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ELECTRON-PROTON INTERACTIONS AT ISABELLE+

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I. Introduction

The investigation of weak interactions through the study of high energy electron and muon collisions with nucleons has been discussed for many years. Since the discovery of weak neutral currents which may interfere with the electromagnetic interaction, these discussions have increased in intensity. The major limitation to now has been the absence of sufficiently high energy beams to make the experiments practical. The interference effect is expected to be of the order $\sim 10^{-4}\ Q^2$, which is a few percent for the highest energy muon beams.

With the construction of high energy storage rings imminent, one can make an enormous leap in the energy regime that could be investigated by the addition of a rather modest electron storage ring. For example, a 20 GeV electron ring, in collision with one of the 400 GeV ISABELLE rings, would result in a center-of-mass energy squared (S) of 32,000 GeV^2. This could result in interference effects, and even pure weak effects, which are of the same order as, or even larger than, the electromagnetic interactions.

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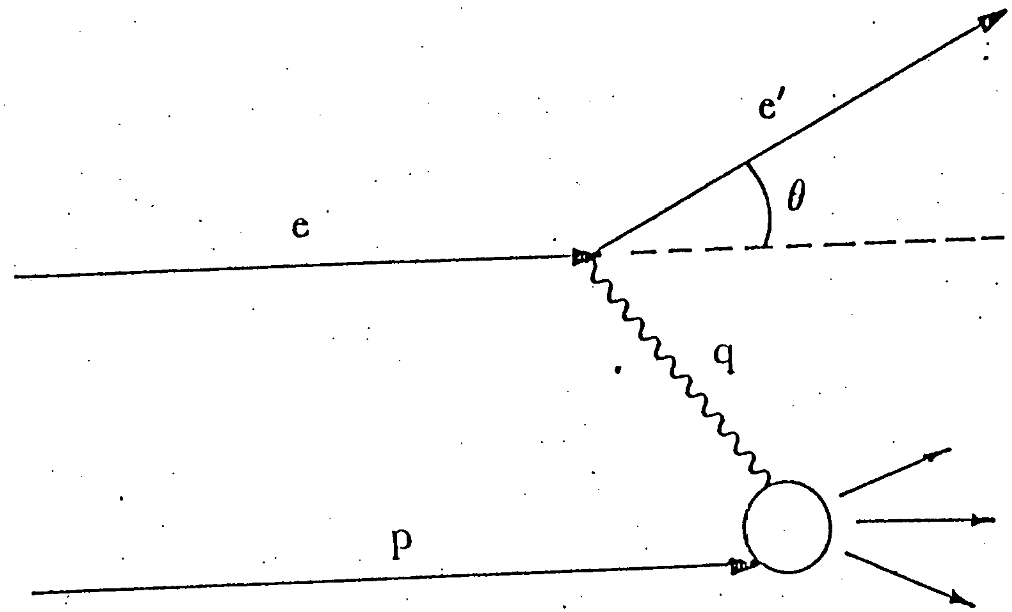


E_e

$e=(e_e, E_e,0,0)$
$e'=(E_e', E_e'\cos\theta, E_e'\sin\theta, 0)$
$p=(E_p, -E_p, 0, 0)$
$s=(e+p)^2=4\,E_e E_p$
$Q^2=-q^2=-(e-e')^2=4\,E_e E_e'\sin^2\theta/2$

$$\nu=\frac{q\cdot p}{2}=\frac{2\,E_p}{M_p}\,(E_e-E_e'\cos^2\theta/2)$$

p.c. x

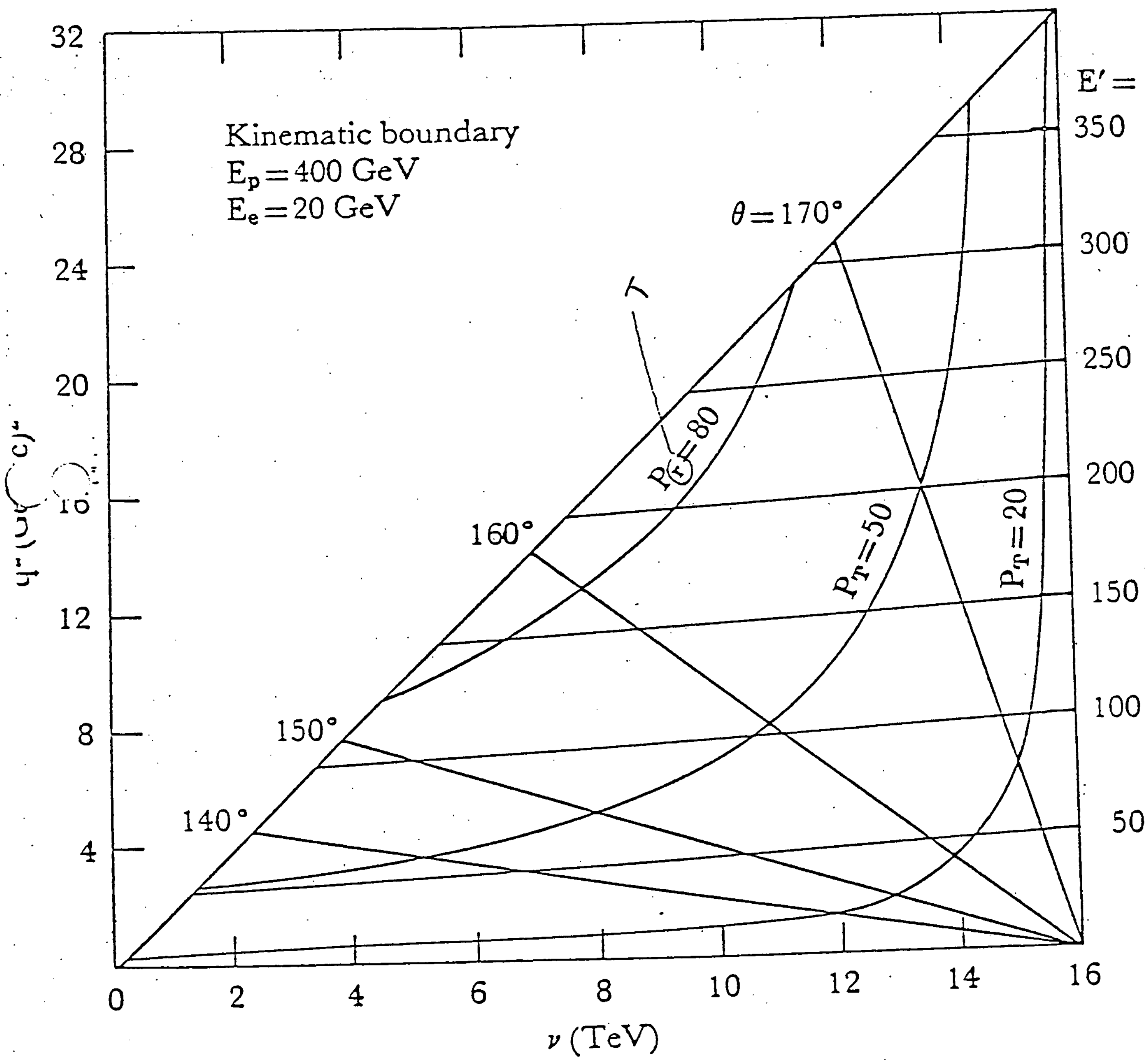
$$x=\frac{Q^2}{2\,M_p\nu}\,,\quad y=\frac{\nu}{\nu_{max}}\,,\ Q^2=s\times y$$

$$Q_{max}{}^2=s \qquad \nu_{max}=\frac{2\,E_e E_p}{M_p}$$

$p_t{}^2=Q^2(1-y)$

Hampelmann/Simon
Electron-Proton

Fig. 1



Electron - Proton

Humphrey/Linen Fig 2

Recently, there have been numerous studies of both the machine designs and the physics capabilities of such machines.[1-4] The purpose of this paper is to investigate the physics possibilities specific to ISABELLE at 400 GeV, with an electron/positron storage ring of 20 GeV.

II. Kinematics

The allowed kinematic region is shown in Fig. 2, where we use the usual definitions shown in Fig. 1.

Fig. 1

Fig. 2

Of particular interest are the lines of constant outgoint lepton angle, and the lines of constant P_T. The leptons from the high Q^2 interactions are going backwards in the lab at rather high energy. This means that the

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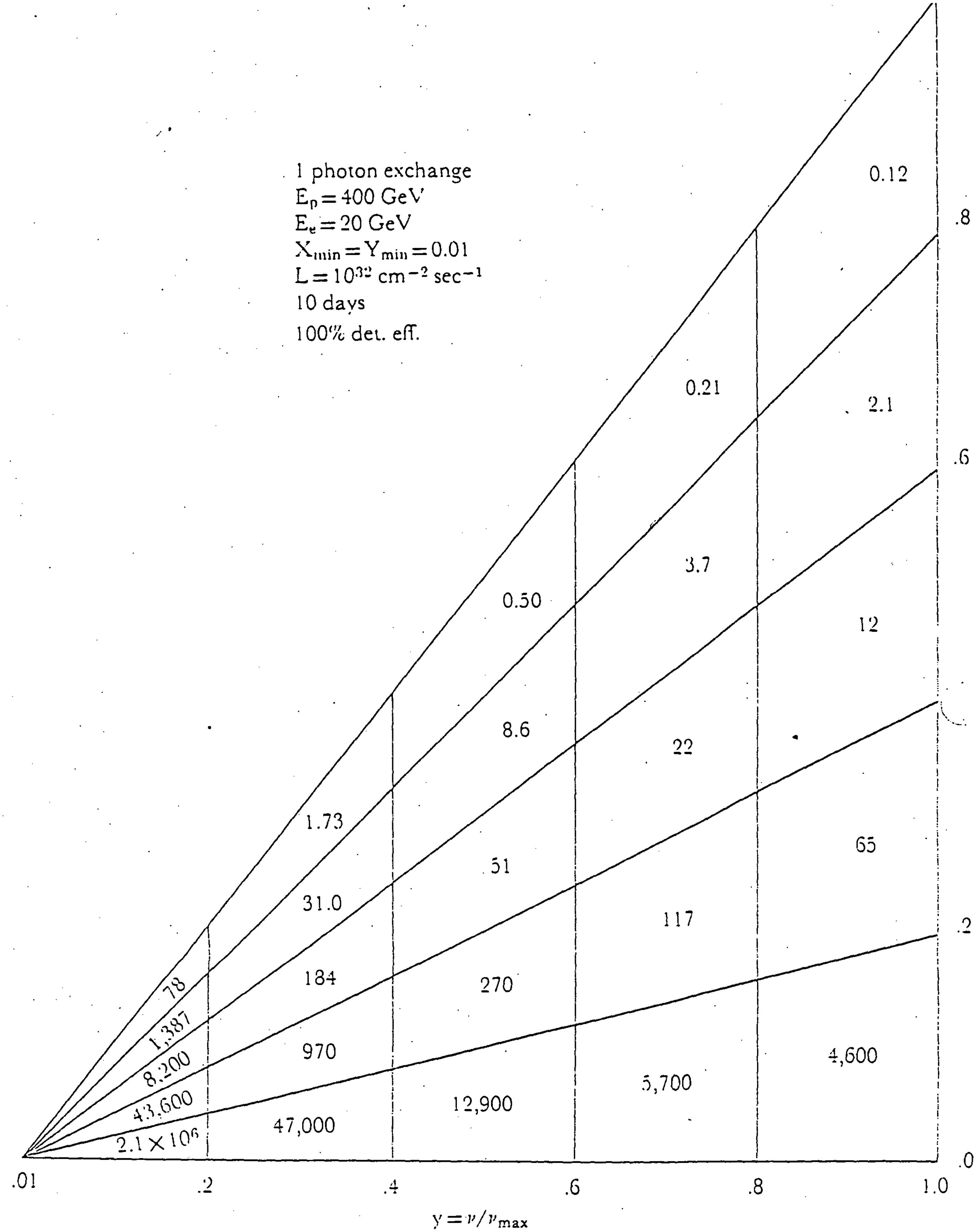
1. Various Fermilab Summer Studies, particularly 1973, 1976 and 1977 have looked at the technical and physics problems of ep colliding beams.
2. PEP Summer Study, 1974.
3. CERN has published a number of excellent reports on ep collisions, among them: "The Physics Interest of a 10 TeV Proton Synchrotron, 400 x 400 GeV^2 Proton Storage Rings, and Electron-Proton Storage Rings," edited by L. Camilleri: CERN Yellow Report 76-12, "An e-p Facility in the SPS"; CERN ISR-ES-GS/76-50.
4. "Physics with Large Electron-Proton Colliding Rings," C.H. Llewellyn-Smith and B.H. Wiik, DESY 77/38.



Electron-proton ... Fig. 3

detector only has to cover the backward hemisphere (relative to the electron incident direction), and that it will be easy to detect the absence of the lepton in the reaction $e + p \rightarrow \nu$ + anything. A reasonable trigger might be large hadronic transverse momentum. Experience at Fermilab shows that using segmented calorimeters to measure high P_T makes a clean trigger. Setting the P_T threshold at $P_T \geqslant 10$ GeV/c will cover almost the whole kinematic region of interest, and will strongly suppress a major background, beam-gas scattering of the protons.

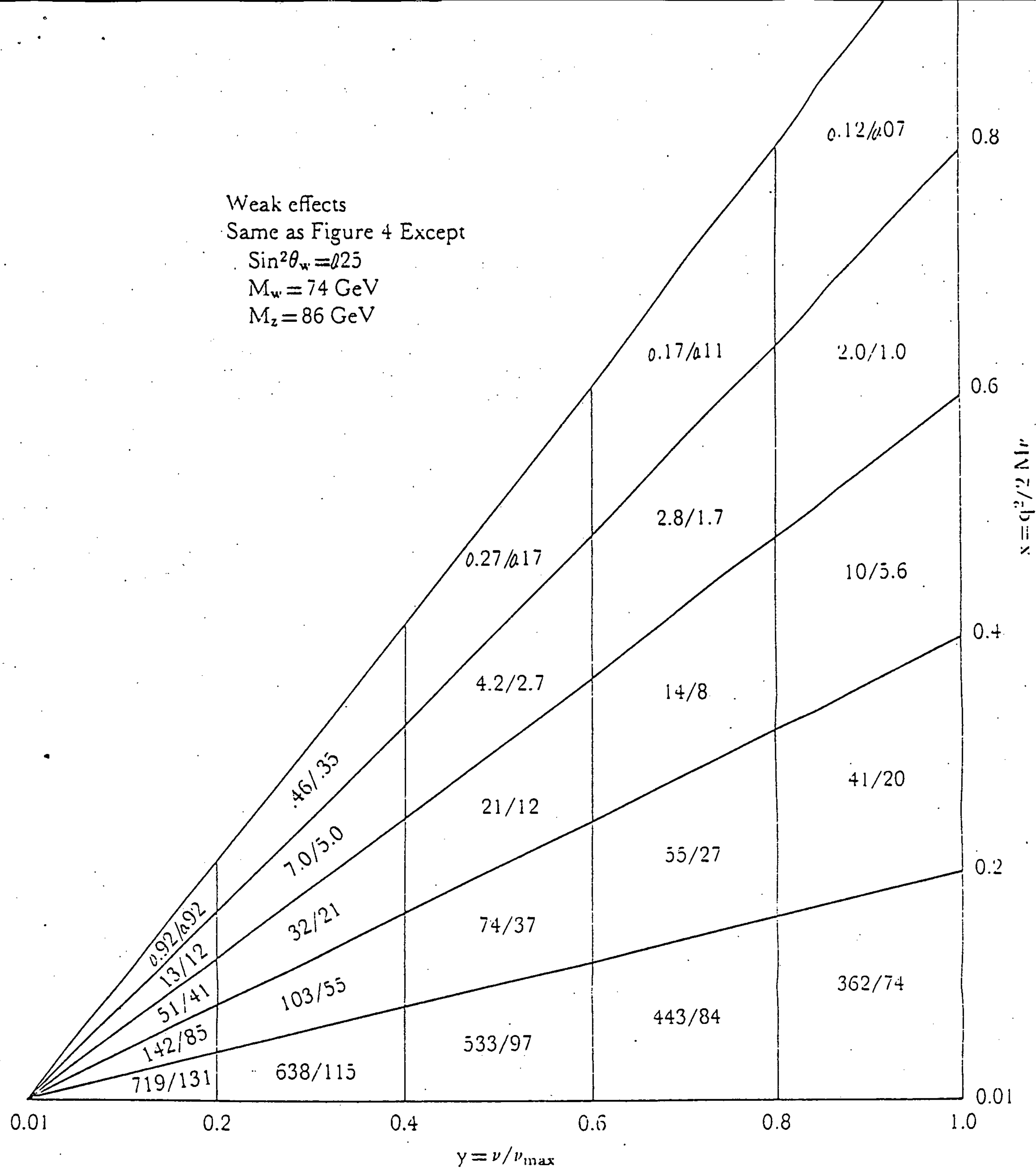
III. Electron-Proton Cross Sections

In order to calculate the rates, we have used cross section formulae as published in Llewellyn-Smith and Wiik[4] shown in the appendix. The assumptions for the rates shown are:

1. $L = 10^{32}$ cm^{-2}sec^{-1} for 10 days.
2. $\nu W_2^{em} = 2.8(1 - x)^3 - 4.0(1 - x)^4 + 1.6(1 - x)^5$ from a recent analysis of SLAC and Fermilab data.[5]
3. Perfect Bjorken scaling. Examples of the consequences of various scale breaking models are discussed in Ref. 4.
4. The electron beam is unpolarized. Figure 3 shows the rates for the one photon exchange process in bins of $\Delta x = \Delta y = 0.2$.

Fig. 3

5. T.B.W. Kirk, private communications.



Weak effects
Same as Figure 4 Except
Sin²θw=0.25
Mw=74 GeV
Mz=86 GeV
0.12/0.07
0.17/0.11
2.0/1.0
2.8/1.7
0.27/0.17
10/5.6
4.2/2.7
14/8
.46/.35
21/12
41/20
7.0/5.0
55/27
0.92/0.92
32/21
74/37
13/12
362/74
51/41
103/55
443/84
142/85
533/97
719/131
638/115
0.8
0.6
0.4
0.2
0.01
x=q²/2Mν
0.01
0.2
0.4
0.6
0.8
1.0
y=ν/νmax

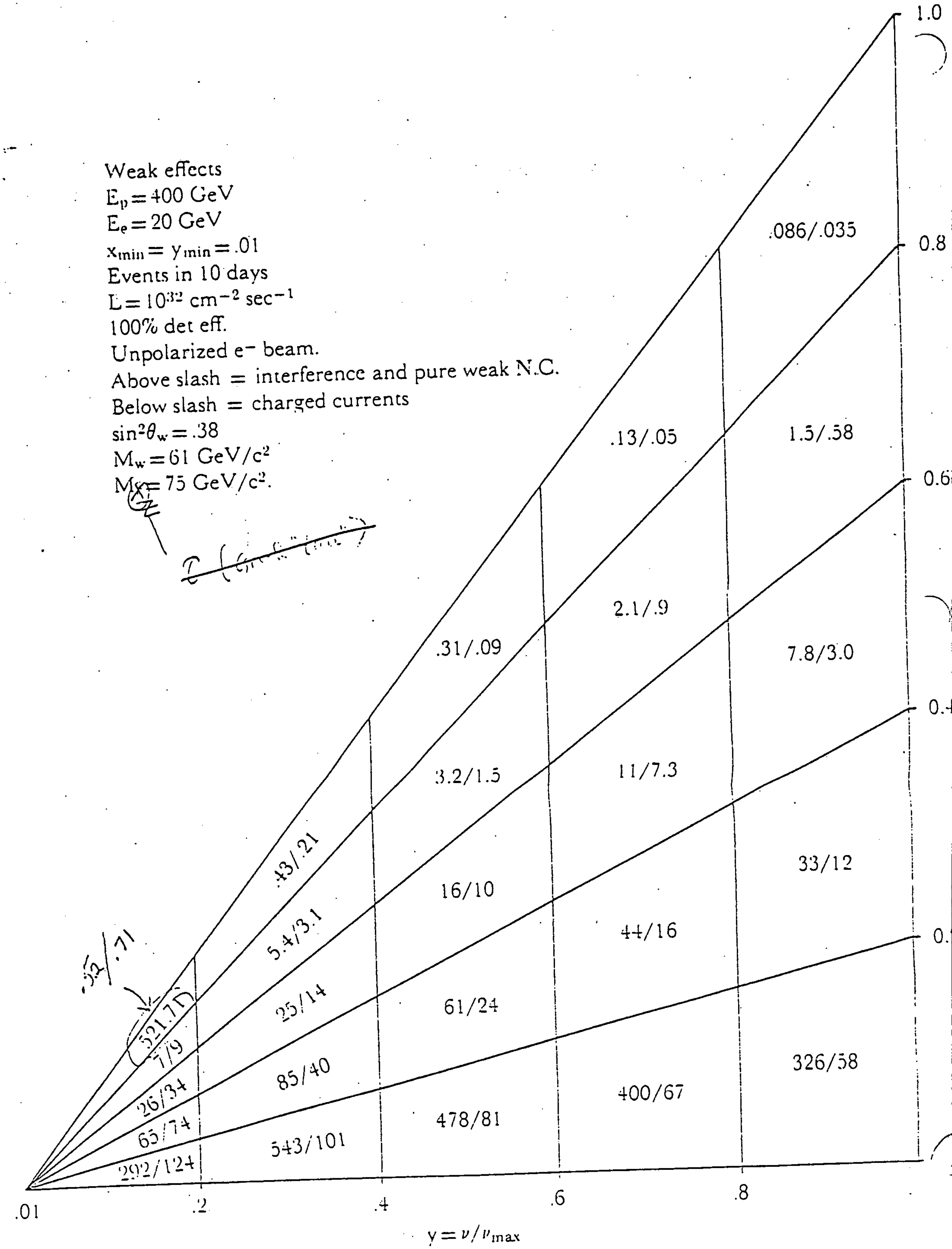

Weak effects
$E_p = 400$ GeV
$E_e = 20$ GeV
$x_{min} = y_{min} = .01$
Events in 10 days
$L = 10^{32}$ cm^{-2} sec^{-1}
100% det eff.
Unpolarized e^- beam.
Above slash = interference and pure weak N.C.
Below slash = charged currents
$\sin^2\theta_w = .38$
$M_w = 61$ GeV/c^2
$M_Z = 75$ GeV/c^2.
1.0
0.8
0.6
0.4
.086/.035
.13/.05
1.5/.58
2.1/.9
.31/.09
7.8/3.0
3.2/1.5
11/7.3
.43/.21
33/12
16/10
5.4/3.1
44/16
.52/.71
61/24
25/14
7/9
85/40
326/58
26/34
400/67
478/81
65/74
543/101
292/124
.01
.2
.4
.6
.8
$y = \nu/\nu_{max}$

Figure 4 shows the number of neutral current interference and pure weak neutral current events for $\sin^2 \theta_\omega = 0.38$. The numbers below the slash are the number of events for $e^- + p \to \nu$ + anything.

Fig. 4

To show the effect of the Weinberg angle, Fig. 6 repeats Fig. 5 for $\sin^2 \theta_\omega = 0.25$. The effect of the weak interaction increases with increasing W and Z mass. Note that for x and y greater than 0.4, there is a 4.5σ effect in 10 days of running.

APPENDIX - CROSS SECTION FORMULAE

These formulae are copies from Ref. 4, with the exception of the charged current cross section, and with the correction of some typographical errors

$$\left(\frac{d^2\sigma}{dxdy} \right)_{1 \text{ photon}} = \frac{4\pi\alpha^2}{sx^2y^2} [(1 - y)F_2(x,Q^2) + y^2xF_1(x,Q^2)] .$$

For transverse virtual photons

$$2xF_1 = F_2$$

and assuming scaling

$$F_i(x,Q^2) \to F_i(x) .$$

Assuming that there is only one neutral vector boson, Z, we can write the cross section for $e^{\pm} + p \to e^{\pm}$ + anything, including the weak-electromagnetic in reference and the pure weak terms:

$$\left.\frac{d^2\sigma}{dxdy}\right|_a = \left(\frac{d^2\sigma}{dxdy} \right)_{1 \text{ photon}} \left\{ 1 + \frac{\sqrt{2}GQ^2M_z^2}{e^2(Q^2 + M_z^2)} g_a \frac{(1 - y)F_2^I + y^2xF_1^I - b_a y(1 - y/2)xF_3^I}{(1 - y)F_2 + y^2xF_1} \right\}$$

$$+ \frac{G^2s}{8\pi} \frac{M_z^4}{(Q^2 + M_z^2)^2} g_a^2 \left\{ (1 - y)F_2^{wk} + y^2xF_1^{wk} - b_a y(1 - y/a)xF_x^{wk} \right\} .$$

We have introduced six new structure functions, F_i^I for the interference term, and F_i^{wk} for the pure weak neutral current term.

Assuming a simple spin 1/2 parton model and the Weinberg model, we have for protons as the target:

$$F_2^I = \frac{\sqrt{2}}{6}(12 \sin^2 \theta_w - 5) F_2$$

$$xF_3^I = \frac{5\sqrt{2}}{6} F_2, \quad 2xF_1^I = F_2^I$$

and

$$F_2^{wk} = \frac{1}{3}(24 \sin^4 \theta_w - 20 \sin^2 \theta_w + 9) F_2$$

$$xF_3^{wk} = \frac{1}{2}(20 \sin^2 \theta_w - 9) F_2$$

$$2xF_3^{wk} = F_2^{wk} .$$

Particle	Polarization	g_a	b_a
e^-	L	g_L	+ 1
e^-	R	g_R	- 1
e^+	L	gR	+ 1
e^+	R	g_L	- 1

where,

$$g_R = 2\sqrt{2} \sin^2 \theta_w$$

$$g_L = \sqrt{2} (s \sin^2 \theta_w - 1)$$

and

$$M_Z = \frac{74.4}{|\sin 2\theta_w|}$$

charged current cross sections.

The charge current formulae are:

$$\left.\frac{d^2\sigma}{dxdy}\right|_{e_L^- p \to \nu + ..} = \frac{G^2 S}{8\pi} \left(\frac{M_w^2}{(Q^2 + M_w^2)} \right) \{(1 - y) F_2^{cc} + y^2 xF_1^{cc} + y(1 - y/2) xF_3^{cc}\}$$

$$\left.\frac{d^2\sigma}{dxdy}\right|_{e_R^+ p \to \bar{\nu} + ..} = \frac{G^2 S}{8\pi} \left(\frac{M_w^2}{Q^2 + M_m^2} \right)^2 \{(1 - y) F_2^{cc} + y^2 xF_1^{cc} - y(1 - y/2) xF_3^{cc}\} .$$

The cross sections for other processes, e^-_R, e^+_L, etc., are identically zero. With the assumptions:

$$xF_3^{cc} \cong 4F_2 \cong F_2^{cc}$$

we have

$$\frac{d^2\sigma}{dxdy} = \frac{G^2 s}{2\pi} \left(\frac{M_w^2}{Q^2 + M_w^2} \right)^2 F_2(x) \quad \text{for } e^-_L p \to \nu + \ldots$$

and

$$\frac{d^2\sigma}{dxdy} = \frac{G^2 s}{2\pi} \left(\frac{M_w^2}{Q^2 + M_w^2} \right)^2 (1 - y)^2 F_2(x) \quad \text{for } e^+_R p \to \bar{\nu} + \ldots$$

and

$$M_w = \frac{37.2}{|\sin 2\theta_w|} .$$