FERMILAB-Proposal-0586

STUDY OF CONSTITUENT SCATTERING
IN HADRONIC COLLISIONS

P. Franzini
Columbia University

C. N. Brown, R. D. Kephart
Fermilab

M. Adams, G. Coutrakon, R. J. Engelmann,
G. Finocchiaro, R. J. Fisk, M. L. Good, A. S. Ito,
H. Jöstlein, J. Kirz, J. Lee-Franzini, R. L. McCarthy
State University of New York at Stony Brook

January 1978

Spokesman:
R. L. McCarthy
Department of Physics
State University of New York
Stony Brook, New York 11794
(516) 246-4079

45 pp.

STUDY OF CONSTITUENT SCATTERING IN HADRONIC COLLISIONS

We propose to study constituent scattering in hadronic collisions. Instead of attempting to detect jets, we restrict our attention to single particle production at very high $x_{\perp}$ in each arm of a double arm spectrometer. We plan to identify each hadron in order to measure the quantum number flow in constituent collisions.

The apparatus to be used is a double arm magnetic spectrometer with Čerenkov counters to identify hadrons. The experimental configuration is very similar to that of E-494 except for the following changes:

1. hydrogen target
2. larger aperture
3. incident π^+, π^-, p beams

We request 1200 hours of data acquisition and 200 hours to tune the experiment.

Changes Relative to P559

This proposal is very similar to proposal P559. For the benefit of those people who have read P559, we here summarize the important changes relative to the previous proposal:

1. We are in the process of publishing the results from E-494[1-3]. These results lead to a clearer definition of the kinematic region in which we can hope to study quantum number flow in constituent scattering. This leads to an increase in our estimated rates. (See pages 5,6,14,15.)
2. A beam has been approved[4] for the M1 line which is suitable for the performance of the experiment. (See page 9.)

INTRODUCTION - GENERAL METHOD

In order to motivate our discussion, we quote the views of Field and Feynman[5] regarding quark fragmentation (jet formation). We consider a quark emerging from a hard scatter. The quantity z represents the momentum fraction which a hadron possesses relative to the quark momentum. (Quoted from Ref. 5.)

> The theoretical picture which we use to guide our thinking is this. As the quark q (presumably colored) leaves the others the forces responsible for confinement build up an ever larger field until pairs of quarks q, $\bar{q}$ are produced which breaks down the field. The many quarks and antiquarks produced now gather into color singlets, $q\bar{q}$ and qqq forming hadrons. ...
>
> The field (color field), being independent of the flavor of q, makes new pairs in a manner independent of q. The original quark finds itself in one of the hadrons near the higher end of the momentum distribution, in particular if z is near 1 so that the hadron carries most of the available momentum that hadron contains the original quark.

Independently of theory this view is obviously reasonable. If a hadron has $x_\perp > .5$ $(x_\perp \equiv 2p_\perp/\sqrt{s}\,)$ it possesses over half the transverse momentum available in the center of momentum. Thus its momentum fraction z relative to the fragmenting quark must be near 1. Hence, this particle is the only particle produced at high $p_\perp$ and it should contain the original quark.

PREDICTIONS - NAIVE QUARK MODEL

It is possible using the ideas of Field and Feynman, to predict particle ratios at high $x_\perp$. They envision hadronic interactions at large $p_\perp$ as due to quark-quark elastic scattering. They assume that the quark-quark scattering cross section is independent of the quark identity so that particle ratios at very high $x_\perp$ can be predicted from the quark-parton model. Field and Feynman use measured values for the quark distribution functions.[5] We simply indicate the wealth of predictions available using the naive quark model. The valence quark content:

$\pi^+ = u\bar{d}$	$K^+ = u\bar{s}$	$p = uud$	$n = udd$
$\pi^- = \bar{u}d$	$K^- = \bar{u}s$	$\bar{p} = \overline{uud}$	$\bar{n} = \overline{udd}$

enables one to identify the outgoing hadrons in the following way. Suppose we wish to study the $\pi^+\pi^+$ to $\pi^+\pi^-$ ratio produced in pp collisions at high $x_\perp$. From the elastic scatter of a u and a u we cannot produce any π^- since π^- does not contain u. Thus restricting attention to π^+ or π^- we must produce $\pi^+\pi^+$. In accord with the preceeding ideas the probability of a u acquiring a $\bar{d}$ to form a π^+ equals the probability of a d acquiring a $\bar{u}$ to form a π^-.

p p	→	π π
		1. uu → $\pi^+\pi^+$
u u		2. uu → $\pi^+\pi^+$
		3. ud → $\pi^+\pi^-$
		4. uu → $\pi^+\pi^+$
u u		5. uu → $\pi^+\pi^+$
		6. ud → $\pi^+\pi^-$
		7. du → $\pi^-\pi^+$
d d		8. du → $\pi^-\pi^+$
		9. dd → $\pi^-\pi^-$

So $\pi^+\pi^+ : \pi^+\pi^- : \pi^-\pi^- = 4 : 4 : 1$. The particle ratios can be calculated. Furthermore for single particle production $\pi^+ : \pi^- = 12/6 = 2$. Predictions from the naive quark model are given in Table 1.

DESIGN CONSIDERATIONS

The Chicago-Princeton Group[6] has measured the single hadron ratios $\pi^+ : \pi^-$ for pp and pn collisions and obtain good agreement for both naive quark model predictions. (Their data fits the Field-Feynman prediction even better.) Besides confirming the quark model predictions in a rather stunning way, the Chicago-Princeton Group has also showed that the data does indeed approach the naive quark model prediction for $x_\perp \approx .5$. They show that $x_\perp$ and not $p_\perp$ is the relevant variable in accord with the ideas of Feynman.[7] Thus to study constituent scattering we are best off at low s. The rate at constant $x_\perp$ is expected to increase rapidly as $\sqrt{s}$ and $p_\perp$ decrease.[6]

The above reasoning shows us that when $x_\perp > .5$ for the leading hadron in a jet, it is nearly certain to contain the original quark. However, if we take the region of x_e scaling[3] as the region appropriate to the study of constituent scattering we must also require $p_\perp > 2.8$ GeV. Apparently at lower $p_\perp$ more complex processes dominate. We see from Fig. 1, that this lower limit does not decrease with s. Consequently, there is a lower limit to the s values appropriate to this study ($\sqrt{s}_{min} \approx (2 \times 2.8)/.5 = 11.2$).

Actually we note from Ref. 3 (footnote 11 and Fig. 2) that the x_e scaling region is best defined by $(p_{\perp 1} + p_{\perp 2}) > 5.6$ GeV. We also presume that in a pair experiment both leading hadrons should contain the original quark if $(x_{\perp 1} + x_{\perp 2}) > 1$. This presumption is reasonable in a region of constituent scattering because of the effects of trigger bias. The requirement $x_{\perp 1} > .5$ can be partially satisfied by selecting constituents with initial transverse momentum toward side 1, thus lessening the fraction of the quark momentum taken up by the leading hadron. The symmetric requirement $(x_{\perp 1} + x_{\perp 2}) > 1$. is unaffected by trigger bias and hence should be more effective in ensuring that each leading hadron contain its original quark than the effectiveness of the single arm requirement $x_{\perp 1} > .5$ on side 1 only, discussed above. Consequently we consider two types of requirements below in calculating rates:

1. $x_{\perp 1} > \text{min}$ and $x_{\perp 2} > \text{min}$ - conservative
2. $(x_{\perp 1} + x_{\perp 2}) > 2 \times \text{min}$ - involves a reasonable presumption

However, we add to requirement 2 the additional conditions $p_{\perp 1} > 2$ GeV and $p_{\perp 2} > 2$ GeV in order to ensure that we stay in the x_e scaling region. (See Fig. 2 of Ref. 3.)

In accord with the above ideas, we must set our thresholds near the following $p_\perp$ values ($x_\perp = .5$), according to the incident momentum P_{LAB}.

P_{LAB}(GeV)	$p_{\perp\text{threshold}}$(GeV) $= .5 \times (\sqrt{s}/2)$
100	3.44
130	3.91
200	4.85
300	5.94
400	6.85

The table is based on pp collisions, but the πp case is about the same.

The rate at constant $x_\perp$ will increase rapidly with decreasing s. Hence, we choose to run at 130 GeV, the peak of pion production curves[8] with 400 GeV protons incident.

We summarize the requirements for a good experiment to measure constituent scattering:

1. high luminosity
2. moderately low s
3. hydrogen - deuterium target
4. variety of species incident

The first two requirements imply that the experiment should be done at a fixed target accelerator, not a storage ring. Our present experiment E-494 is almost suited to the task right now. The desired changes are listed below in order of importance:

1. We must use a hydrogen-deuterium target.
2. We must increase the aperture of each arm. (See rate estimates.) In addition, we should modify our apparatus to accept both charges in each arm. This will increase our acceptance and decrease systematic errors in charge ratio measurements.
3. We should use a high intensity pion beam where π^+,π^-,p are available as incident particles.
4. We should improve the $p_\perp$ resolution of our trigger.

Advantages Over Jet Experiments

1. By focussing attention on single particles at high $x_\perp$, we study quantum number flow in the basic constituent collisions. Jet experiments attempt to detect fragmentation products at low $p_\perp$ in addition to those at high $x_\perp$. The information gained by this additional effort is not directly relevant to the basic collision process.
2. By detecting only single particles we assign ourselves a well-defined task which we are sure we can carry out. Jet detection involves considerable difficulties because of the components at low $p_\perp$. It is difficult experimentally to even define a jet.
3. By using a relatively small solid angle per arm but with a large incident intensity we achieve a higher rate for the interesting high $x_\perp$ pairs than do jet experiments. (See rate extrapolations.)

RELEVANCE TO THEORY

We do not seriously expect to measure the pair ratios as indicated in Table I. We merely use these ratios from the naive quark model to indicate the richness of quantum number correlation data. More serious predictions also indicate this richness[9]. We have found that the flavor independent quark-quark scattering model does not hold exactly but does approximately agree with data[3]. Presumably the effects of gluons must be present. Since gluons are electrically neutral they may be studied only in hadronic processes. So we hope, in this experiment, not only to study the properties of valence quarks but to study as well the glue that holds them together.

BEAM

Because we desire to run at very high intensity all detection elements are placed downstream of the spectrometer magnets (following the design of E288). Consequently, a particle's momentum is inferred from its trajectory under the assumption that the particle was produced in the target. Hence, an accurate momentum measurement requires a very fine spot in the vertical direction. A beam suitable for our severe requirements has been approved for the M1 line[4].

intensity $\sim 10^{10}$ π/pulse (assumes 10^{13} protons incident)

spot size (σ)

vertical $\delta y = 2$ mm

horizontal $\delta x = 2$ mm

divergence (σ)

vertical $\delta\Theta_y = 0.7$ mr

horizontal $\delta\Theta_x = 0.5$ mr

momentum spread (σ)

$\delta p/p = 0.058$

A suitable beam is probably also obtainable in p-West.

APPARATUS

The experimental plan is given in Figure 2. We show a design using similar apparatus to that of Experiment 494. This apparatus has been described in publications[3], so we mainly note the differences in the new experiment.

Target

The target is liquid hydrogen (liquid deuterium) 2m in length (.33 interaction lengths).

Spectrometers

Each spectrometer axis is set at $\tan\beta = .120$. (This is 90^{o} in CM at $p_{LAB} = 130$ GeV. β = lab horizontal production angle.) By making full use of the magnet aperture and moving the magnets a factor of 2 closer to the target, compared with Experiment 494 the lab solid angle of each arm is increased by a factor of 9.28. The new aperture is specified by:

horizontal production angle $\tan\beta = .077$ to $.163$

vertical production angle $\tan\alpha = -.017$ to $+.017$

In addition, due to the large target, the beam penumbra extends from $\tan\beta = .070$ to $.170$.

The trajectories are measured by two sets of proportional wire chambers (3 planes each) placed at 7.3 and 15.5 m from the target in each arm (see Figure 3). An additional plane (drift chamber or PWC) at 21m measures the vertical position. Trigger scintillation counters are placed at 16.0 and 21.5 m from the target.

Particle Identification

The fraction of hadrons within momentum bands enabling identification is quite large in the proposed experiment. (See P. 15.) The improvement in the new geometry compared to E494 is due to the larger lab production angle. We can reach the same $p_\perp$ at lower momentum.

The $\check{C}$ counters are 7.7m and 4.6m long respectively. The gases are He in $\check{C}_1$ and Ne-N_2 in $\check{C}_2$. Helium is required in the first counter in order to give us an appreciable acceptance for particle identification at $p_\perp = 4$ GeV. Neon, for instance, would cut our single arm acceptance by a factor of 1.7 (and hence would cut our pair acceptance by a factor of 3). We are using such a Čerenkov system in E-494 and collect about 10 photoelectrons in $\check{C}_1$ per fast particle. This number is so low that we would not like to shorten $\check{C}_1$ further.

Hadron Calorimeter

The hadron calorimeter in each arm will be made either of inexpensive scintillator and steel or water (as in E-494). We have found in E-494 that good calorimeter resolution is not essential in a system with a good magnetic spectrometer. We do, however, plan to construct a hardware device which reconstructs a track's momentum on-line so that the magnetic spectrometer can be used in the trigger. In this way we hope to avoid writing a large number of tapes.

If a steel-scintillator calorimeter is used, we will make the first plate out of lead in order to absorb electromagnetic showers from the neutral beam. We do not anticipate that neutrons will be a problem since we are at 90° in CM and often have pions incident. (We will study this question further, however.)

RESOLUTION

Momentum

Our momentum resolution is dominated by the vertical spot size of the pion beam. We plan to run the magnets with a transverse momentum kick of 1 GeV. Thus

$$\frac{\delta p}{p} = \frac{2\times10^{-3}\text{ m} / 5.6\text{ m}}{1\text{ GeV} / 40\text{ GeV}} = 0.014 \quad (\sigma)$$

Including the contribution of other measurement uncertainties we expect

$$\frac{\delta p}{p} = 0.016 \quad (\sigma) \quad \text{at } p_\perp \simeq 4\text{ GeV}$$

Transverse Momentum

Our production angle resolution is dominated by the divergence of the pion beam.

$$\frac{\delta\Theta_x}{\Theta_x} = \frac{0.5\text{ mr}}{100\text{ mr}} = 0.005$$

so

$$\frac{\delta p_\perp}{p_\perp} = \sqrt{(0.016)^2 + (0.005)^2} = 0.017 \quad (\sigma)$$

$x_\perp = 2p_\perp/\sqrt{s}$

Our resolution in $x_\perp$ is dominated by the momentum spread of the pion beam.

$$\frac{\delta x_\perp}{x_\perp} = \sqrt{(\delta p_\perp/p_\perp)^2 + (\delta P_{LAB}/2P_{LAB})^2}$$

$$= \sqrt{(0.017)^2 + (0.029)^2} = 0.034 \quad (\sigma)$$

RATE EXTRAPOLATION

Using E494 data, we can extrapolate to our expected rates at P_{LAB} = 130 GeV. The data are shown in Table II. The number of protons per hour on target during E494 is taken to be:

$$10^{10} \text{ protons/pulse} \times 5 \text{ pulses/minute} \times 60 \text{ minutes/hour}$$
$$= 3 \times 10^{12} \text{ protons/hour on target (E494)}$$

F. W. Busser et al.[10] have shown that at ISR energies the conditional probability of finding a second high $p_\perp$ hadron (into a given center of momentum system (CMS) solid angle ($\Delta\Omega^*$) above a minimum $p_\perp$) opposite a high $p_\perp$ trigger is roughly independent of s. If we assume this independence of s is rigorous, we expect the pair rate to scale with the single hadron rate as s is varied at constant $p_\perp$. The single hadron rate[6] is proportional to $(1-x_\perp)^9$ so the predicted pair rate with incident momentum P_{LAB} is

$$R(P_{LAB}) = \frac{[(1-x_\perp)^9 \ (\Delta\Omega^*)^2] \text{ at } P_{LAB}}{[(1-x_\perp)^9 \ (\Delta\Omega^*)^2] \text{ at 400 GeV}} \times R(400)_{E494}$$

in terms of the E494 measured rate at 400 GeV. We see from Table II that the predictions agree fairly well with the low energy data for $p_{\perp min}$ = 3.9 GeV, but the data with $p_{\perp min}$ = 3.4 GeV (with higher statistical precision) are lower than the predictions.

In calculating the rate into the proposed 130 GeV configuration we include the fact that pions are more efficient than protons[11] in producing particles at high transverse momentum. The improvement is a factor of 2.5 at $x_\perp$ = 0.5 ($p_\perp$ = 3.9 GeV) and a factor of 1.7 at $x_\perp$ = 0.43 ($p_\perp$ = 3.4 GeV). This factor is relevant to the pion running in the new experiment. For proton running we can turn up the intensity if necessary. We include this factor linearly since we assume that the conditional probability will remain roughly constant under the change from a proton beam to a pion beam. We also include an extra factor of 2 in the new configuration because both signs of charge are collected in each arm. However, we divide the 130 GeV predictions by a factor of 2 because of the variation with s of the conditional probability near 130 GeV apparent in Table II (and Fig. 1). In addition we divide by 1.93 to extrapolate[2] the E494 beryllium rates to nucleon number A=1.

In calculating rates into the proposed aperture we cannot simply multiply by the square of the solid angle ratio. The reason is that two-body kinematics are relevant, where the component of the "away" hadron's momentum (p_{out}) in the ϕ direction relative to the trigger must be limited (see Fig. 4). Indeed, the CCHK collaboration[12] finds that $\langle p_{out} \rangle = 0.53$ GeV. In the Θ direction, however, we expect little correlation because the colliding quarks' center of momentum frame may be different from the beam-target CMS frame. So if we write

$$\Delta\Omega^* = \Delta(\cos\Theta^*)\ \Delta\phi^*$$

we can square $\Delta(\cos\Theta^*)$ in calculating the effects of the larger aperture. The spread expected in ϕ^* is given by

$$\delta\phi^* \simeq \pm \frac{\langle p_{out} \rangle}{3.9\ \text{GeV}} = \pm\ 0.136$$

The size of our proposed CMS aperture is given by

$$\Delta(\cos\Theta^*) = 0.709 \qquad \text{and} \qquad \Delta\phi^* = 0.310$$

(The average $\Delta\phi^* \equiv \Delta\Omega^*/\Delta(\cos\Theta^*)$.) Note that $2 \times \delta\phi^* \simeq \Delta\phi^*$, so that our ϕ aperture has approximately the largest value for which the pair rate will vary as the square of the single arm acceptance. Consequently, in calculating the rates into the proposed aperture, we multiply by

$$2/3 \times (\Delta\Omega^*_{\text{proposed}} / \Delta\Omega^*_{\text{E494 at 130 GeV}})^2$$

The results for dihadrons are given in Table II.

To obtain the final rates for identified pairs, we must multiply by the relevant pair identification efficiencies. In the proposed experiment the π,K (K,p) separation can be made between momenta of 17 and 59 GeV (26 and 46 GeV). This leads to the identification efficiencies and pair rates quoted below:

Requirement	Pair Identification Efficiency	+- Identified Pairs Expected per hour	per 250 hours
1. $x_{\perp 1}$ and $x_{\perp 2} > 0.5$	0.81	0.51	128
2. $x_{\perp 1} + x_{\perp 2} > 1.0$	0.69	2.19	546
1. $x_{\perp 1}$ and $x_{\perp 2} > 0.43$	0.85	4.14	1035
2. $x_{\perp 1} + x_{\perp 2} > 0.86$	0.74	14.07	3519

Similar numbers of ++ and -- pairs would be collected simultaneously with the +- pairs.

Because of the correlation arguments just presented, we can estimate the ratio of our acceptance to the acceptance of jet experiments for the interesting high $x_\perp$ pairs. As an example of a jet experiment we take the CERN SPS experiment NA3. Their acceptance is given by[13]

$$\Delta(\cos\Theta^*)_{NA3} = 1.34 \qquad \text{and} \qquad \Delta\phi^*_{NA3} = \pi/2$$

$$\frac{\text{our acceptance}}{\text{NA3 acceptance}} = \left(\frac{0.709}{1.34}\right)^2 \times \left(\frac{0.310}{\pi/2}\right) = 0.055$$

Since NA3 plans to run at 10^7 incident particles per pulse while we propose to run at 10^{10} , we have about 55 times their sensitivity for high $x_\perp$ pairs. This estimate does not include the relative pair identification efficiencies. We presume our pair efficiency is the better of the two by another factor of about ten (because of our well-defined trajectories, well separated from magnetic fields) but we cannot find a quoted efficiency for NA3.

SINGLE ARM RATES

According to the previous discussion, in changing between E494 and the configuration of this proposal, the single arm cross section will drop by a factor of 13 for $P_\perp > 3.4$ GeV. The center of mass single arm solid angle increases by a factor of 3.4 so we expect the single arm rate for $P_\perp > 3.4$ GeV to drop by a factor of 3.8. To the extent that single arm background is proportional to the high $P_\perp$ rate, this background will decrease in the new configuration.

However, it is probably safer to discuss background extrapolations in the lab. The important background consists of low momentum particles which confuse the PWC. In E494 this background started to become serious at $\sim 4 \times 10^{10}$ incident protons /second, a factor of 4 higher than the proposed intensity. From our E494 running at 200 GeV(compared with 400 GeV), we estimate that the low $P_\perp$ rate in the E494 aperture drops by a factor of 1.55 between 400 GeV and 130 GeV. Extrapolating to the larger horizontal production angle and larger vertical aperture, the singles rates are expected to increase by a factor

$$\frac{1}{1.55} \times \frac{1}{2.61} \times 4.85 = 1.2$$

This is quite satisfactory since we started with a safety factor of 4.

PROPOSED RUNNING TIME

We request 1200 hours of data acquisition divided as follows:

Reaction	hours	
$\pi^- p$	250	
$\pi^- d$	250	
$\pi^+ p$	250	
$\pi^+ d$	250	
p p	100	front porch
p d	100	front porch
	1200	total

The π^- data (500 hours) would be suitable as a first run. We request 200 hours of front porch running(130 GeV) with 3×10^{10} primary protons incident on our hydrogen target in order to perform a clean proton measurement. This can then be used to separate the effects of $\pi+$ and p in the nominal $\pi+$ beam.

RESPONSIBILITIES

Because of the increased aperture, all of the detection devices except the upstream PWC will have to be rebuilt. Since we have built similar devices in the past, however, we believe we can carry out the task. We do hope to borrow some equipment. We note that the only development project is the hardware reconstruction device. This device is not vital, but would be a great aid to the experiment.

We request from Fermilab:

Magnets - The E288/494 magnets are available[14].

Target - liquid hydrogen (2 m) We also require a solid target suitable for the performance of beam profile measurements.

Prep electronics - the E288/494 allotment

CDC 6600 time - standard treatment

Rigging - We will need rigging assistance in assembling the hadron calorimeters.

ADDITIONAL PHYSICS

The proposed apparatus is suitable for the performance of experiments studying other subjects in addition to quantum number flow in constituent collisions. This proposal has concentrated on the most interesting subject, so we list here other uses for the apparatus. The first three items will be automatically at least partially studied during the course of the proposed experiment.

(1) x_e scaling: A better measurement of the scaling region is desirable[3], especially with a hydrogen target and variable incident beams (π^+, π^-, p). A run with 400 GeV/c protons would be quite interesting.

(2) quantum number flow at moderate $x_\perp$: Once the high $x_\perp$ region is understood this region may prove quite interesting. The effects of gluons (binding) should be important here. Data rates should be high, enabling us to perform studies at variable s.

(3) single hadrons : Our single hadron acceptance is very large. In E494 we had no single hadron background out to $p_\perp \sim 6$ GeV so we may be able to make a contribution toward understanding high $p_\perp$ production by pions.

(4) A-dependence : A better measurement of the A dependence of the production of identified pairs is clearly desirable[2], especially at high dihadron $p_\perp$.

(5) dimuons : With the use of a beryllium absorber the apparatus could be used to study the pion excitation of high mass dimuon resonance and continuum states. Depending upon the experimental situation at the time, this might be quite interesting.

REFERENCES

1. R. D. Kephart et al., Phys. Rev. Lett. 39, 1440 (1977).

2. R. L. McCarthy et al., Phys. Rev. Lett. 40, 213 (1978).

3. R. J. Fisk et al., "Correlations Between Two Hadrons at Large Transverse Momenta", submitted to Phys. Rev. Lett., copy attached.

4. Meson Area Upgrade Report - March 1978
   See also Appendix I of this proposal.

5. R. D. Field and R. P. Feynman, Phys. Rev. D15, 2590 (1977).

6. D. Antreasyan et al., P.R.L. 38, 113 (1977).

7. R. P. Feynman, Photon-Hadron Interactions,, W. A. Benjamin, Inc. (1972).

8. See for example R. J. Stefanski and H. B. White, "Neutrino Flux Distributions", F.N. 292 (2060.000) May 10, 1976 (in Fermilab Library).

9. R. P. Feynman, R. D. Field and G.C. Fox, Nucl. Phys. B128, 1 (1977), See Figs. 25-27.

10. F. W. Busser et al., Nucl. Phys. B106, 1 (1976).

11. G. Donaldson et al., Phys. Rev. Lett. 36, 1110 (1976).

12. M. Della Negra et al., Nucl. Phys. B127, 1 (1977).

13. Experiments at CERN in 1976, CERN - Service d'Information Scientifique and SPS Proposal #24.

14. L. M. Lederman, private communication.

TABLE II. RATE EXTRAPOLATIONS

		E494 DATA				THIS PROPOSAL
P_{LAB}(GeV)		400	300	200	130	130
CMS solid angle (millisteradians)		64.1	62.4	56.5	47.3	220.
Requirement				events per hour		
$p_{\perp min} = 3.9$ GeV						
1. $p_{\perp 1}$ and $p_{\perp 2} > 3.9$	measured	1.5±0.17	0.73±0.30	0.24±0.14	-	-
	predicted	-	0.81	0.23	0.034	0.63
2. $p_{\perp 1} + p_{\perp 2} > 7.8$	measured	7.3±0.39	4.0 ±0.54	0.64±0.23	-	-
	predicted	-	3.9	1.1	0.17	3.17
$p_{\perp min} = 3.4$ GeV						
1. $p_{\perp 1}$ and $p_{\perp 2} > 3.4$	measured	9.1±0.47	3.6±0.51	0.73±0.24	-	-
	predicted	-	5.4	1.9	0.38	4.87
2. $p_{\perp 1} + p_{\perp 2} > 6.8$	measured	36.0±0.94	17.0±1.1	3.1 ±0.50	-	-
	predicted	-	21.	7.5	1.5	19.02

Rates are shown for hadron pairs h^+h^- without regard to particle identification for E494 data and the proposed experiment.

TABLE I

PARTICLE RATIOS FROM THE NAIVE QUARK MODEL AT HIGH $x_\perp$

$pp \to$	$\pi\pi$	$\pi^+\pi^+:\pi^+\pi^-:\pi^-\pi^-=4/4/1$	$\pi^+:\pi^-=12/6$
	KK	$K^+K^+:K^+K^-:K^-K^-=4/0/0$	$K^+:K^-=\infty$
	pp	$p^+p^+:p^+p^-:p^-p^-=9/0/0$	$p^+:p^-=\infty$
$pn \to$	$\pi\pi$	$\pi^+\pi^+:\pi^+\pi^-:\pi^-\pi^-=2/5/2$	$\pi^+/\pi^-=9/9$
	KK	$K^+K^+:K^+K^-:K^-K^-=2/0/0$	$K^+/K^-=\infty$
	pp	$p^+p^+:p^+p^-:p^-p^-=9/0/0$	$p^+/p^-\ \ \infty$
$\pi^+p \to$	$\pi\pi$	$\pi^+\pi^+:\pi^+\pi^-:\pi^-\pi^-=4/2/0$	$\pi^+/\pi^-=10/2$
	KK	$K^+K^+:K^+K^-:K^-K^-=2/0/0$	$K^+/K^-=\infty$
	pp	$p^+p^+:p^+p^-:p^-p^-=3/3/0$	$p^+/p^-=9/3$
$\pi^+n \to$	$\pi\pi$	$\pi^+\pi^+:\pi^+\pi^-:\pi^-\pi^-=2/4/0$	$\pi^+/\pi^-=8/4$
	KK	$K^+K^+:K^+K^-:K^-K^-=1/0/0$	$K^+/K^-=\infty$
	pp	$p^+p^+:p^+p^-:p^-p^-=3/3/0$	$p^+/p^-=9/3$
$\pi^-p \to$	$\pi\pi$	$\pi^+\pi^+:\pi^+\pi^-:\pi^-\pi^-=0/4/2$	$\pi^+/\pi^-=4/6$
	KK	$K^+K^+:K^+K^-:K^-K^-=0/2/0$	$K^+/K^-=4/3$
	pp	$p^+p^+:p^+p^-:p^-p^-=3/3/0$	$p^+/p^-=9/3$
$\pi^-n \to$	$\pi\pi$	$\pi^+\pi^+:\pi^+\pi^-:\pi^-\pi^-=0/2/4$	$\pi^+/\pi^-=2/10$
	KK	$K^+K^+:K^+K^-:K^-K^-=0/1/0$	$K^+/K^-=2/3$
	pp	$p^+p^+:p^+p^-:p^-p^-=3/3/0$	$p^+/p^-=9/3$
$\bar{p}p \to$	$\pi\pi$	$\pi^+\pi^+:\pi^+\pi^-:\pi^-\pi^-=2/5/2$	$\pi^+/\pi^-=9/9$
	KK	$K^+K^+:K^+K^-:K^-K^-=0/4/0$	$K^+/K^-=6/6$
	pp	$p^+p^+:p^+p^-:p^-p^-=0/9/0$	$p^+/p^-=9/9$
$\bar{p}n \to$	$\pi\pi$	$\pi^+\pi^+:\pi^+\pi^-:\pi^-\pi^-=1/4/4$	$\pi^+/\pi^-=6/12$
	KK	$K^+K^+:K^+K^-:K^-K^-=0/2/0$	$K^+/K^-=3/6$
	pp	$p^+p^+:p^+p^-:p^-p^-=0/9/0$	$p^+/p^-=9/9$

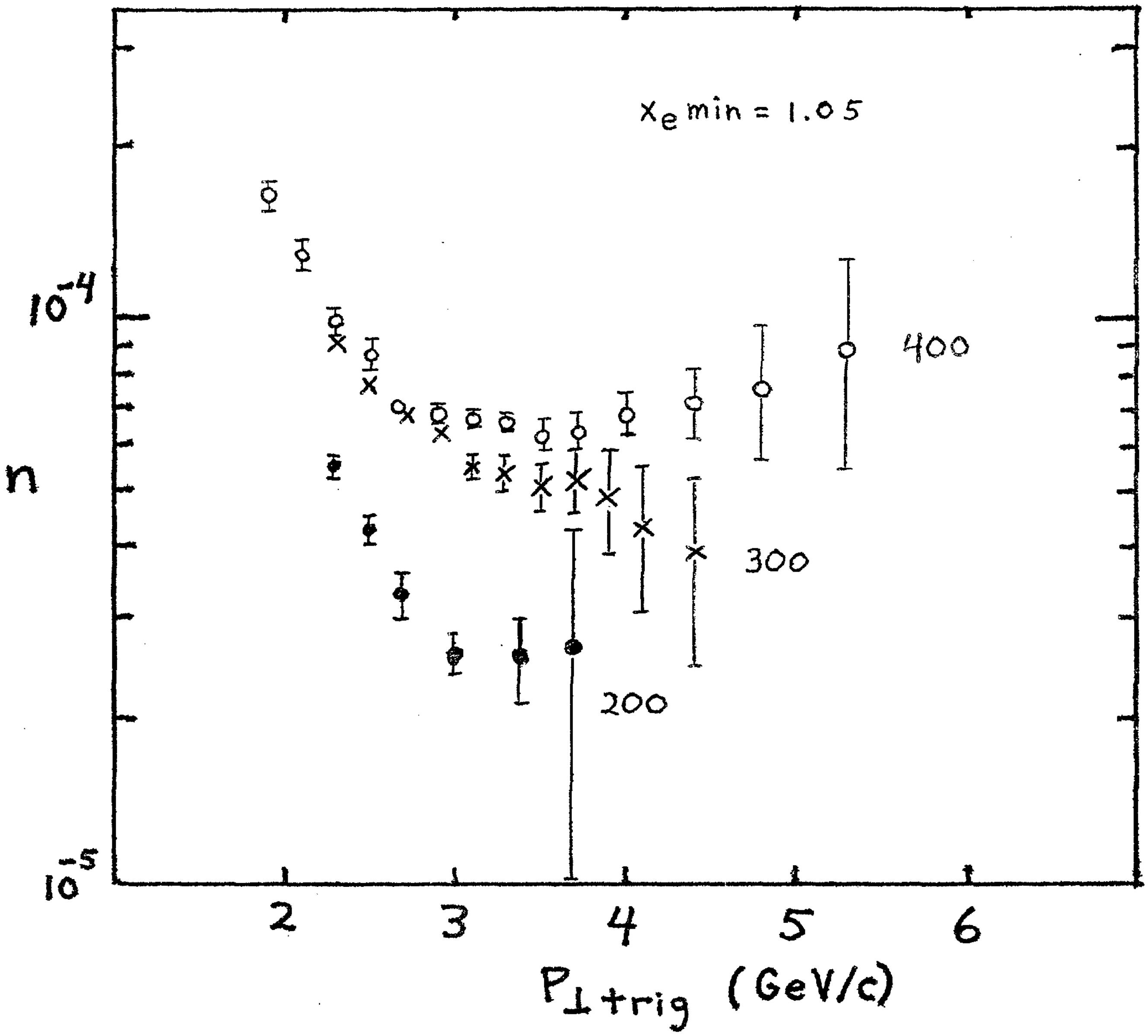
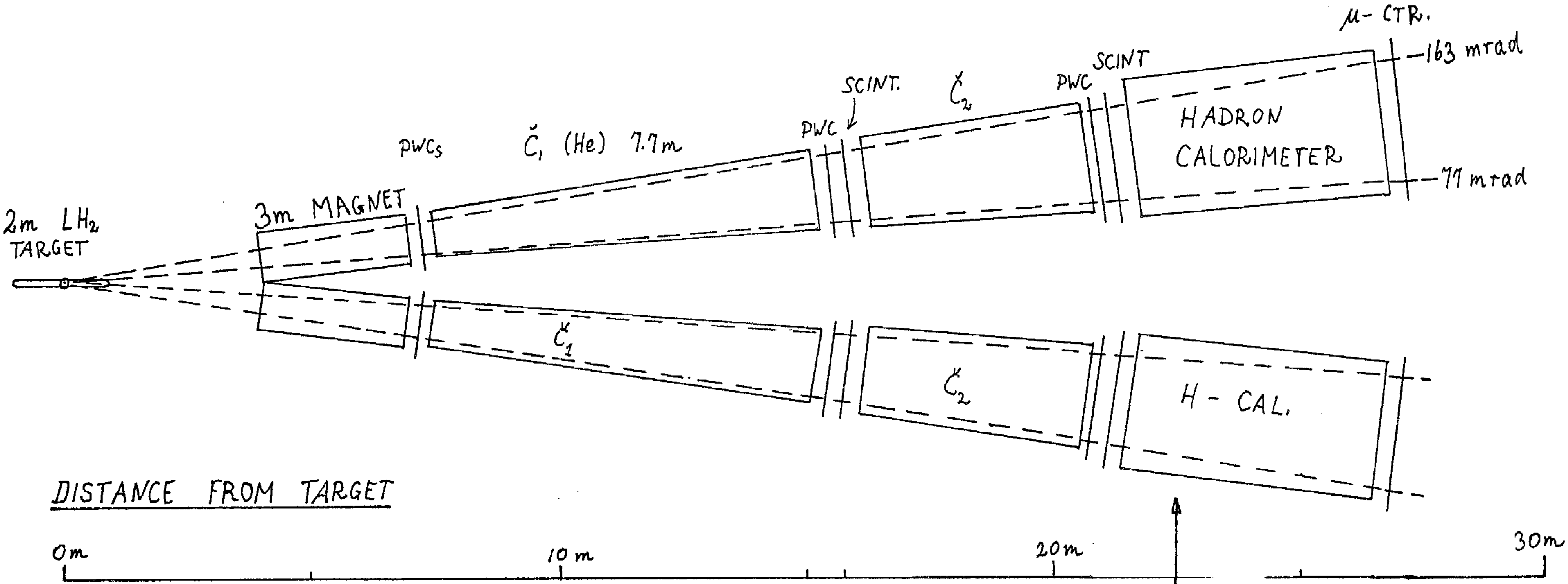


Fig. 1 The away side multiplicity n(1.05) is plotted as a function of trigger transverse momentum $p_{\perp trig}$ for dihadrons $(h^{\mp}h^{\pm})$ for incident proton momenta of 400, 300, 200 GeV/c. These are E494 data. See Ref. 3 for definitions of the symbols used.



Note: If a steel/scintillator calorimeter is used, the apparatus ends here

Fig. 2. Plan view of apparatus.

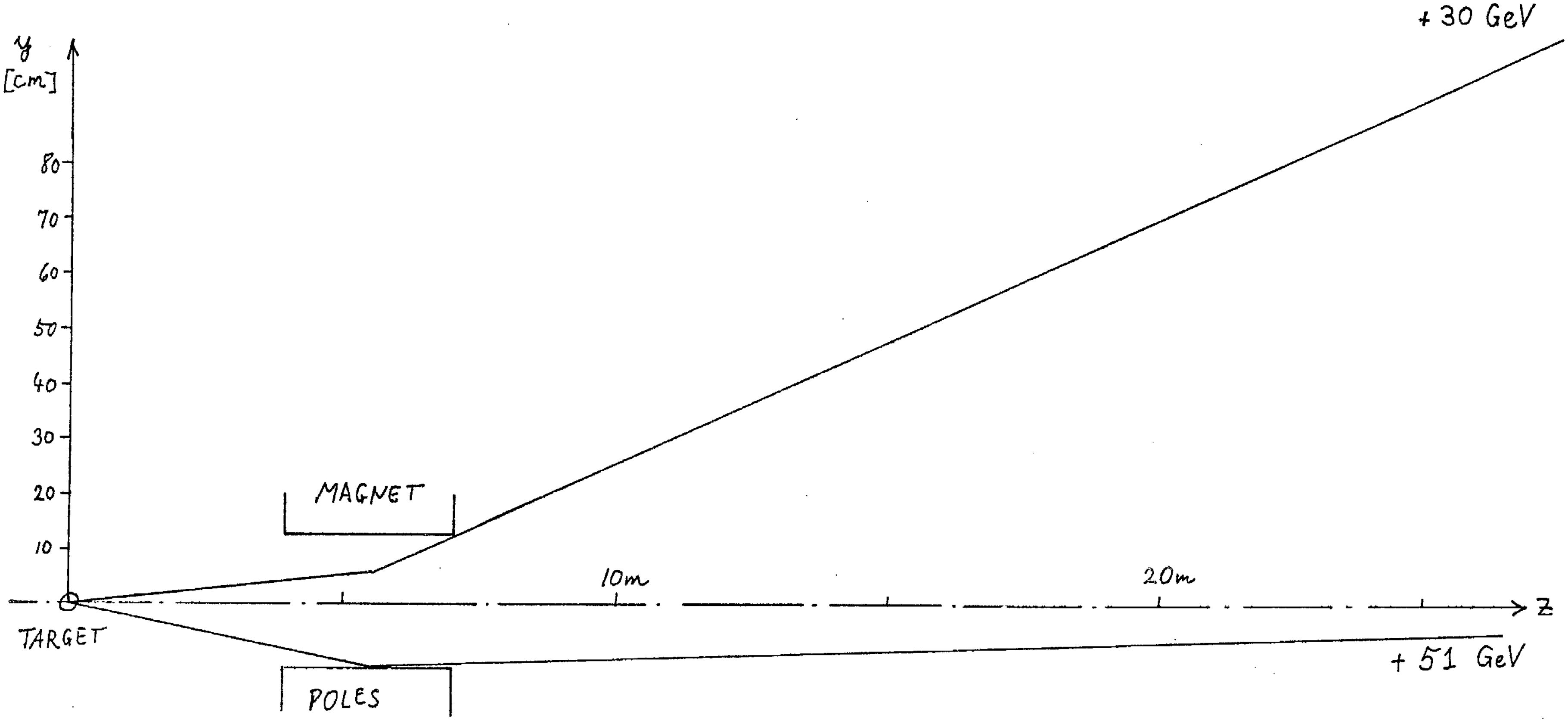
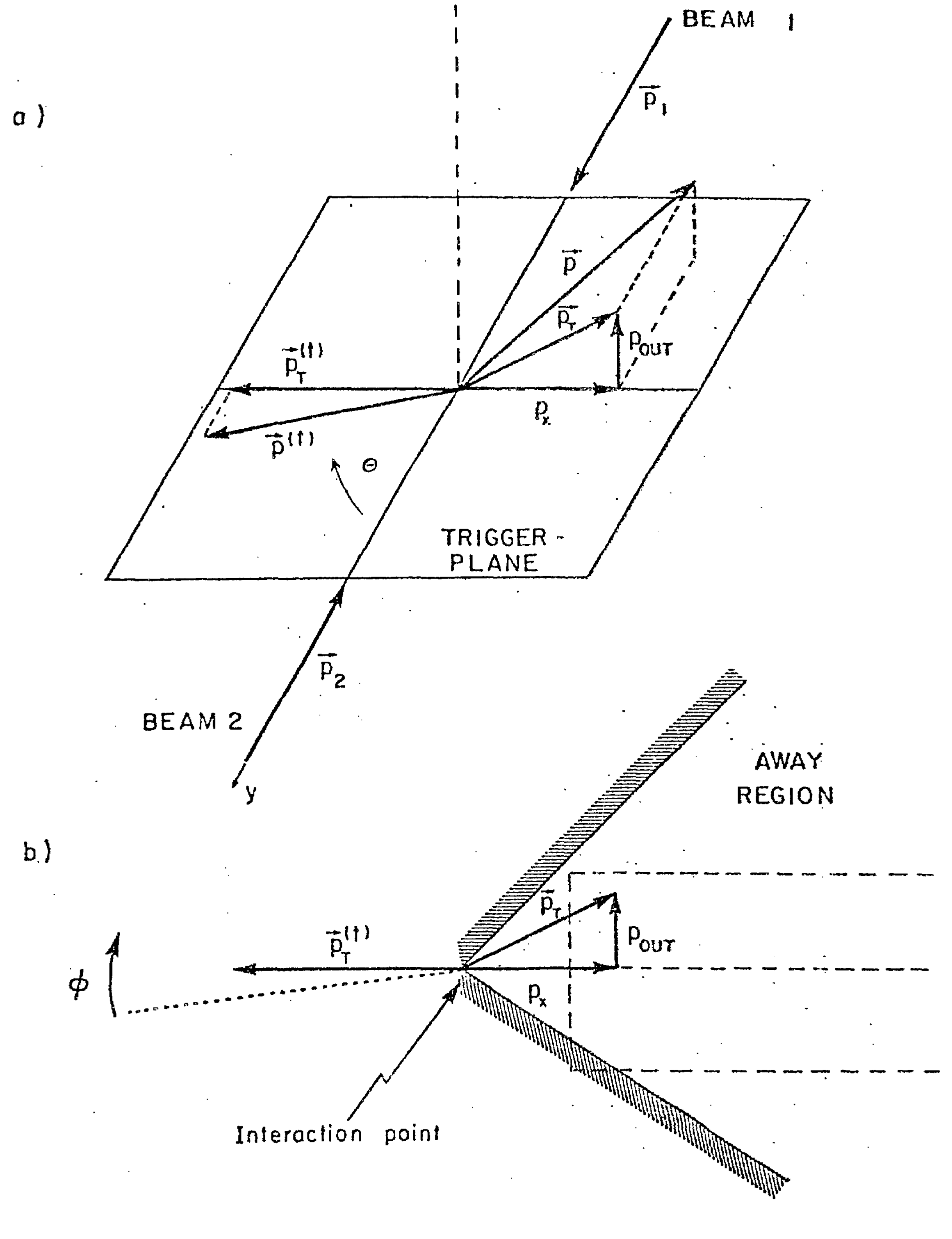


Fig. 3. VERTICAL APERTURE



from Ref. 12

Fig. 4.

March 14, 1978

ADDENDUM A TO PROPOSAL 586

Can P586 Be Performed With the E302 Apparatus?

Both P586 and E302 utilize a double-arm magnetic spectrometer with Čerenkov particle identification in an intense pion beam. Consequently, it is natural to ask whether P586 can be performed with the E302 apparatus. The answer is no. The two experiments are designed with totally different philosophies in mind. Essentially the entire E302 apparatus would have to be replaced and the p-West beam would have to be substantially modified in order to carry out P586. The aspects of E302 which would require modification are listed below:

(1) E302 PWC and Čerenkov Counters Are Upstream of the Analysing Magnets. This limits E302 to 10^7 interactions per pulse. Since P586 is to be carried out at $\sim 5 \times 10^9$ interactions per pulse, the E302 detectors upstream of the magnets would have to be replaced by detectors downstream of the magnets. This would imply a drastic change in the philosophy of the experiment. Momenta would no longer be measured directly but would be inferred from the trajectories measured downstream of the magnets via knowledge of the beam spot position on the target.

Note: Footnote 4 of the proposal refers to an Appendix I which was to explain the characteristics of the intense M1 pion beam in lieu of the Meson Area Upgrade Report. Due to the delay of consideration of post-pause proposals, the Upgrade Report should be available when P586 is considered. Consequently, Appendix I does not exist.

(2) The p-West Beam Spot is Too Large

The proposed M1 beam is designed for high intensity experiments requiring a fine spot. The spot size (∿1.3 mm RMS) is sufficient to provide a momentum resolution $\delta p/p = .014$ RMS in P586. In p-West, however, there has not been a strong effort to optimize the spot size. None of the presently approved p-West experiments require a fine spot. With the present beam, minimum spot sizes are ∿5 mm RMS at the first focus[1] and ∿10 mm RMS at the E302 focus[2]. The latter case would yield a P586 momentum resolution $\delta p/p = .073$ RMS which is unacceptably broad (especially in the presence of single hadron background falling as $p_\perp^{-8}$). Reproduction of the M1 spot size in p-West, without decreasing the pion intensity, would require substantial modifications of the p-West beam.

(3) E302 has no Hadron Calorimeters

Hadron calorimeters are required to reject background at high $p_\perp$ with no detectors upstream of the magnets.

(4) The E302 Acceptance for Identified Pairs is too Small

The E302 apparatus has a lower acceptance for identified high $p_\perp$ pairs than P586 by a factor of ∿20. The detectors presently upstream of the magnets would be far too small to maintain even the present E302 acceptance if they were placed downstream of the magnets. Consequently most of the detectors would have to be replaced in order to perform P586.

---

1 Brad Cox, private communication 3/9/78

2 Morgan May (E302), private communication 3/8/78, (Brad Cox will attempt to improve this number.)

June 3, 1978

ADDENDUM B TO PROPOSAL 586

REQUESTS FROM FERMILAB

We present here a more detailed list of our requests than given on p. 18 of the proposal:

Magnets - The E288/494 magnets are available. However, the two coils nearest the incident beam may need to be modified or replaced. The magnet gaps should be maintained at vacuum as in E494.

Target - liquid hydrogen/deuterium (2 m). We also require a solid target suitable for the performance of beam profile measurements.

Beam Č Counter - Although we cannot hope to identify incident particles event by event, we do want to periodically monitor the ratios $\pi/K/p$, by integrating the current in a threshold counter at high intensity (or by taking a short run at low intensity). One threshold counter (presently in M1) could be used for this purpose. (It could be placed downstream of the target.)

PREP Electronics - (~$75K)

CDC 6600 Time - standard treatment

Rigging - We will need rigging assistance in assembling the hadron calorimeters.

Lead - shielding for hadron calorimeters (11 ft^3)

EXPERIMENTER'S RESPONSIBILITIES

We give here cost estimates of the new equipment which is to be provided by the experimenters:

Hadron Calorimeters - $80K

We need two hadron calorimeters, each $1.8 \times 2.3\ m^2$. Our estimate represents the cost of two 6.5 interaction length calorimeters, each consisting of 40 one inch steel plates separated by 1/4 inch slabs of acrylic scintillator. The scintillator is segmented into 8 inch strips horizontally. The energy signals from both top and bottom of each strip are read out by 1/4 inch thick wave shifter bars into 24 fast phototubes for each calorimeter. We presume that all necessary polishing of the scintillator could be done at Stony Brook.

Čerenkov Counters - $30K

We need four Čerenkov counters. The apertures are larger than in E494 but much of the equipment can be reused. Each $\check{C}_1$ has 6 mirrors (1 phototube/mirror) which cover a total area $1.0 \times 1.6\ m^2$. Each $\check{C}_2$ has 12 mirrors covering a total area $1.6 \times 2.1\ m^2$.

Scintillation Counters - $20K

P586 uses two planes of scintillation counters (T0 and T1) in each arm for triggering. Each T0 plane is $1.0 \times 1.6\ m^2$ and is segmented into 12 counters (6 segments vertically, 2 segments horizontally). Each T1 plane is $1.5 \times 2.0\ m^2$ and is segmented into 14 counters (7 segments vertically, 2 segments horizontally). All scintillators are 1/4 inch thick. Our cost estimates include only scintillator and light pipes. We own the necessary phototubes.

HARDWARE RECONSTRUCTION DEVICE - $3K

The required materials are inexpensive. The major cost of such a device is the design work.

We presume that P586 can be expeditiously scheduled in the M1 beam just prior to P605 so that we could use the E288/494 PWC and electronics system which belongs largely to Columbia and Fermilab. Stony Brook will provide the hadron calorimeters and Čerenkov counters. In addition Fermilab will provide the scintillation counters. Either Columbia or Stony Brook will work on the hardware event processor. Every effort will be made to ensure that the new equipment built for P586 can also be used for P605.

TRIGGER

From the T0 and T1 counters in each arm we plan to form the logical signal

$$T \equiv (T0 \cdot T1)_{\text{channels}}$$

indicating a track in the arm under consideration. (The T0·T1 coincidence is performed in channels, requiring that the track point back to the magnet aperture.) From each calorimeter we plan to construct an analog signal

$$P_{T,AN} \equiv \sum_{\text{segments } i} E_i \times \theta_i$$

by attenuating the energy E_i of each segment by a factor inversely proportional to θ_i , the production angle of that segment. Then if P_T is a logical signal indicating that $P_{T,AN}$ is greater than a preset threshold, and if M is the corresponding logical signal requiring $M_{AN} \equiv (P_{T,AN1} + P_{T,AN2})$ greater than a preset "mass" threshold, our pair trigger is

$$T_1 \cdot T_2 \cdot M$$

(where the subscript here labels a spectrometer arm) while our single hadron trigger is

$$T_1 \cdot P_{T1} \quad \text{or} \quad T_2 \cdot P_{T2}$$

In E494 we used similar trigger schemes with moderate success. The main problem was the resolution (43%σ) of our (inexpensive) water calorimeters. This poor resolution caused our pair event sample written on tape to be dominated by events with a mass lower than our nominal threshold. In order to improve our resolution we have decided to build steel-scintillator calorimeters. (The improved resolution also aids background rejection.) But we also hope to make a hardware reconstruction device which will enable us to calculate the momentum of each track on-line. Then we could exclude low mass events completely, before writing them on tape.

NEUTRALS

In E494 the neutral beam in each arm was stopped by ~4 m of steel before reaching the hadron calorimeter. (The steel was actually intended to protect the lead-glass.) It is not practical to block the neutral beam in P586 because the large solid angle accepted in P586 implies that the neutral beam subtends approximately half the useful aperture. Consequently we should consider the effects of the neutral beam on the hadron calorimeter in P586.

If each spill is 1 second long, we accept (1 second/spill)/ $(18.8\times10^{-9}$seconds/bucket$) = 5.3\times10^{7}$ buckets/spill. Our two meter hydrogen target contains 0.25 absorption lengths. Assuming 10^{10} incident particles/pulse we can calculate the number of inelastic interactions per bucket

$$B_{int} = \frac{(1-e^{-.25})\times10^{10}}{5.3\times10^{7}} = 42 \text{ interactions/bucket.}$$

Actually, we have found in E494 that about half the expected buckets are empty so we expect

$$B_{int} \simeq 80$$

after correction for the duty factor of the accelerator. (As in E494 we plan to veto superbuckets using a Čerenkov bucket monitor.)

We can then calculate the number of neutrals expected per bucket

$$n_{neutral} = \frac{B_{int}}{\sigma_{int}} \left.\frac{d\sigma_{neutral}}{dy}\right|_{y_{CM}=0} \Delta y(\Delta\phi/2\pi)$$

where $\Delta y(\Delta\phi/2\pi) = (0.75)\times(.310/2\pi) = .037$ for one of our spectrometer arms. We find[1]

$$n_{\pi^o} = 2.2 \text{ particles/bucket} \qquad \langle p_\perp \rangle = 0.4 \text{ GeV/c}$$

$$n_{neutron} = 0.36 \text{ particle/bucket}$$

so that in both calorimeters together we expect a total of 5.1 neutral particles/bucket, each on the average carrying 0.4 GeV/c in transverse momentum. We plan to eliminate the energy deposited by the π^o's by shielding each calorimeter with 3 inches (13.6 radiation lengths) of lead[2]. Then the net effect of neutrals on our calorimeter trigger is to cause a baseline shift of the analog mass signal given (crudely) by the number of neutrons per bucket

$$\Delta M_{AN} \simeq (n_{neutron} \pm \sqrt{n_{neutron}}) \langle p_\perp \rangle = (0.29 \pm 0.34) \text{ GeV/c} \ .$$

(We must restrict the width of each calorimeter pulse to one bucket by using fast phototubes and perhaps clipping the signals.) The shift itself causes no harm (at constant B_{int}) because we can adjust the trigger threshold. The net effect is a deterioration of the mass resolution given by

$$\left(\frac{\delta M_{AN}}{M_{AN}}\right)_{neutrals} \simeq \frac{0.34}{6.8+.29} = .047$$

if we wish to trigger at $M_{AN} = 6.8$ GeV. Calorimeter studies[3] lead us to expect a resolution

$$\left(\frac{\delta M_{AN}}{M_{AN}}\right)_{calorimeters} \simeq .12/\sqrt{2} = .085$$

(from 2 calorimeters) in this mass region. Hence the neutrons broaden this resolution to .097 . However, in eliminating the π^o's, we also lose ~12% of the energy[4] of a normal hadron. This causes a deterioration[5] of the mass resolution of our trigger to

$$\left(\frac{\delta M_{AN}}{M_{AN}}\right) \simeq .14$$

This is still far better than the $.43/\sqrt{2} = .30$ from E494.

In eliminating the π^0's we expect to create a low energy tail[6] on the calorimeter resolution function. (The serious danger at high $p_\perp$ would be a high tail.) We do not expect this tail to be a serious problem, however, since 3 inches of lead only contains .41 absorption lengths and the cross section for $\pi^- p \rightarrow$ neutrals[7] is only 0.1 mb at our typical momentum of 40 GeV/c. This low tail can be studied during data-taking by accepting prescaled events satisfying a loose study trigger (using, for example, the Čerenkov counters). Using our Čerenkov bucket monitor and such study triggers we also plan to monitor the intensity dependence of the calorimeter resolution.

Off-line the neutrals problem is even less severe. By requiring a calorimeter segment containing a pulse to lie on a charged track we can exclude the neutron background by another factor of ~20. (If we succeed in making a hardware reconstruction device, this information could be used on-line.) The major off-line function of the calorimeter is to provide an energy signal enabling construction of the E/p ratio (energy/momentum). Our E494 experience shows that background tracks typically show $E/p \lesssim .1$ while E/p should be $\simeq 1.0$ for normal tracks. The preceeding arguments indicate that in ~2% of the tracks neutrons will add ~10% to the E signal. This addition does not affect normal tracks because the addition drives them higher above the cut ($E/p \sim .5$). The only way neutrons can affect the data is to add an unusually large energy into the calorimeter segment at which a background track points. Even if the added energy is sufficient to cause the background track to pass the E/p cut, it will probably still be excluded by the fact that it will not point to the target horizontally. (See next section on accidentals.)

We note that events with neutrons at high $p_\perp$ are interesting physics. E494 experience indicates that with our improved calorimeter resolution in P586 we may be able to trigger the experiment on the mass signal M alone and collect correlation data including neutrons.

Conversion of low $p_\perp$ neutrals in a spectrometer arm will increase the T0 rates in that arm. Such a conversion must occur downstream of the magnet but upstream of (or in) the T0 counters. The material in this region amounts to .031 radiation lengths (dominated by the $\check{C}_1$ mirror) implying[8] ~10.9% of the buckets will contain a gamma conversion T0 count in each arm. These events (e^+e^- pairs) will not trigger the calorimeter or count in the upstream PWC and will be excluded from the analysis. In order to exclude them also from the T rate we plan to place the T1 counters in the hadron calorimeter, after the 3 inches of lead and the first 2 inches of steel (total of .71 absorption lengths). The resulting loss of hadrons should be small and easily monitored via the study triggers.

The environment is much cleaner for the upstream PWC, however. Between the magnet and the center of these PWC there are only 2.0×10^{-3} radiation lengths (dominated by the 10 mil mylar vacuum window) implying only 6.7×10^{-3} of the buckets contain a gamma conversion count in these PWC. Since our PWC memory time is typically 3 buckets, we expect approximately 2% of our tracks in P586 to contain an extra gamma conversion hit in these PWC.

This agrees with our E494 experience when we ran these same PWC in the neutral beams successfully at intensities of up to 3×10^{10} protons/pulse on target. At 10^{10} protons/pulse the average efficiency per plane was 96% for reconstructed tracks implying a 2 out of 3 efficiency for the upstream station of 99.5% . In a typical run at 10^{10} protons/pulse there were an average of 0.86 extra hits/event per upstream plane as opposed to .75 extra hits/event for a typical downstream PWC plane (out of the neutral beam in E494). Thus it seems likely that the major background in P586 (as in E494) will be due to low $p_\perp$ charged particles, presumably arising from interactions in the magnet coils, which happen to scatter out of the magnet and into our apparatus.

ACCIDENTALS

The ratio of arm to arm accidentals to real events is given by[9]

$$\frac{\text{accidentals}}{\text{reals}} = \frac{B_{int}}{R}$$

where $R(p_{\perp 1}, p_{\perp 2})$ is the two particle correlation function[10] in the region of interest as specified by the $p_{\perp}$'s in the spectrometer arms. According to our results[11] from E494, R ≃ 550 near our threshold, $(p_{\perp 1}+p_{\perp 2}) > 6.8$ GeV/c. Hence the accidental fraction would be

$$\frac{80}{550} = .15 \quad .$$

However in P586 the 2 m long target is an advantage in eliminating accidentals because we can point each track back to the target in the horizontal plane and require that the two tracks come from the same region of the target. Thanks to the fine spot of the M1 beam we can achieve typical resolutions in the longitudinal position at the target of

$$\delta z_{target} \simeq 12 \text{ mm} \quad .$$

Consequently, if we require that the two tracks originate at the same position ± 2 σ

$$B_{int,effective} \simeq \frac{48 \text{ mm}}{2000 \text{ mm}} \times 80 = 1.9$$

and

$$\frac{\text{accidentals}}{\text{reals}} \simeq \frac{1.9}{550} = .0035 \quad .$$

Hence in P586 we expect accidentals to be completely negligible.

TRIGGER RATE SUPPRESSION

Using our E494 data at 400 GeV/c we can estimate the trigger rate suppression factor required from the calorimeters. The $T_1 \cdot T_2$ coincidence is expected to be dominated by accidentals as in E494. (The T counts are mostly low $p_\perp$ where $R \simeq 1$.) The charged single hadron rates (p. 16 of the proposal) are expected to be essentially the same as in E494. Since we believe we have eliminated gamma conversion T counts in P586, only neutron conversions can cause excess T counts. Between the magnet and the center of the T0 counters there are $\sim 5 \times 10^{-3}$ absorption lengths (mostly the $\check{C}_1$ mirror) implying a probability per bucket of 1.8×10^{-3} for a nuetron conversion T count. From our E494 experience we expect $\sim 2.6 \times 10^{-2}$ of the buckets to contain a T count from a charged track. So in P586 we expect the T rates to increase by ~7% due to neutron conversion and the (accidental) coincidence rate should go up by ~14%. We can write ~100 events/pulse onto tape without incurring prohibitive deadtimes. Thus the required trigger rate suppression factor is

$$\left[1.14 \times (T_1 \cdot T_2)/\text{pulse in E494}\right] / 100 \simeq 350$$

We expect no trouble attaining this suppression factor in P586. In E494 we attained essentially the same supression factor with a factor of 2 worse calorimeter resolution, at lower mass ($p_{\perp 1} + p_{\perp 2} >$ 6 GeV), and at higher s ($p_{LAB} =$ 400 GeV/c). The purpose of the hardware reconstruction device would be to suppress unwanted events written on tape by another factor of 100 or 1000.

SINGLE HADRON RATES

Because of our large solid angle and high luminosity it is of interest to calculate our inclusive rates for collection of single hadron events. Our E494 experience indicates that these events should be free of background at least out to $p_\perp = 6$ GeV/c. In 250 hours of running with 10^{10} incident protons/pulse at 400 GeV/c we expect for the number of events n per 1 GeV/c $p_\perp$ interval

$$\frac{dn}{dp_\perp} = L \int \frac{d\Omega}{\sin^2\theta} f(p_\perp)\, p_\perp$$

where $L = \int \mathcal{L}\, dt$ = integrated luminosity = 6.4×10^{40} cm^{-2}

$\int \frac{d\Omega}{\sin^2\theta} \simeq .466$ ($\simeq$CM solid angle for both arms)
θ = production angle

$f(p_\perp)$ = invariant cross section[12] for π^-

$$= \frac{7.8\times10^{-27}\times (1-x_\perp)^{9.9}}{p_\perp^{8.5}}$$

$p_\perp$ (GeV/c)	$dn/dp_\perp$ π^- events/GeV/c in both arms	
4.	2.36×10^{8}	would be prescaled
5.	1.51×10^{7}	would be prescaled
6.	1.15×10^{6}	would be prescaled
7.	9.15×10^{4}	
8.	6.81×10^{3}	
9.	4.19×10^{2}	
10.	18.0	
11.	0.39	
12.	2.17×10^{-3}	

These rates do not include Čerenkov identification efficiency which reaches zero at $p_\perp$ = 60 GeV/c × .163 = 9.8 GeV/c. Consequently our apparatus may be able to make interesting single hadron measurements in a 400 GeV/c beam of 10^{10} protons/pulse. After the doubler is in operation such intensities at 400 GeV/c should be available for pions in M1.

In P586 we can reach $p_\perp \simeq 6.5$ GeV/c, ($x_\perp \simeq .83$) close to the kinematic limit, 4.2 events/250 hours with 130 GeV/c protons incident. As in E494, we plan to prescale low $p_\perp$ single hadron data.

REFERENCES for ADDENDUM B

1. We use pp cross sections consistently. σ_{int} = 33 mb. For π^o we use $(d\sigma/dy)_{\pi^+}$ at $y_{CM}=0$ (24.5 mb) from T. Kafka et al., Phys. Rev. D16, 1267 (1977). We presume neutrons ≈ protons in abundance near $y_{CM}=0$ (see J. Engler et al., Nuclear Physics B84, 70 (1975)) and take $(n/\pi^o) \simeq (p/\pi^+) \simeq .16$ (see Kafka et al. p.1264 also D. Antreasyan et al., Phys. Rev. Lett. 38, 116 (1977)). We take $<p_\perp>$ from Kafka et al. Fig. 13 and presume it is the same for π^o and n as for π^+.
2. F. J. Sciulli, "Photon-Detecting Hadron Calorimeters", Proceedings of the Calorimeter Workshop, Fermilab, May 1975, Fig. 17 .
3. Ibid., Fig. 20.
4. Ibid., Fig. 7.
5. Ibid., Fig. 13.
6. Ibid., Fig. 16.
7. CERN/HERA 72-1, May 1972, p. 85.
8. Bruno Rossi, High-Energy Particles, Prentice-Hall, Englewood Cliffs, New Jersey, p. 84.
9. If n_1 is the probability per bucket with b interactions to observe an event in arm 1

$$n_1 = b\ \varepsilon_1$$

where the proportionality constant ε_1 depends on the $p_\perp$ of interest. The probability per bucket of observing an accidental pair event (resulting from two different interactions) is

$$n_{12}^{acc} = b\ \varepsilon_1\ (b-1)\ \varepsilon_2 \quad .$$

The probability to observe a real pair event is (see footnote 10)

$$n_{12} = b\ R\ \varepsilon_1\ \varepsilon_2 \quad .$$

Averaging over the Poisson distribution of interactions per bucket with average value

$$<b> \equiv B_{int}$$

we find

$$<b\ (b-1)> = B_{int}^2$$

so that with regard to average values

$$\frac{n_{12}^{acc}}{n_{12}} = \frac{B_{int}}{R}$$

10. R is the ratio of the probability to observe a pair (from one interaction) to the probability of observing two single hadrons independently:

$$R = \frac{(n_{12}/B_{int})}{(n_1/B_{int}) \times (n_2/B_{int})}$$

$$= \frac{\sigma_{int} \quad E_1 E_2 \quad \dfrac{d^6\sigma}{d^3p_1 d^3p_2}}{E_1 \dfrac{d^3\sigma}{d^3p_1} \quad E_2 \dfrac{d^3\sigma}{d^3p_2}}$$

11. E494 paper in preparation, to be submitted to Physical Review. We find that R is only weakly dependent on s.

12. D. Antreasyan et al., Phys. Rev. Lett. 38, 116 (1977).