\mu\tau} < 2.7 \cdot 10^{-4}$

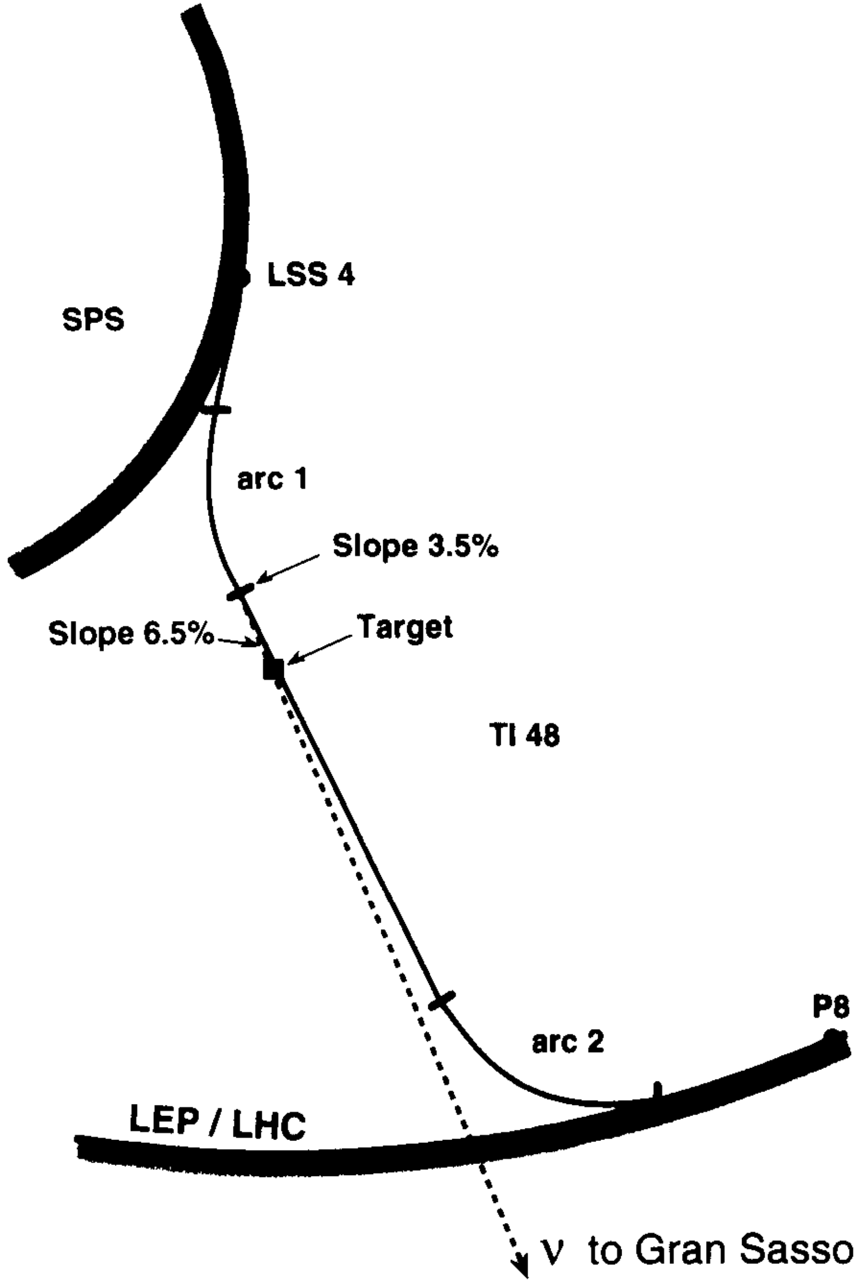
⇨ INCREASE SENSITIVITY TO

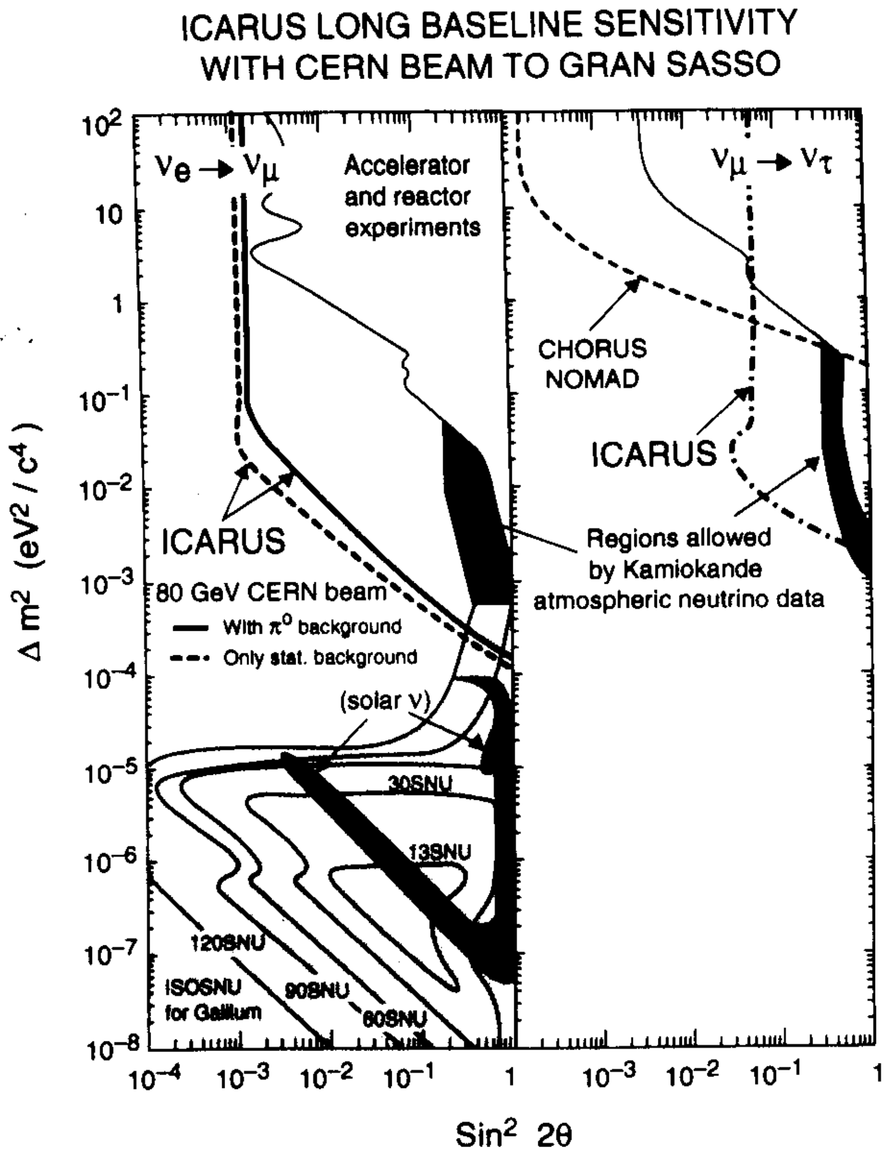
$\sin^2 2\theta_{\mu\tau} \sim 10^{-5}$

NEW EXPERIMENT 50 TIMES

MORE (TARGETMASS LESS BACKGR.




LSS 4
SPS
arc 1
Slope 3.5%
Slope 6.5%
Target
TI 48
P8
arc 2
LEP / LHC
ν to Gran Sasso


ICARUS LONG BASELINE SENSITIVITY
WITH CERN BEAM TO GRAN SASSO
νe → νμ
Accelerator
and reactor
experiments
νμ → ντ
CHORUS
NOMAD
ICARUS
ICARUS
80 GeV CERN beam
With π⁰ background
Only stat. background
Regions allowed
by Kamiokande
atmospheric neutrino data
(solar ν)
30SNU
13SNU
120SNU
ISOSNU
for Gallium
90SNU
60SNU
Δ m² (eV² / c⁴)
Sin² 2θ