FERMILAB-Conf-85/14
0102.000

A FIXED TARGET FACILITY AT THE SSC*

S. C. Loken
Lawrence Berkeley Laboratory, Berkeley, California 94720

and

Jorge G. Morfín
Fermi National Accelerator Laboratory, Batavia, Illinois 60510

January 1985

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*Submitted to the Proceedings of Snowmass '84, Snowmass, Colorado, June 23 - July 13, 1984.

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S. Loken
Lawrence Berkeley Laboratory, Berkeley, CA

Jorge G. Morfín
Fermilab, Batavia IL

Introduction

The question of whether a facility for fixed target physics should be provided at the SSC must be answered before the final technical design of the SSC can be completed, particularly if the eventual form of extraction would influence the magnet design. To this end, an enthusiastic group of experimentalists, theoreticians and accelerator specialists have studied this point. The accelerator physics issues were addressed by a group led by E. Colton whose report is contained in these proceedings. The physics addressable by fixed target was considered by many of the Physics area working groups and in particular by the Structure Function Group[1]. This report is the summary of the working group which considered various SSC fixed target experiments and determined which types of beams and detectors would be required. The members of the group were:

S. Childress - Fermilab
G. Gollin - Princeton University
R. Heinz* - Indiana University
L. Jones.- U. of Michigan
S. Loken - L.B.L.
J.G. Morfín - Fermilab
J. Ritchie* - Stanford
D. Stork* - U.C.L.A.
C.R. Sun* - SUNY at Albany
W. Walker - Duke University

The members singled out by an asterix have submitted individual contributions which follow this summary.

This is not the first document to address the topic of a Fixed Target Facility (FTF) at the SSC. There was a Fixed Target Subgroup of the PSSC whose summary is contained in the final PSSC report and, in particular, there was a Fixed Target Workshop held in January the at Woodlands, Texas. The table of contents of the proceedings[3] of this workshop is reproduced in Fig. 1. As can be seen, a great deal of thought has already gone into this topic. Rather than just rewrite some of the original work that was carried out for the Texas Workshop and to facilitate reference, the workshop contributions of those authors who were also members of this working group are included as appendices to this summary. The interested reader is strongly encouraged to refer directly to the Texas Workshop proceedings for further results.

Physics

Although the main thrust of the Physics at the SSC will be the investigation of the 40 TeV (c.m.) collider interactions, there are many interesting and crucial topics which either are solely addressable by fixed target methods or where a fixed target facility would make a significant contribution. As is mentioned in Reference 4 and Appendix 1, a fixed target program would provide the opportunity to vary both beam and target particles and, with the use of lepton beams, the desired quark flavor in the interaction could be emphasized. In particular the following topics, with relevant references, have been examined:

1. Comparison of Measured Structure Functions with Predictions of Quantum GeometroDynamics. The recent publication of calculated nucleon structure functions based on the MQM/QCD phenomenological approach shows that the difference between this approach and QCD should be apparent at large Q^2 since MQM/QCD predicts a $1/Q^2$ (higher twist!) dependence and not a $1/\ln Q^2$ effect.

2. Measuring QCD via Deep Inelastic Structure Functions: ref. 1, ref. 5, ref. 6, Appendix 1 and Appendix 2. It would appear that an SSC fixed target program would be superior to HERA capabilities as presently envisioned.

3. A-dependence of Structure Functions and Fragmentation: Functions: Appendix 1, ref. 5.

4. Beam Jet Fragmentation: Fixed Target experiments offer the opportunity to study both the current jet and target jet. This is very difficult with collider events since the target fragments tend to be swallowed by the beam pipes.

5. Study of Like-sign Dimuons: Appendix 1, ref. 5.

6. Extraction of Gluon Distributions: ref. 1. Inelastic scattering data over a wide range of x and Q^2 is crucial to the determination of $G(x;Q^2)$.

7. Measurement of Higher Twist Effects: Appendix 1, ref. 1. All present experiments have attempted to elude higher twist effects by going to high Q^2. Precise measurements of $F_2(x,Q^2)$ and $xF_3(x,Q^2)$ over a large range of x and Q^2 would allow us to extrapolate back to the "higher twist region" (low Q^2) and measure the effects.

8. Tests of Superweak Models: ref. 7 Depending on what takes place at BNL or other lower energy facilities before the startup of the SSC, the use of an SSC high energy kaon factory could be significant.

9. Measurements of Charmed Baryon Magnetic Moments: ref. 8.

Further fixed target physics can be found in the individual contributions and summaries of the other physics and detector groups.

Fixed Target Beams

The accelerator area fixed target group have proposed[9] several ways of extracting a beam for fixed target experiments. Either the 20 TeV protons would be extracted directly, or the secondaries from the PP interactions would be extracted. Two main types of beams have been considered; neutral beams[7,10,11] and lepton beams[12,13,App1]. For both types of beams, the overall conclusion is that the extracted proton produced beams are far superior and are required by the physics one would like to perform. Details of the various types of neutral and lepton beams considered can be obtained directly from the references. The calculated yields of K^0_L's (ref.7) can be summarized in the following table which assumes an extracted proton beam of 4.2×10^{13} 20 TeV protons per hour on a 1-λ target. Two geometries have been considered, 0° production (.5 μster) and 2 mr (.1μstr).

	0°	2mr
$K^0/10^7$ sec	4×10^{15}	6×10^{13}
K_L Decays/100m-10^7 sec	1×10^{13}	8×10^{11}
Average K^0 momentum	2 TeV	210 GeV
Average momentum for decays	1 TeV	120 GeV
Typical 2 body opening angle	0.5mr	4mr
K_L/neutron	1/6	3/4

For c and b production, ref. 9 assumed a lumunosity of 10^{32} and predicted a flux of 4 charm and 0.8 bottom paticles after channeling through ~ 2 meters of tungsten which protects the detectors. The calculations of reference 11 for a high energy photon beam yields (for 4.2×10^{13}protons/hour) 10^7 monochromatic photons per second with an energy of 9.0 ± 0.5 TeV.

Since many of the interesting physics topics listed at the beginning of this summary involve lepton beams, a significant effort has gone into the design of these beams in order to offer maximum physics potential for minimum investment in dollars and real estate. A summary of conventional 20 TeV lepton beams and yields can be found in Appendix I. At this meeting an attempt was made to design an efficient high energy single source muon and neutrino beam. The source is a beam dump designed to allow maximum decays of the produced D's, F's, and B's. It would appear that a 14m long dump composed of a mix of thin tungsten sheets with air in between to give an effective interaction length of 2m (~ 4.8% W) would minimize the reabsorbtion of D's and still permit the gathering of a sufficient large flux of muons at the downstream end of the dump. The muons are subjected to a large angle bend with a superconducting string such that 3km downstream the neutrino beam and final muon beam are 10-15 meters apart. The flux of muons through the neutrino detectors is minimum since the ν detector is on the high momentum side of the bend. The neutrino flux passing through an r=1m detector at this position 3km from he dump is shown in Figures 2 & 3. With the event energy distribution shown in Figure 4. With a relatively modest 100 ton neutrino detector at this position, event rates would be (for 10^{18} protons on the dump):

ν_τ: 2×10^5 events: $\langle E \rangle = 2.7$ TeV

ν_ℓ: 7×10^7 events: $\langle E \rangle = 3.0$ TeV

where ν_ℓ is the sum of ν_μ and $\bar{\nu}_\mu$ ν_e and $\bar{\nu}_e$ (i.e. ~ 20 million of each!). The muon flux entering the superconducting dipole string just downstream of the dump is shown in figure 5. At the 3Km position all muons with E < 8 TeV have been swept away and the integrated flux with E > 8 TeV is ≈ $10^7/10^{13}$p with $\langle E_\mu \rangle \approx 10$ TeV. Muon event rates would then be similar to the rates shown in Appendix 1. An attempt is now in progress to use the magnet design suggested in Ref. 12 which could improve the flux considerably. This is sufficient rate to accomplish the physics program outlined earlier without seriously affecting the collider program.

Detectors and Experiments

Various designs for experiments and the corresponding detectors are given in references 4,7, 8, 10, 11. The hard scattering spectrometer of reference 4 is constructed with conventional elements at a modest cost of $4M - which includes a VAX! The K^0 decay experiment of reference 7 is similar to that used in Fermilab E731 and is also quite inexpensive.

A number of designs for high energy muon and neutrino detectors have been proposed. Most are based on minimal upgrades of existing detectors. The improvements include improvement of spatial resolution (to ≈ 100 μm) and increasing the field integral (∫Bdl) and/or increasing the lever arm. These detectors could be installed at the SSC for rather low cost.

The principal concern in evaluating detector alternatives is whether they provide resolution adequate to satisfy the goals of the experiment.

The requirements are most stringent for the determination of structure functions. Here the rapid variation of cross-section and the need for high precision place large demands on the detector.

We have carried out a Monte Carlo simulation to evaluate the effect of detector resolution on the systematic errors in the determination of the structure functions F_i. For the purposes of this study we characterize detector performance with the following parameters.

$$\sigma(E_o)/E_o = 0.01 \text{ at } 15 \text{ TeV}$$

$$\sigma(p)/p = 0.01\ p/10 \text{ TeV}$$

$$\sigma(\theta) = 0.03 \text{ mr}$$

$$\sigma(\nu)/\nu = 0.01 + 0.7/\sqrt{\nu}$$

These would, for example, characterize the CCM (Chicago Cyclotron Magnet), with a 45m lever-arm. The results of this simulation are summarized in Table I. Over the entire kinematic range accessible to an SSC muon experiment, the systematic errors due to detector resolution in the determination of structure functions $F_i\ (x,Q^2)$ are entirely negligible.

It should be noted that the determination of $\nu = E_\mu - E'_\mu$ by calorimetric measurement of the hadronic energy is critical for measurements of $F\ (x, Q^2)$ near the elastic limit $x = 1$. In this region because of the small values of ν and the rapid variation of F as a function of x, there will be significant smearing in x and large systematic shifts in the reconstructed x. Even crude determination of ν directly can reduce the systematic errors to a negligible level.

In summary, straightforward extrapolations of existing muon and neutrino detectors will provide the main determination of the structure functions and will at the same time permit study of other lepton processes. The cost of these fixed target detectors will be quite minimal and essentially negligible when compared to the 1/4 - 1/3 billion dollars which the collider detectors are estimated to cost.

Conclusions

After carefully examining the various aspects of fixed target physics at SSC energies, we have come to the following conclusions:

1. There are a large number of extremely interesting physics topics which are either solely addressable or best studied at a fixed target facility (FTF).

2. When compared with the other future high energy leptoproduction facility HERA, physics results at the FTF can be extracted much more easily, with far smaller smearing corrections and with resultant smaller errors.

3. High energy neutral and lepton beams can be designed to yield high intensities for minimal monetary and real estate investment. The example given in this report of a beam dump source of prompt (D,B and F) produced leptons would yield high energy 's and 's for less than 10 million dollars.

4. Fixed target detectors at the FTF need be little more than refinements of existing detectors. No expensive R & D programs will be required to provide detectors to do the physics we have outlined here.

5. The sociological importance of a) having more than a few collider experiments to accommodate the physics community, and b) the structure of these additional experiments being on a much smaller scale than the collider experiments, cannot be over emphasized.

Table I - Shift and Systematic Error in the Measurement of X_{Bj} and Q^2.
P_m = 15TeV

x=		0.2	0.4	0.6
y=0.2	$<Q_2>$	2210 GeV^2	3730	
	<x Shift>	0.06%	-0.2%	
	$<\sigma X>$	8.5×10^{-3}	1.3×10^{-2}	
	$<Q^2$ Shift>	0.03%	.04%	
	$<\sigma Q^2>$	2.2×10^{-2}	1.9×10^{-2}	
0.4		3740	6440	
		0.04%	0.1%	
		6.8×10^{-3}	$1.1 \times 1.^{-2}$	
		.01%	.01%	
		1.7×10^{-2}	1.5×10^{-2}	
0.6				

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Fig. 1

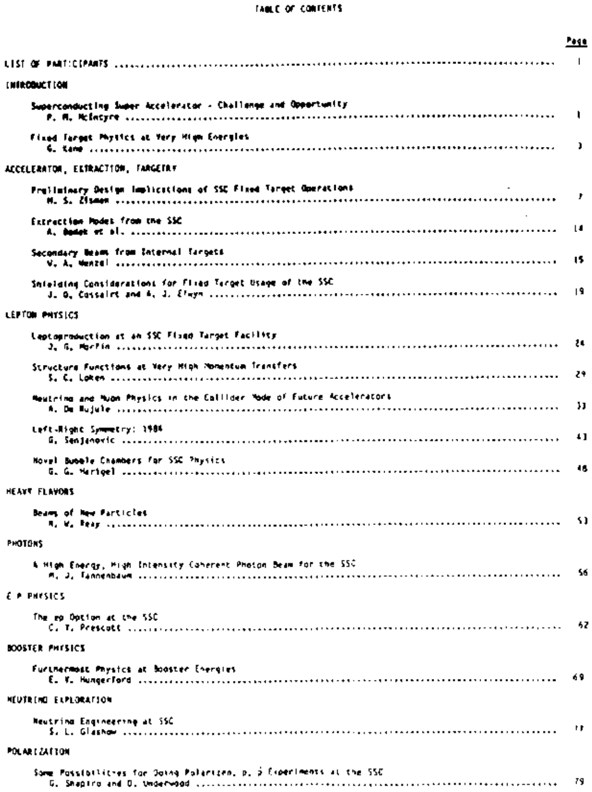

TABLE OF CONTENTS

Page

LIST OF PARTICIPANTS i

INTRODUCTION

Superconducting Super Accelerator - Challenge and Opportunity
P. M. McIntyre 1

Fixed Target Physics at Very High Energies
G. Kane 3

ACCELERATOR, EXTRACTION, TARGETRY

Preliminary Design Implications of SSC Fixed Target Operations
M. S. Zisman 7

Extraction Modes from the SSC
A. Bodek et al. 14

Secondary Beams from Internal Targets
V. A. Wenzel 15

Shielding Considerations for Fixed Target Usage of the SSC
J. D. Cossairt and A. J. Elwyn 19

LEPTON PHYSICS

Leptoproduction at an SSC Fixed Target Facility
J. G. Morfin 24

Structure Functions at Very High Momentum Transfers
S. C. Loken 29

Neutrino and Muon Physics in the Collider Mode of Future Accelerators
A. De Rujula 33

Left-Right Symmetry: 1984
G. Senjanovic 43

Novel Bubble Chambers for SSC Physics
G. G. Harigel 48

HEAVY FLAVORS

Beams of New Particles
N. W. Reay 53

PHOTONS

A High Energy, High Intensity Coherent Photon Beam for the SSC
M. J. Tannenbaum 56

E P PHYSICS

The ep Option at the SSC
C. Y. Prescott 62

BOOSTER PHYSICS

Furthermost Physics at Booster Energies
E. V. Hungerford 69

NEUTRINO EXPLORATION

Neutrino Engineering at SSC
S. L. Glashow 77

POLARIZATION

Some Possibilities for Doing Polarized p, $\bar{p}$ Experiments at the SSC
G. Shapiro and O. Underwood 79

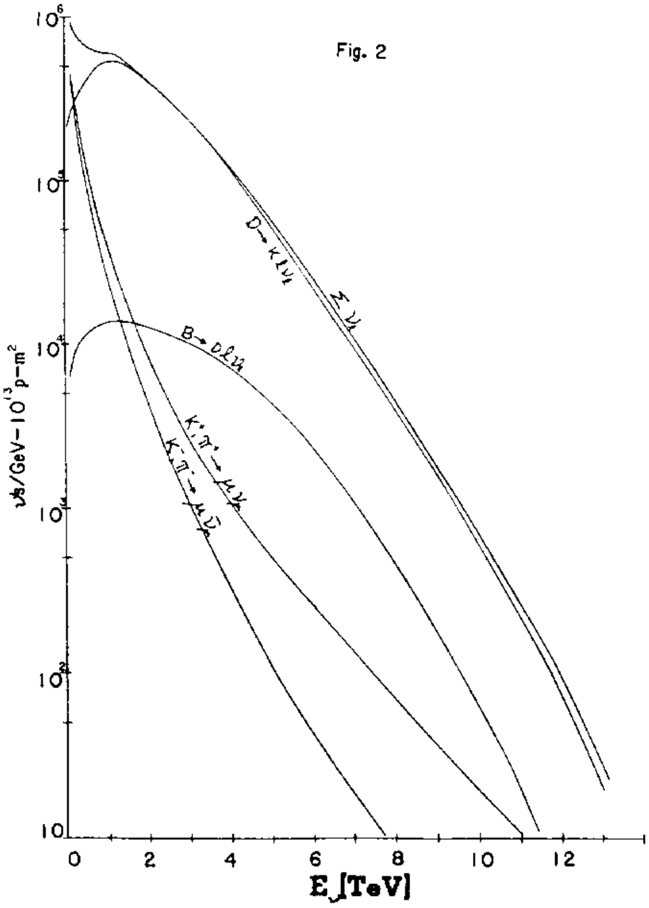

Fig. 2

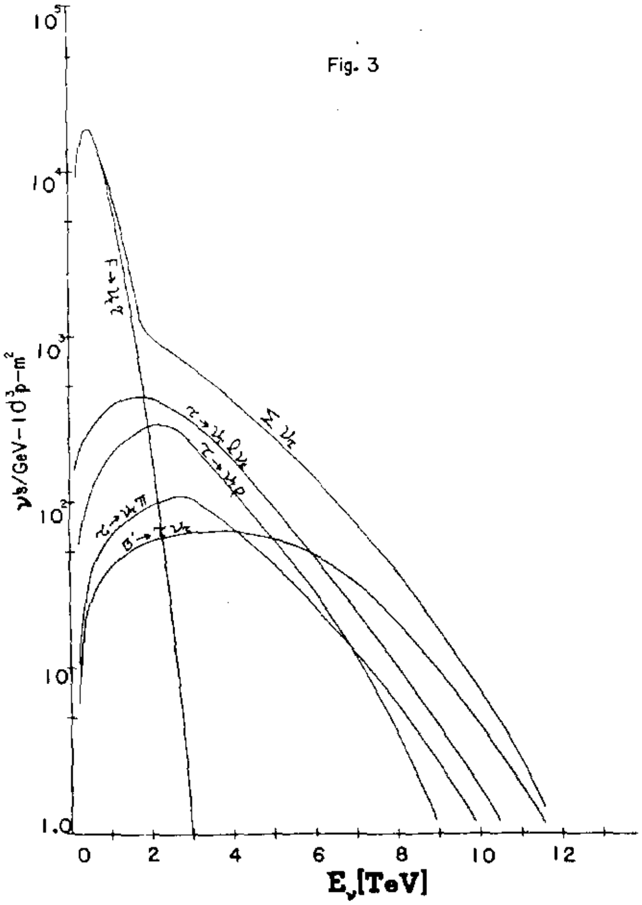

Fig. 3

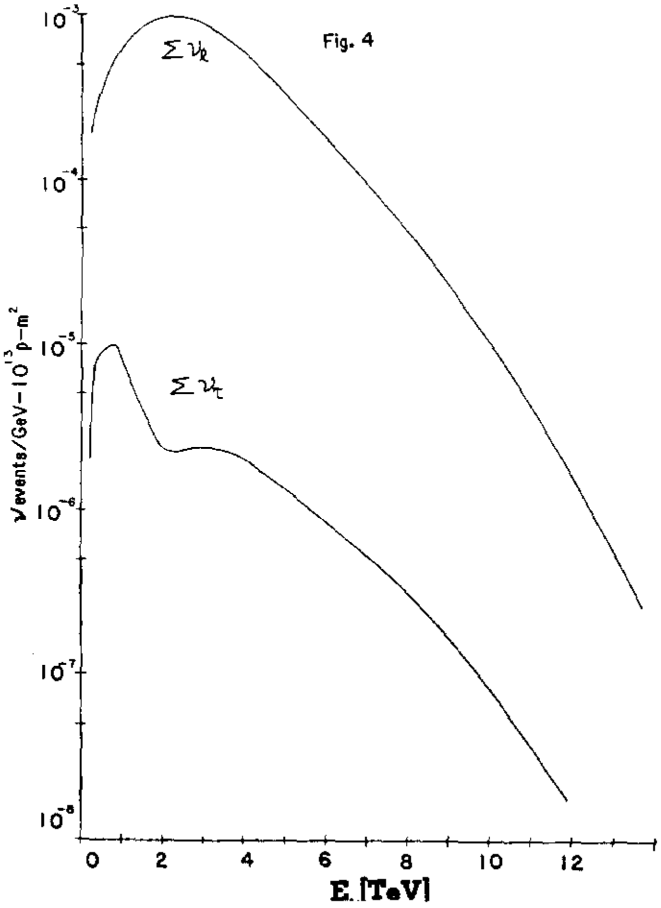

Fig. 4

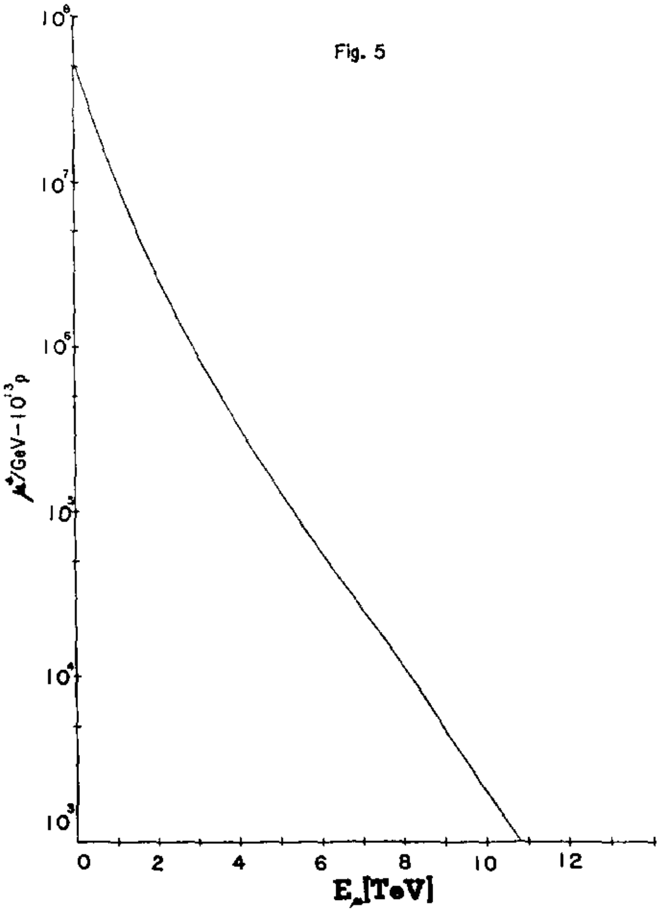

Fig. 5

Appendix I

Leptoproduction at an SSC Fixed Target Facility

Jorge G. Morfín
Fermilab

At a recent three day workshop, various aspects of a possible Fixed Target Facility (FTF) at the SSC were examined. This report summarizes the results of a subgroup formed to examine lepton physics within the kinematic bounds allowed with 20 TeV protons on a production target. The group consisted of:

G. Harigel	CERN
S. Loken	LBL
J. Morfín	Fermilab
L. Stutte	Fermilab
M. Tannenbaum	BNL

with some theoretical guidance from G. Kane (Michigan).

Our goal at this initial meeting was to organize the group so that we could eventually answer the following questions: what would an FTF do particularly well; what would the increase in energy over the Tevatron bring us; how would the FTF results compare with HERA expectations; and finally what kind of beam intensity and spill structure would be required.

In general, there seems to be no doubt of the contribution which could be made with ultra high energy lepton beams. Leptoproduction has been instrumental in understanding basic nucleon structure. We probably would not understand the quark parton model and QCD as well as we do today without the input of leptoproduction experiments. It may very well be that future lepton beams will be the tool needed to expplore possible quark substructure just as contemporary lepton beams have yielded so much information about nucleon structure. An FTF at a 20 TeV accelerator would not only have a high luminosity charged lepton (μ^+,μ^-) facility but also high intensity ν_μ, ν_e and ν_τ beams with which interactions with a particular quark flavor could be emphasized. Following is a brief review of several potential FTF physics topics which could be studied with these beams. It is not meant to be exhaustive, but to stimulate thought for further consideration at Snowmass this summer.

I. Structure Functions

Of the various aspects of leptoproduction which will be discussed in this report, that which seems to best demonstrate the basic need and possible superiority (compared to HERA) of a leptonic FTF is the study of nucleon structure functions. Neutrinos, electrons, and muons have provided the means for a careful study of the nucleon structure function. F_2 has been measured by all three of the above mentioned leptons, and xF_3 by neutrinos, up to a $Q^2 \sim 200$ GeV². Scaling (approximate) and, with increased Q^2 range, scale breaking were first demonstrated using these lepton beams. It was the Q^2 evolution of the structure functions that provided the first clear test of QCD. What an FTF would add to this study is not just the effective peak Q^2 of ~ 13000 GeV² with reasonable statistics, but also the very large range of x_{Bj} and Q^2 available to experimenters.

Within the currently explored Q^2 bounds, the experimental and theoretical uncertainty with respect to higher twist ($1/Q^n$) contributions and other nuclear effects has limited the effective Q^2 range to $\sim$ (25-200) GeV². Note that this Q^2 range represents only a factor of 1.6 in $\ln Q^2$ which is the pertinent Q^2 dependence of QCD. By extending Q^2 to 15000 GeV² we will not only double the range of $\ln Q^2$ but also permit a measurement of these non-perturbative effects. This could be done by measuring the $\ln Q^2$ dependence accurately in a high Q^2 range (i.e. $Q^2 > 50$ GeV²) and then extrapolating back to lower Q^2 and measuring the deviation from the expected $\ln Q^2$ values. Figure 1 shows the expected Q^2 evolution (Duke and Owens parameterization) of xF_3 at $x=0.55$ with and without a twist-4 contribution consistent with our present crude measurements.

This brings us to the first significant advantage of the FTF over HERA. With e^+ and e^--proton interactions, there are six charged current (CC) structure functions involved and it will be extremely difficult to extract them individually. They clearly cannot be extracted as easily as via the sum and difference of ν and $\bar{\nu}$-isoscalar target cross sections or muon-isoscalar target scattering. Furthermore in the neutral current (NC) case the Q^2 dependence of the ($\sin^2\theta_W$ dependent) couplings and the structure functions are intermixed. At HERA, a final model independent solution will only be provided when deuterons are accelerated. This will obviously be a later generation HERA experiment and have a much more limited effective Q^2 range as well as lower luminosity. A further implication of this is the possibility of measuring the Q^2 and A dependence of the "EMC effect" at an FTF which is clearly impossible at HERA.

Another important structure function measurement is the ratio of $xF_1(x,Q^2)$ and $F_2(x,Q^2)$. This ratio determines the absorption of longitudually and transversely polarized I.V.B. At best, this is an extremely difficult measurement to perform. From contemporary fixed target lepton beams there are some low energy fixed x results from SLAC, several large error measurements from earlier ν experiments and a very recent attempt by the CHARM collaboration to measure the x dependence of

$$R(x,Q^2) = \frac{F_2(x,Q^2)}{2xF_1(x,Q^2)} - 1.0$$

For fixed target experiments R is obtained by holding x and Q^2 fixed and measuring the cross section at different y by varying the beam energy. This is not the case at HERA since the xF_3 terms do not disappear in the cross section ratios. At HERA one has to measure both $\sigma(e^+)$ and $\sigma(e^-)$ with fixed x and Q^2 at two different values of s. The value of R is then obtained by taking the ratio of the sums. Note that a 5% relative normalization error in the luminosities at the two values of s results in $(\Delta R/R) = 0.1$.

Up to this point we have only compared the basic operating principles of an ep collider and a fixed target facility without discussing detectors and experimental resolution. For comparison of experiment related matters, the report of E. Longo (Univ. di. Roma) presented at the International Workshop on Experimentation at HERA, Amsterdam, June 1983 has been used. Various detectors are specified through their resolution in energy and angle without explicating how these resolutions can be obtained. The so called "ideal" or "perfect" detector is shown in Figure 2. Other detectors with relative degradation in energy and/or angular resolution are also presented. The effect that these resolutions have on the measurement of a structure function of fixed Q^2 is shown in Figure 3. With respect to full QCD fits, the following table summarizes the error in Λ, resulting only from detector resolutions, when a value of 200 MeV is used as input

	Detector	$\Lambda_{\text{non-singlet}}$	Λ_{singlet}
NC			
	perfect	200±27 MeV	200±190
	$\sigma(E_e)/E = .1/\sqrt{E}$ $\sigma(\theta_e) = 10$mr	200±43	200±210
CC			
	perfect	200±154	200±800
	$\sigma(E_j)/E = .5/\sqrt{E}$ $\sigma(\theta_j) = 10$mr	200±180	--

In addition there will be systematic uncertainties which have been quanitized as follows: any of the following errors will change the input value by 50% (200 MeV to 100 or 300 MeV)

a) propagator M_Z or M_W wrong by 5 GeV
b) $\sin^2\theta_W$ wrong by .005
c) Relative normalization between $E_p = 200$ & $E_p = 820$ GeV wrong by 5%

This is without other possible sources of error such as errors in absolute energy calibration and radiative corrections.

The attainable resolution of possible detectors at the FTF has not been studied to the extent that the projected resolution of HERA detectors has been. This will certainly be a topic to address at Snowmass this year. G. Harigel has described one hybrid detector in detail in a separate report of this workshop. In general the kinematics of leptoproduction at the FTF will be a multi-TeV lepton incoming and scattering off a nucleon constituent resulting in a multi-TeV lepton and/or a multi-TeV hadron shower leaving the interaction vertex. The whole question of resolution with respect to structure functions reduces to how accurately one can measure two of the three four-vectors (ℓ_{in}, ℓ_{out} or h_{out}). In the case of muoproduction the incoming muon can be accurately tagged $\Delta P_\mu/P_\mu \le 1\%$ and fine grained calorimetry could measure $\Delta E_H/E_H = 1\%$ as well as $\Delta\theta_H/\theta_H = 10\%$, with these figures coming from H. Anderson's ICFA report. Neutrino scattering will be more difficult since knowledge of the incoming neutrino energy will be somewhat limited. As will be explained shortly, narrowband or dichromatic ν beams will be difficult to produce. Thus even though the outgoing hadron shower angle and energy can be accurately measured, a way must be found to measure the outgoing lepton energy and neutrino flux to study structure functions with neutrinos at the FTF.

One further aspect of this topic is the moments of these structure functions

$$M_N(Q^2) = \int x^{n-2} F(x, Q^2)\,dx$$

It is these moments that are directly predicted by QCD. There have been several experimental difficulties in measuring these moments the most important being; the large smearing corrections and low statistics at high x which are particularly devastating for high N, the extrapolation of the integral from x=0 to $x = x_{min}$ where

$$x_{min} = \frac{Q^2}{2M\nu_{max}}$$

which dominates the low N moment determination. Obviously, the Q^2 range over which these moments can be measured without being adversely affected by x_{min} will be greatly expanded at the FTF.

The question of expected statistics both at HERA and at the FTF is not easy to address. It depends both on the hoped for luminosity and "realistic" duty cycle chosen. Event rates as a function of beam type, spill structure and target at the FTF will be summarized shortly. It has been difficult to find similar event rates for HERA which have been corrected for loss via the beam pipe, e/π ambiguities, accelerator efficiency etc. However it seems that in general the event rates at HERA and at the FTF will be comparable with effective peak $Q^2 = 15000$ GeV^2 for both facilities.

II. Hadronic Shower Structure

The principle advantages of the FTF in comparison to HERA in terms of hadronic shower analysis will be the presence of an intrinsic direction $\vec{Q}$ and a minimal loss of secondaries (limited beam pipe if any). This will allow a detailed look at the Breit frame where independent measurements of α_s should be possible. Recall that whether a particle goes forward (current fragment) or backward (target fragment) in the Breit frame depends on the P_T of that particle with respect to Q. If gluon bremstrahlung takes place, the P_T of that particle with respect to Q increases so that some of the particles which should be classified as forward are incorrectly classified as backward. This creates an inbalance of P_T in the forward Breit frame. Both the amount of the imbalance ($\le Q/2$) and the fraction of events with an imbalance are a direct measure of α_s.

The high particle detection efficiency will enable an investigation of particle fragmentation functions over the complete x, z and Q^2 range and in particular, allow a test of x-z factorization at high Q^2 where non perturbative effects should be small.

III. Like sign Dilepton Production

(information gathered by L. Stutte)

The anomalously high production of like sign dimuons has been seen only in neutrino interactions. It is furthermore the only observed reaction in conflict (factor 5) with the Standard Model. We do not know a great deal about this reaction except that its rate relative to $\nu N \to \mu^- x$ is about 10^{-3}. The upcoming holographic 15' bubble chamber run could accumulate as many as 50 like sign dileptons so there might be a few hundred accumulated by the time an FTF would be functional. If there are still unanswered questions which require higher energy neutrinos, only the FTF would be able to contribute.

IV. Weak-EM Interference

The measurement of γ-Z^0 interference effects will be one of the more accurate ways of checking the validity of the standard model at high Q^2. One measure of the interference is the difference in $\mu+$ and $\mu-$ cross-sections with given polarizaation λ. This difference over the sum of the cross-sections is of order $10^{-4} Q^2$(GeV^2) so that whereas the effect is =

.03 at Tevatron energies, values of 0.3-0.5 would be attainable at the FTF. It's interesting to note that for E_μ = 15 TeV, a reasonable μ energy with 20 TeV protons on target, the electroweak force actually ddominates the electromagnetic (single photon exchange) force over a large part of the kinematic range.

V. Beams, Extraction and Event Rates

There could be a full range of lepton beams at an FTF including bare target and dichromatic neutrino beams, high intensity and controlled polarization muon beams, and exotic lepton beams of of ν_τ etc. Currently A. Malensek and I are attempting to construct a beam dump based facility that would be able to produce all of the above mentioned beams, except the dichromatic ν beam, using a single primary proton transport and minimal secondary beam transport. It capitalizes on the extremely high rate of prompt lepton production (via D and F's) expected with 20 TeV protons on target and thus could eliminate the very costly 10-20 Km long decay pipe needed with conventional beam design. Until this work is complete, quoted rates are from the calculations of S. Mori contained in the previously mentioned 20 TeV ICFA workshop.

For a conventionally designed bare target neutrino beam, Mori assumed a 4Km decay path and predicts ~ 750 events/10^{13}P in a 100 ton detector of radius r=0.5m with $\langle E_\nu \rangle$ = 4.5 TeV. The average ν energy can be raised significantly by employing a dog-leg arrangements of dipoles with a collimator upstream of the second bend (Figure 4). Obviously the event rate decreases, however the depletion occurs mainly for $E_\nu \lesssim 3$ TeV. A dichromatic neutrino beam is, in principle, possible by choosing a narrow momentum band of parent π's and K's. However, to preserve the desired dichromatic feature of E_ν vs R_ν at the detector, very small beam divergence must be maintained. The event rate would be on the order of 50 events / 100 ton-10^{13}p. Mori's beam dump calculations predicted an event rate for ν_τ of 1.2 * $A^{1/3}$ where A is the atomic number of the dump material. Thus for a copper dump we would expect 10 events while for tungsten dump we would have 16 events per 10^{13}p for a 100 ton detector. The corresponding rates for ν_μ (= $\bar{\nu}_\mu$ = ν_e = $\bar{\nu}_e$)are 310 events in Cu and 500 events in tungsten. However, much has been learned about D production since Mori's report was written in late 1979. The cross-section seems to be rising with s and the x_F distribution seems to be much flatter than assumed by Mori. These new observations plus the non-negligible absorption of the D's and F's with 20 TeV protons on target will be taken into account in the new calculations currently underway at Fermilab.

With respect to muon beams, there are several alternatives being considered. The most novel beam would use only the direct muon production which accompanies the ν_μ prompt production mentioned above The dump would act as a conventional target to be followed by a doublet or triplet. The beam thus gathered would pass through a bend and a series of magnetic "scrapers" (such as are being installed in the new Teavtron muon beam) to select the desired momentum bite and reduce the halo. This concept has the added feature that the muon beam elements could act as as active shield to lower the muon background in the prompt ν detectors downstream of the dump. The disadvantage of this scheme, assuming that the muon flux proves to be satisfactory, is the inability to control the polarization of the beam. To do that we must use a more conventional beam which gathers the parent π and K particles, makes the desired momentum selection, and allows a sufficient decay path along a FODO to get reasonable muon flux rates. Whichever way one chooses to make the muon beam, the following table taken directly from H. Andersons ICFA report summarizes the expected event rates for 10^{40} μ^+ x nucleons/cm². This is roughly equivalent to 10^{18} (10^{17}) p on the production target with a 10m(1m) long D_2 (Fe) target. Note that the y ≥ 0.2 cut eliminates a fair fraction of the low Q^2 (≤ 800 GeV²) events.

← x →

		0	.2	.4	.6	.8	1.0
↑	.2						
		384610	53600	5525	505	13	
	.4						
		592570	12060	1140	100	2	
y	.6						
		889110	4125	350	30	1	
	.8						
↓		1444500	1575	105	7	--	
	1.0						

μ^+ event rates (y_+ > 0.2) for 10^{40} muons x nucleons/cm². Total μ^+ events = 3.39 x 10^4, correspondng μ^- = 3.53 x 10^4

The details of the various spill modes considered at the workshop will be related in the report of A. Bodek. Here are summarized the consequences of the different modes. Since the collider will probably dump "old" beam and refill every twelve hours or so, a slow parasitic extraction where 10^{14} p are dumped over ~ 100 seconds twice per day would have essentially no effect on the collider program. A dedicated slow spill could be as many as 2 spills/hour with 10^{14}p over 100 seconds. A third possibility is a dedicated ping beam which would distribute the proton intensity more evenly in time. One could have ~ 100 pings/hour of length 3 μsec. The intensity per ping would be dictated by the maximum instantaneous event rate an experiment could handle and the detector target mass. For example, If the data acquisition facility of a ν experiment could handle 5-10 events/ping then with 2 x 10^{12} p/ping either the detector mass would be limited to ~ 10 tons with the bare target beam or to ~ 100 tons with a narrow band beam.

To summarize one would expect the following event rates per "week" where a "week" is an effective 110 hours of combined accelerator and detector running i.e. 2/3 combined efficiency. The entire extracted proton intensity is assumed to be dedicated to the beam in question.

Neutrino Beams (100 ton detector, r=0.5m).

	Beam Type	Extraction	Events
1.	Bare Tgt	slow parasitic	70000
		slow dedicated	1630000
		ping(2x10^{12}p/ping)	110000(10 ton detector)

2. Dichromatic ~ (5-10)% of the above

3. Beam Dump (tungsten)

Beam Dump (tungsten)	slow parasitic	ν_τ:1500 $\overset{(-)}{\nu}_\mu, \overset{(-)}{\nu}_e$:47300 each
	slow dedicated	ν_τ:35250 $\overset{(-)}{\nu}_\mu, \overset{(-)}{\nu}_e$:1100000 each

Muon Beam (15 TeV, μ^-/proton = 0.5 μ^+/proton)

Target	Extraction	Events (y > 0.2)
Fe-1m	slow parastic	μ^+: 34000 μ^-: 18000
	slow dedicated	μ^+: 782000 μ^-: 415000

D_2-10M = 0.1 x above rates.

For a direct comparison between HERA and the FTF muon beam the following table summarizes the event rates for the kinematic region x > 0.2 and y > 0.2. For HERA $L = 5 \times 10^{31}$ is assumed as well as the 2/3 combined efficiency assumed at the FTF. Muon rates are for the 10m D_2 target so should be multiplied by 10 for 1m Fe target. The five entries in each box correspond to: (events per "week")

HERA (from L. Maiani's Report)
$\mu^- D_2$;slow parasitic
$\mu^+ D_2$;slow dedicated
$\mu^+ D_2$;slow parasitic
$\mu^- D_2$;slow dedicated

← x →

y	.2 – .4	.4 – .6	.6 – .8	.8 – 1.0
.2	32.6	6.1	0.7	--
	30.8	3.5	0.4	--
	710	60.0	7.7	0.2
	53.6	5.6	0.5	--
	1230	127	11.7	0.3
.4	16.6	2.6	0.2	--
	8.9	1.1	0.1	--
	205	23.8	2.3	0.2
	12.0	1.1	0.1	--
	275	26.2	2.3	--
.6	9.8	1.4	0.2	--
	4.2	0.5	0.1	--
	95.0	11.5	1.1	0.1
	4.1	0.4	--	--
	94.9	8.1	0.7	--
.8	6.8	0.9	--	--
	2.1	0.3	--	--
	48.1	5.1	0.4	--
	1.6	0.1	--	--
	36.2	2.5	0.2	--
1.0				

VI. Conclusion

It is hoped that this brief review of potential physics at SSC fixed target facility will serve as a basis for further discussion at Snowmass this summer. In general, preliminary indications are consistent with an FTF-Detector combination performing at least as well and in many cases decidedly better than currently envisioned HERA facilities. This, however, must be confirmed by less approximate calculations and careful consideration of likely FTF detectors.

References

HERA: All HERA related information in this report came from the Proceedings of the Workshop: *Experimentation at HERA, Amsterdam, June 9-11. DESY* Publication 83/20. In particular the contributions of:

E. Longo, "Currents and Structure Functions", pg.285
L. Maiani, "The Virtues of HERA", pg.3
D.H. Perkins, "Lepton-Nucleon Collisions", pg.39

ICFA: The various International Committee for Future Accelerators (ICFA) reports referred to come from: Proceedings of the second ICFA Meeting. Les Diablerets, Switzerland, 1979.

H.L. Anderson, "Muon Spectrometer for E_μ = 15 TeV", pg.299
G. Barbiellini, "Deep Inelastic Experiments" pg.289
S. Mori, "Neutrino Beams in the Energy Range of 20 TeV", pg.333

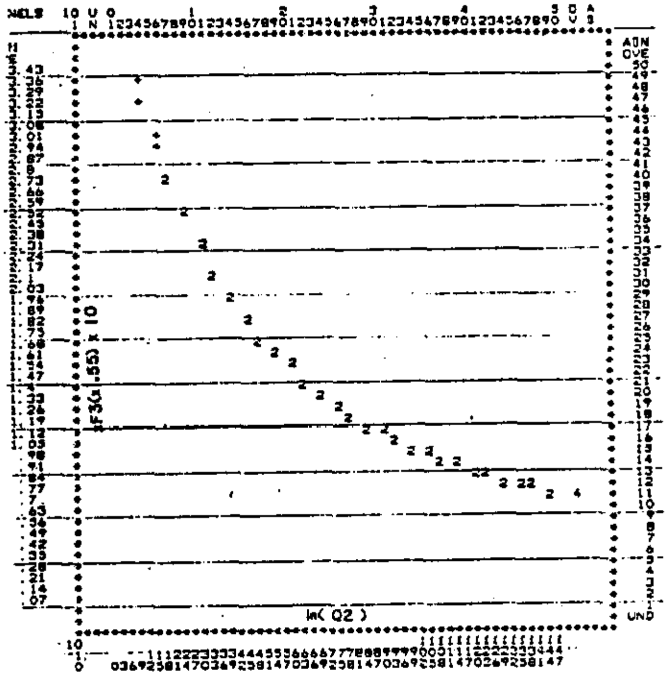

Figure 1 - XF_3 vs Q^2 for x = 0.55. The upper curve is pure QCD while the lower curve includes an estimated twist-4 contribution.

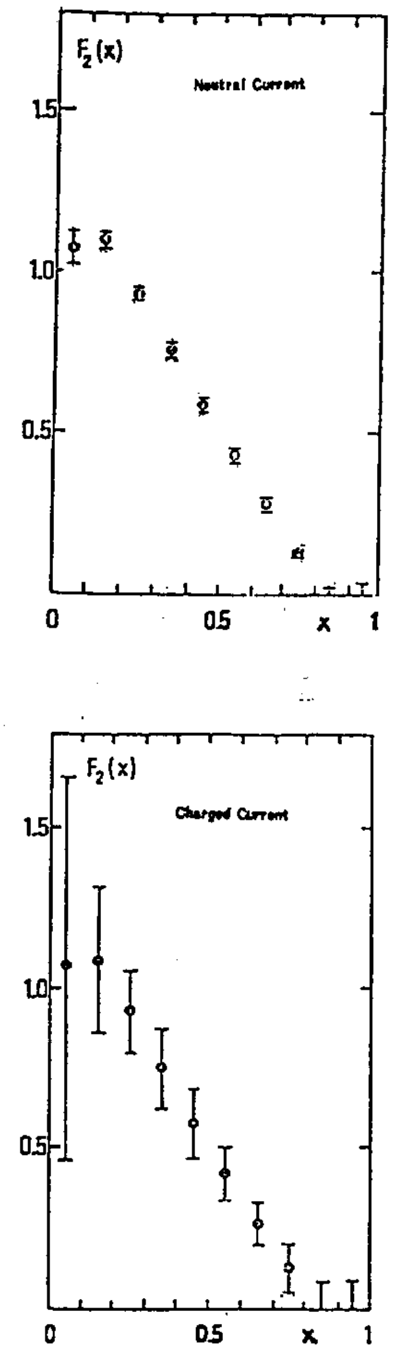

Figure 3 - From E. Longo. Uncertainity in determining $F_2(x)$ at fixed Q^2 coming from the "ideal" detector i.e. no statistical error.

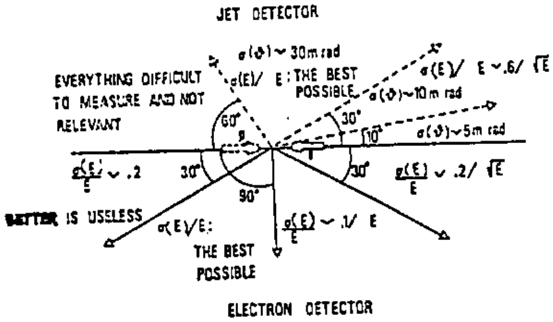

Figure 2 - From E. Longo's report. The "ideal" HERA detector referred to in the text.

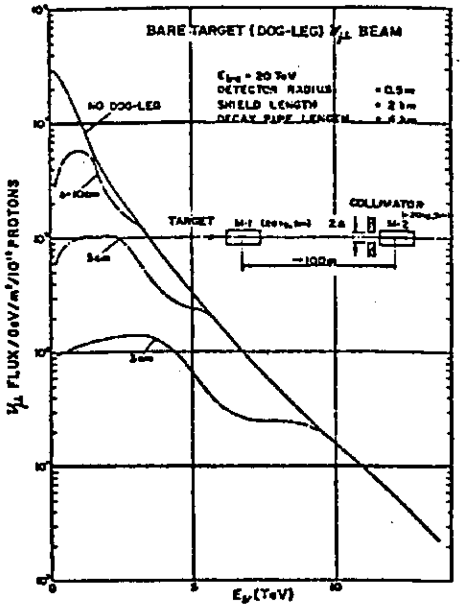

Figure 4. Muon neutrino fluxes as a function of a beam collimator aperture in a dog-leg arrangement. The detector radius was 0.5m and the incident proton energy was 20 TeV. From S. Merl.

Appendix II

STRUCTURE FUNCTIONS AT VERY HIGH MOMENTUM TRANSFER

Stewart C. Loken
Lawrence Berkeley Laboratory
University of California, Berkeley, CA 94720

Summary

The measurement of structure functions provides information on the quark-momentum distribution within hadrons. Precise measurement of the evolution of the structure function over a wide range of kinematic variables provides a determination of the strong coupling constant and the QCD parameter Λ.

Several types of experiments can provide the measurements needed for the study of structure functions. Fixed target lepton scattering (e, μ or ν_μ) provide a range of beams, targets, and detectors and have historically been a rich source of new data. Fixed target experiments at the SSC can extend the measurements to very high momentum transfer and compete favorably with the planned e-p collider at HERA. Higher energy e-p colliders using the SSC proton beam can extend the range of momentum transfer by orders of magnitude but the experiments are very difficult. Drell-Yan measurements provide an independent measurement of the nucleon structure function and also permit study of the structure of mesons and, at the SSC, of hyperons. Determination of structure functions in e^+e^- annihilation is plagued by theoretical uncertainties and by background problems.

Introduction

The measurement of structure functions is one of the most fundamental determinations in hadron physics. In the quark model the structure function is proportional to the momentum distribution of quarks in the hadron. In QCD this momentum distribution "evolves" as the quarks radiate gluons and the gluons produce quark - antiquark pairs. This decreases the population of high momentum quarks, and increases the number with low momentum.

The goal of experiment is to measure the various structure functions over the widest range of kinematic variables, with high statistics and with the smallest systematic errors. In the next sections we review the range of possible fixed target and collider experiments that can provide these determinations.

Inelastic Muon Scattering

At high energies, muons instead of electrons, are used as the basic electromagnetic probe of the nucleon. The process of interest is shown in figure 1. The details of hadronic structure are contained in the structure functions F_1 and F_2 are functions of two Lorentz invarients $Q^2 = -q^2$ and p.q.

The differential cross section for the process can be written as

$$\frac{d^2\sigma}{dydv} \quad \frac{4\pi\alpha^2}{S}\,\frac{1}{v^2y}\left[\frac{1+(1-y)^2}{2}F_2(x,Q^2) - y^2 F_L(x,Q^2)\right\},$$

where $y \equiv \nu/\nu_{max} = \nu/E$

$v \equiv Q^2/Q^2{}_{max} = Q^2/S$

$x = Q^2/2M\nu = v/y$

$F_L = F_2 - 2\ x\ F_1$

In the quark parton model F_2 is given by

$$F_2 = x\sum_i Q^2{}_i\ [q\ (x) + \bar{q}\ (x)]$$

The longitudinal structure function F_L is related to the non spin 1/2 constituents, or to the transverse momentum of quarks, and is experimentally small.

The determination of $F_2(x,Q^2)$ requires not only high energy, but a large range of energy (figure 2). At fixed x, the maximum value of Q^2 is given by $Q^2 = 2MEx$. At low Q^2, acceptance and resolution limit the Q^2 range of experiments. Lower energy data are necessary, and at the same time provide determination of F_L or $R \equiv \sigma_L/\sigma_T = F_L/2\ x\ F_1$.

The data of figure 2 are fitted using the Altarelli-Parisi equations to determine the QCD parameter Λ.[1] The result shown in figure 3, is

$\Lambda_{LO} = 225 \pm 43$ MeV.

The determination, in fact, is limited by systematic uncertainties as shown in Table 1.

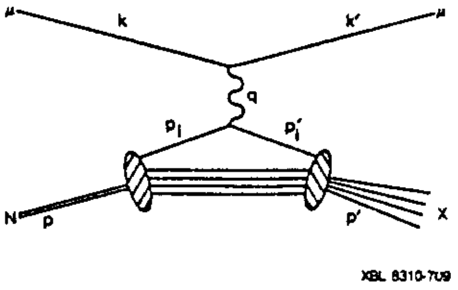

Figure 1. Feynman diagram for inelastic muon scattering.

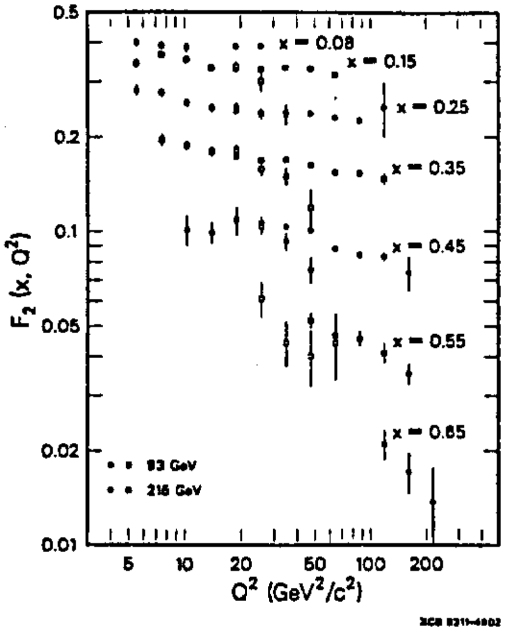

Figure 2. Structure function $F_2(x,Q^2)$ as a function of Q^2 at fixed x. Data are from the BFP experiment at Fermilab.[1]

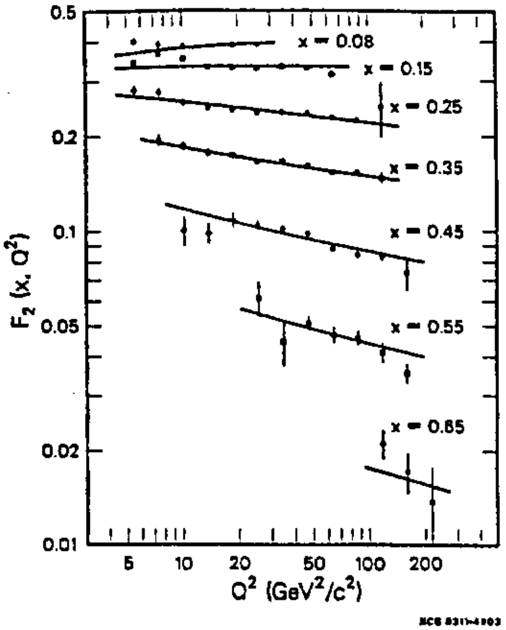

Figure 3. QCD fits to the data of figure 2.

Table 1

Source	ΔΛ MeV
Magnetic field calibration (0.5%)	<10
Beam energy (0.5%)	15
Trigger efficiency	19
Resolution smearing	50
93/215 GeV normalization	60
Total	82.

Future experiments at the Tevatron may be expected to reduce these uncertainties by at least a factor of 2.

The fixed target muon experiments can be "scaled" to a 15 TeV beam. The counting rate scales as E^{-1} and can be compensated by longer targets. The scattered muon energy is (1-y) E and the characteristic scattering angle scales as $E^{-1/2}$. None of these changes appear to pose serious problems for builders of new-generation fixed target experiments.

Neutrino Scattering

High energy neutrino scattering provides a complementary technique for the study of structure functions. The data for ν and ν are combined to extract values of F_2, F_L and xF_3.

$$\frac{d^2(\sigma^{\nu}+\sigma^{\overline{\nu}})}{dyd\nu} = \frac{G^2}{2\pi}\frac{s}{y}\left[(1 + (1-y)^2)\ F_2(x,Q^2) - y^2\ F_L(x,Q^2)\right]$$

$$\frac{d^2(\sigma^{\nu}-\sigma^{\overline{\nu}})}{dyd\nu} = \frac{G^2}{2\pi}\frac{s}{y}\left[(1 - (1-y)^2)\ x\ F_3(x,Q^2)\right]$$

At very high momentum transfer, $Q^2 > M^2_W$, these cross sections are modified by the W propagator. The cross sections are then proportional to the muon case.

The value of F_2 for neutrinos is related to the F_2 for muons by the mean-square charges of the quarks. The function xF_3 is the difference in the quark-antiquark composition of the nucleon. This function has the experimental advantage that its determination is essentially independent of the value of R. It has the additional advantage that its value does not depend on the gluon distribution.

The kinematics of neutrino scattering are idential to those for muon scattering and the systematics of experiments are comparable. Neutrino experiments at the SSC will provide a determination of F_2 and xF_3 up to momentum transfers of approximately 15000 (GeV/c)^2.

An important feature of neutrino experiments is the ability to determine the strange quark sea. Multi-muon production by neutrinos proceeds by the mechanisms

$$\nu_\mu + \begin{Bmatrix} s \\ d \end{Bmatrix} \to \mu^- + \underset{\hookrightarrow \mu^+}{c}$$

$$\overline{\nu}_\mu + \begin{Bmatrix} \overline{s} \\ \overline{d} \end{Bmatrix} \to \mu^+ + \underset{\hookrightarrow \mu^-}{\overline{c}}$$

The strange sea ($s = \overline{s}$) dominates at small x while the contribution of d (not $\overline{d}$) shows the valence behavior extending to large x.

In summary, the fixed target lepton experiments, with both muons and neutrinos, will be a rich source of information about the constituents of hadrons. The experimental techniques of the Tevatron will scale to the energies of the SSC beams.

e-p Colliders

The e-p colliding beams provide the highest possible momentum transfer (figure 4). At the low end, HERA has a maximum Q^2 of 10^3 $(GeV/c)^2$ although the luminosity of the machine will limit the effective Q^2 to that of the SSC fixed target experiments. At the high end, an e-p facility at the SSC could extend the range of Q^2 by more than two orders of magnitude.

Systematic uncertainties will dominate the study of structure functions. While it is reasonable to expect normalization uncertainties of less than 1% in fixed target expeirments, such accuracy will be difficult to achieve in a e-p collider while varying the electron or proton energies over a large range.

The effects of resolution in experiments at HERA have been studied extensively by the proponents.[2] In the HERA detectors, the kinematic quantities are measured by reconstructing the hadronic jets. The results of their study are summarized in Table 2.

Table 2

Process	Detector	Λ(non singlet)	Λ(singlet)
Neutral current	"Perfect"	200±27	200±190
	"Typical"	200±43	200±210
charged current	"Perfect"	200±154	200±800
	"Typical"	200±180	

The errors on the determination of Λ are comparable to, or larger than, those of current muon or neutrino experiments. Normalization uncertainties of 5% would contribute an uncertainty of 100 MeV.

For an e-p facility at the SSC, the large ratio of proton energy to electron energy makes the detection problems even more difficult.[3] There has, as yet, been no detailed study of the capabilities of this facility for the measurement of structure functions.

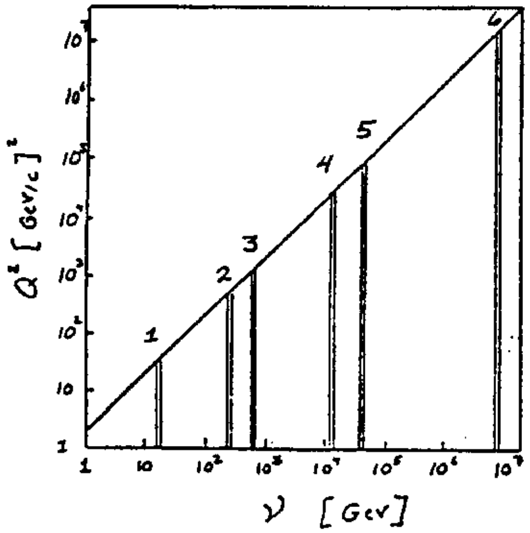

Figure 4. Q^2 vs ν for various inelastic scattering experiments. The diagonal line is the kinematic limit for elastic scattering. The maximum ν is given by the numbers for experiments at 1, SLAC e-p; 2, Fermilab/SPS fixed target; 3, Fermilab Tevatron fixed target; 4, SSC fixed target; 5, HERA e-p; and 6, SSC e-p (200 GeV x 20 TeV).

Drell-Yan Process

The production of muon pairs provides an alternative means to extract structure functions for the proton and for other particles which cannot be used as targets.

The process is shown schematically in figure 5. The muon pair momentum p* land the invariance mass $M_{\mu\mu}$ determine the kinematical variables of the annihilating $q\bar{q}$ pair

$$M^2_{\mu\mu} = x_1 \, x_2 \, s$$

$$X = x_1 - x_2 = 2p^*/\sqrt{s}$$

where x_1 and x_2 are the fractional momenta of the quark in the beam and target particle, respectively, neglecting the quark transverse momenta.

The differential cross-section is then given by

$$\frac{d^2\sigma}{dx_1 dx_2} = \frac{4\pi\alpha^2}{3S} \, \frac{1}{3x_1 x_2} \sum_i \frac{Q_i^2}{x_1 x_2} \left[f_i^{h_1}(x_1) - f_i^{h_2}(x_2) + f_i^{h_1}(x_1) f_i^{h_2}(x_2) \right]$$

with a sum over quark flavors. $f^{h}_i(x)$ and $f^{h}_i(x)$ are the quark and antiquark structure functions of flavor i in the hadron h and Q_i is the quark charge.

The nucleon structure function has been determined from Drell-Yan production by protons and antiprotons.[4] The data are in good agreement with the results from inelastic scattering experiments except for an overall normalization constant. This normalization is due to higher order QCD corrections and is assumed to be independent of kinematic variables.

While Drell-Yan provides an important consistency check, low rates, and some theoretical uncertainties make the process less useful than lepton scattering as the primary source of nucleon structure data. On the other hand, pion and kaon structure can only be studied with this method. At the SSC, Drell-Yan experiments with hyperons may be feasible.

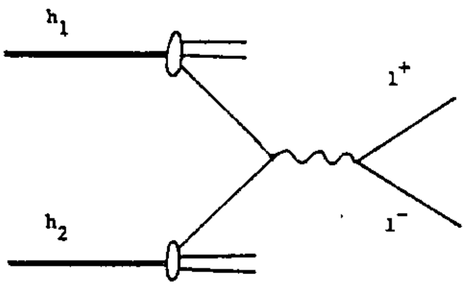

Figure 5. Drell-Yan production of lepton pairs.

Electron-positron Annihilation

Antiproton production in electron-position annihilation

$$e^+e^- \to \bar{p}\,X$$

can be related by crossing with inelastic electron proton scattering

$$e\text{-}p \to eX.$$

The crossing relation strictly holds only at $x = 2E/W = 1$,[5] but it may be hoped to hold also in the region close to $x = 1$. The cross section can be expressed in terms of the proton structure functions F_1 and F_2.[6]

$$\frac{S}{\beta}\frac{d\sigma}{dx}(e^+e^- \to \bar{p}X) = \frac{4\pi\alpha^2}{x}\left[xF_1(x) - \frac{1}{6}\beta^2F_2(x)\right]$$

Figure 6 compares the prediction with data taken at W = 12 and 30 GeV.

Clearly the prediction is not being tested in a region near $x = 1$. For the region where data exist, the prediction lies below the data. Much of the descrepancy is likely due to contributions from baryon production

$$e^+e^- \to hx$$

$$h = \bar{\Lambda} + \bar{p}\pi$$
$$\Sigma + px \text{ etc.}$$

These must be excluded before making the comparison.

Conclusions

A broad range of experiments can provide measurements of structure functions up to very high momentum transfer. An SSC fixed target program will be critical for these determinations with a variety of beams, targets, and detectors.

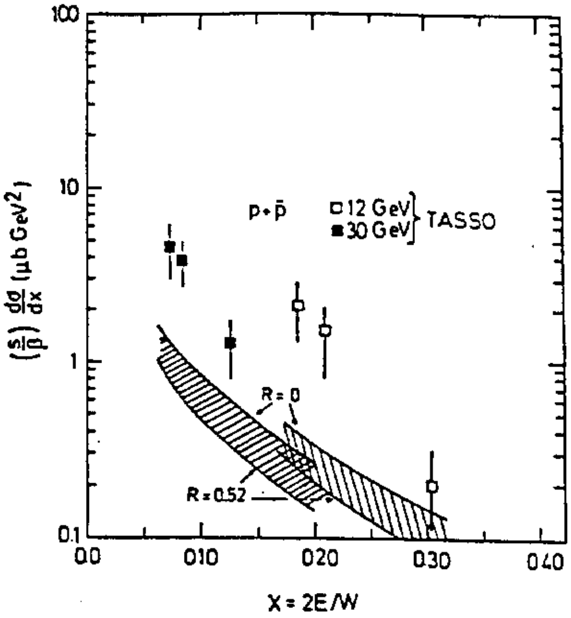

Figure 6. Scaled cross sections for p + p̄ production at W = 12 and 30 GeV compared with prediction.[6]

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1. A.R. Clark et al. Physical Review Letters 51, 1826 (1983).

2. Proceedings of the Workshop Experimentation at HERA, NIKHEF, Amsterdam, June 9-11, 1983.

3. C.Y. Prescott. Summary report in these proceedings and in the PSSC report (to be published.)

4. See for example J. Badier et al. Physics Letters 89B (1979) 145.

   J. Bakier et al. Physics Letters 96B (1980) 422.

5. R. Gatto and G. Preparata. Nuclear Physics B47 (1972) 313.

6. V.N. Gribov and L.N. Lipatov. Physics Letters 37B (1971) 78.