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1. EXECUTIVE SUMMARY

The QCD Parton Model plays an essential role in the proper interpretation of most fixed-target and collider experimental data, in precision tests of the Standard Model, in finding useful signals for New Physics, and in making predictions for future high energy facilities such as the SSC. It is widely recognized by the particle physics community that progress on all these fronts depends on: (i) the consistent application of the QCD-parton framework quantitatively to a wide range of processes; (ii) the availability of reliable parton distributions and fragmentation functions (which are universal to all applications), and (iii) the development of new theoretical tools to handle large higher order corrections systematically and to extend the kinematic range of useful predictions.

The broad scope of this challenge and of the requisite resources demand a coordinated and sustained effort in addition to that provided by the traditional individual undertakings. This is especially true because of the need for cooperation between experimentalists and theorists to make sense of the increasingly complex current experimental results in the context of a highly non-trivial theoretical framework.

This proposal is designed precisely to address this need, focusing on subjects centered on quantitative QCD phenomenology and related Standard Model tests. This initiative evolved naturally from collaborative work on QCD phenomenology, involving both theorists and experimentalists, at past workshops at Snowmass, Breckenridge and Fermilab. The physics projects proposed are driven by established needs, both for sharpening the comparison of theory with on-going experimental results at the current Fixed-target and Collider programs at the Tevatron and for the planning of the next generation of colliders such as the SSC. Some examples are: the precise determination of parton distribution functions, the development of a broad database and associated fitting techniques for global fits, systematic improvements on higher order calculations, development of efficient software to cope with extremely complex next-to-leading order numerical calculations. Although individual efforts on some of these fronts do exist, the organized effort and increased manpower and resources described in this proposal will assure that they be done properly, promptly, and in a manner comprehensive enough to satisfy the need of high energy physics in the 1990's. The perceived program is necessarily a continuing one; the emphasis of the work can and will naturally evolve from Tevatron physics to SSC physics without neglecting either one atany stage.

In addition to the physics objectives detailed in the project description section, the collaboration will initiate several pedagogical undertakings, including: (i) compiling a "handbook" on quantitative QCD analysis for phenomenologists and experimentalists covering all relevant physical processes; (ii) sponsoring a Summer School on Perturbative QCD and the Standard Model addressed to the same audience, and emphasizing theory and real calculations relevant to the understanding and the interpretation of experimental data; and (iii) writing a textbook on perturbative QCD.

The project requires salary release time for the principal investigators, postdoctoral fellow positions, graduate student support, travel funds for visitors and for collaborators, computer equipment for intensive data analysis and global parton distribution fits, one clerical staff, and support for the Summer School. The participating institutions contribute to part of the direct costs. In addition, they cost-share by waiving the considerable indirect costs as required by TNRLC.

2. LIST OF PARTICIPATING SCIENTISTS AND INSTITUTIONAL AFFILIATIONS

Name	Institution	Experiment	Note
Edmond Berger	Argonne Natl Lab		
Raymond Brock	Mich State U	FMM, D0	
John Collins	Penn State U		
Joey Huston	Mich State U	E706	
Sanjib Mishra	Columbia U	CCFR	
Jorge Morfin	Fermilab	E665, BCD	
Joseph Owens	Florida St U		
Jian-Wei Qiu	SUNY, Stony Brook		SSC fellow
Davison Soper	U of Oregon		
George Sterman	SUNY, Stony Brook		
Wu-Ki Tung	Ill Inst Tech		PD
Harry Weerts	Mich State U	D0	

Wu-Ki Tung from IIT will serve as the Project Director

In addition to those listed above, John Huth of Fermilab, QCD group leader on the CDF collider experiment, has been designated as the liaison person to our project by that collaboration. We anticipate close contact with him and with other members of CDF in our work. Likewise, we will actively seek either liaison persons or active participants from the other major relevant experiments such as ZEUS and H1 at DESY, and from the SSCL.

Additional notes on the participants:

1. Jorge Morfin is a staff member at Fermilab. He is not requesting any funding from TNRLC. The time and effort he devotes to this project will be considered as cost-sharing from Fermilab.

2. Davison Soper is currently on Sabbatical leave at CERN, Switzerland. He will participate during the first half year by electronic mail and other communication methods, including possible short visits. He will participate fully in the second half year. Because of the practical difficulties of processing the official documents within a very short time when away from his home institution, no Face Page or budget sheets from him are included in this package. No funding is requested for him from TNRLC in the first year. His biographical material is included.

3. Edmond Berger from Argonne National Lab. will be participating. Due to time constraints, there is no paper from him included in this proposal package. He will not be requesting funding from TNRLC.

3. GENERAL BACKGROUND

The need for task forces of this kind (see first two paragraphs of the Executive Summary) has become increasingly apparent over the last few years. In particular, the Division of Particles and Fields of the American Physical Society set up an Ad Hoc Committee on Particle Theory in 1989 (the Peccei Committee) specifically to examine issues related to those described here. The Committee Report, issued in 1990, made a strong case for finding ways to strengthen theoretical work relevant to current and future experiments and for starting new initiatives to support "Large phenomenological projects related to experimental analysis or projects tackling computationally intensive questions". High on the list of priority projects are the systematic analysis of structure functions, the calculation of relevant hard processes, the development of realistic fragmentation Monte Carlos, a global analysis pertaining to precision tests of the Standard Model, etc.

This proposal is designed precisely to address this need, focusing on quantitative QCD phenomenology and related Standard Model tests. This initiative evolved naturally from collaborative work on QCD phenomenology, involving both theorists and experimentalists, at past Snowmass Workshops, the Breckenridge Workshop, and the Workshop on Hadron Structure Functions and Parton Distributions held at Fermilab, April, 1990 (sponsored jointly by ANL, FNAL, and SSC). Based on experience gained at these workshops, the proposed program concentrates on the interface of theory and experiment and on tasks which demand varying degrees of collaborative efforts to supplement traditional uncoordinated individual endeavors. It also emphasizes cross-fertilization between the triad of theorists- phenomenologists-experimentalists centered around a common theme of general interest to the entire high energy community.

Members of the collaboration are already active participants in existing projects on quantitative QCD analysis and Standard Model phenomenology. The general goal of the collaboration is to pool the expertise and resources of its members to accomplish a set of common objectives that will contribute significantly to their individual projects and to the whole community. For example, one important component of the proposed projects – the global analysis of parton distributions – follows the pioneering work of the Duke-Owens, among others[1]; it will be built upon the on-going work of Jorge Morfin and Wu-Ki Tung[2] which grew out of previous collaborative work with John Collins and the 1988 Snowmass Workgroup on Structure Functions and Parton Distributions.[3] Further progress is going to be based on progress made at the recent (1990) Snowmass Workshop,[4] and on the planned projects to be discussed below.

4. PROJECT DESCRIPTION

The projects are classified into two groups: Physics Projects and Pedagogical Projects.

A) Physics Projects:

A1) The Global Analysis and Timely Updating of The Universal Parton Distributions And Fragmentation Functions:

Reliable knowledge of parton distributions and fragmentation functions is essential for all quantitative calculations of high energy processes involving hadrons, ranging from the precision tests of the Standard Model to predictions of both the signals and backgrounds of New Physics. The widely used leading order parton distributions based on obsolete data of the early 1980's are no longer applicable.[5] The more recent next-to-leading order distribution functions[6][2] are still incomplete because: (i) existing high precision data on deep inelastic scattering (DIS) and lepton-pair production (DY) data are not sufficient to differentiate the various quark flavors, nor do they determine well the gluon distribution[5]; and (ii) although data from direct photon production, W- and Z- production, and other processes promise to improve the situation, much experimental and theoretical work is still needed to put these on the same footing as the DIS and DY processes. Considerably less is known about the fragmentation functions, which are important in understanding semi-inclusive processes. In addition, in order to increase our ability to make quantitative predictions for high energy processes at future colliders such as SSC, it is important to continuously expand the kinematic range over which the parton distribution functions and the fragmentation functions are determined, especially the small-x region.

On the theoretical side, this task depends on the consistent formulation of all physical processes which can contribute to the global analysis – with proper attention given to the uniform choice of renormalization scheme, to the uncertainties associated with the choice of renormalization and factorization scales, and to other theoretical uncertainties. This requires close contact with advances on a wide range of theoretical topics such as higher order calculations, summing of large logarithms, small-x physics, etc.

On the phenomenological front, this task requires the proper treatment of systematic errors and correlations inherent in the experimental data – both often neglected in earlier analyses. This, along with the wide range of physical processes covered by the global analysis, demand a great deal of computer resources as well as sophisticated fitting procedures (which still need to be developed).

It is obvious that this task has to be a long-range one; and that, if done properly, it will require much more man-power than what has been available so far. Progress on this endeavor will go hand in hand with advances on all the theoretical and experimental topics described in the rest of this proposal.

A2) The Formulation of Critical Tests of QCD:

Our current belief that QCD is the correct theory describing the strong interaction is based, so far, on the broad agreement between a wide range of experimental results and perturbative QCD predictions over several orders of magnitude of momentum transfers, rather than on some small number of definitive tests. With the advent of next-to-leading order (NLO) calculations for many measurable processes and significant improvements in the accuracy of measurements in fixed-target and collider experiments, stringent tests of perturbative QCD predictions should become possible. Indeed, one of the primary physics goals of the 1990's should be to formulate and to carry out these tests.

Because of the subtleties of NLO perturbative QCD predictions and the corresponding complexity of precision measurements, however, much more work is needed on both fronts to achieve this goal. This is especially true for collider experiments. A closer collaboration between theory and experiment is essential to ensure that any tests of QCD which seem useful at the parton level (where fundamental calculations are done) remain useful at the hadron level (where experimental measurements are actually made).

The quantitative comparison of theory and experiment in any given physical process can contribute to our physics goals in two ways: first, if sufficiently constrained theoretically and experimentally, it can serve as a test of QCD predictions; and secondly, if it passes the test, it can provide vital information on some combination of parton distributions over a particular (x, Q) range. Examples of processes that will do both and which will be the focus of much of our collaborative work are:

1) Inclusive Jet Cross Section At Colliders.

With the inclusion of $O(\alpha_s^3)$ corrections to the jet cross sections at colliders[7] the theoretical uncertainties have been greatly reduced and are now comparable to the experimental systematic uncertainties. The inclusion of $2 \rightarrow 3$ processes in the jet cross section also predicts for the first time a dependence of the jet cross section (at fixed transverse energy) on the transverse size of the jet used in determining the jet energy. This dependence, predicted by perturbative QCD, can serve as an important test of QCD. Both CDF and D0 are capable of doing this.

This also opens the possibility that, in the near future, the measurement of the jet cross section over an extended rapidity range can make a contribution to the determination of the parton distributions at very low x and very high x (and high momentum transfers). H. Weerts, with the help of W.K. Tung, will devote effort in the next year to investigate the sensitivity of measured jet-crossections at the collider to parameters of the input parton distributions, using the NLO hard-scattering calculation of Ellis-Kunszt-Soper[7] and NLO parton distributions which fit current data but with parameters varied within ranges allowed by these data. The spectrum of parton distributions needed in this type of investigation cannot be found in the "canned" ones in the published literature, but can be systematically extracted from the global fitting program of Morfin-Tung.[2]

2. Direct-photon Production (1 and 2 γ)

This process directly probes the gluon distribution in hadrons. Again NLO calculations of the cross section are available and experiments at fixed target energies (E706) and collider energies (CDF and D0) will soon produce new, high statistics experimental results. The combination of these results will cover the x-range from 0.01 to 0.5 if all experimental results can be used together. The extraction of the gluon distribution though will require the collaboration between phenomenologists and experimenters because of: 1) the effects of the cuts used to define the photon signal; and 2) contributions from bremsstrahlung process which vary from experiment to experiment. The careful study of this process, is a perfect example of something a collaboration like this could undertake. It would involve collaboration between many members from the start (definition of signal. calculation of backgrounds) to the end (including the results in parton distribution fits, thereby limiting the range of the gluon parameters).

The usefulness of the Direct-photon production process was demonstrated in an recent analysis[8] which compared the sensitivity of deep-inelastic lepton-nucleon scattering and direct photon production to the gluon distribution used. The conclusion was that joint fits to both processes were desirable. Another example is provided by a recent paper[9] on correlations in photon plus two-jet final states. There it was shown that it was possible to divide the events into three distinct types, each of which enhanced a particular class of Feynman diagrams. The distinctive predictions discussed therein should provide an interesting test of our understanding of the production dynamics for direct photons.

In order for direct photon production to be able to provide useful constraints on the gluon distribution, it is necessary to have the theoretical uncertainties reduced to the smallest possible level. During this past summer the situation concerning the use of photon isolation cuts has been clarified in several publications by members of this collaboration.[4] Basically, it has been shown that the use of such isolation cuts can be treated in a theoretically consistent manner and that the uncertainty introduced by the presence of a nonperturbative fragmentation component is thereby reduced.

For direct photon production the last remaining hurdle is how best to incorporate existing programs into the proposed parton distribution function analysis. There exists one program[10] for the single photon inclusive cross section, but it can not incorporate the isolation cuts in the manner employed by recent experiments. There exists another program[11] where the integrations are done via Monte Carlo methods and where the isolation cut is handled correctly. However, being based on Monte Carlo techniques, it is not suitable for the current type of fitting program. More work needs to done on resolving this problem.

With regards to two-photon cross sections, a next-to-leading- logarithm program[12] exists for the inclusive cross section, but it can not accommodate the isolation cuts used in current experiments. J. Owens and his collaborators are currently working on a program which will treat this process using the Monte Carlo techniques mentioned above. Since the current collider experiments are obtaining two-photon data, we feel that this program will be of immediate use once it is completed.

On the experimental front, members of this collaboration are involved in the high-statistics fixed-target E706 experiment and in the D0 collider experiment. Close contact will also be maintained with the CDF collaboration on their direct-photon analysis. The event-simulation, data analysis, and comparison of experimental results with theory for this process is extremely computer intensive. J. Huston, in particular, plans to develop capabilities to do all these at MSU to complement the resources available at FNAL.

3) High Precision Deep Inelastic Scattering Studies

Two compelling tests of QCD within deep inelastic experiments are the evolution of structure functions with Q^2 at fixed x and the dependence of R (σ_L/σ_T) on x and Q^2.[13] The evolution of the parity violating structure function xF_3 (the nonsinglet structure function) is the simplest. It is free of the details of gluon densities or the knowledge of R and therefore provides the cleanest channel for testing the Q^2 evolution predicted by the theory. In particular, $\partial ln(xF_3)/\partial ln(Q^2)$ at a given x is directly proportional to the strong-coupling constant, $\alpha_S(Q^2)$, up to the reliably known integral of the splitting function. Perturbative QCD also predicts the absolute magnitude and shape of $R(x, Q^2)$ which can be tested in deep inelastic scattering experiments provided this quantity can be measured at reasonably high Q^2.[14] Precision measurements of R, viable in next generation DIS experiments at HERA and Fermilab will confront this theoretical prediction. This comparison can be made easier if theoretical or phenomenological methods of controlling higher twist effects can be developed. This is another area requiring cooperation between theorists and experimentalists in our collaboration.

4) Semi-inclusive Deep Inelastic Scattering (Single-particle Inclusive, Charm Production, etc.)

Semi-inclusive processes can yield specific information on parton distributions and fragmentation functions not available from total inclusive processes.[15] For example, the strange quark distribution inside the nucleon is traditionally inferred from data on charm production in deep inelastic scattering, according to the naive parton picture. However, closer examination of the QCD parton model reveals that the proper interpretation of the semi-inclusive data requires the application of the full next-to-leading order formalism, and that the gluons inside the nucleon can also make a substantial contribution.[16] As a result, all analyses of this type of data, old and new, need to be re-examined. This reassessment can have important consequences on precision Standard Model tests (see next subsection) as well as on many high energy applications of the QCD parton model. These topics will be carefully studied.

A3) Study of QCD Effects in the Precision Tests of the Electro-weak Sector of the Standard Model.

Among the most important programs in the present-day high energy research efforts is the precision measurements of the parameters of the electroweak theory. Foremost among them is the determination of the Weinberg Angle, the primordial mixing parameter of the precursors of the photon and the Z^0 particles. This parameter is presently determined most precisely in deep inelastic neutrino scattering, atomic parity violation, and the precise measurements of the W and Z bosons.

Unrelated in principle, but extremely important in practice is the influence of the imprecisely determined amount of the strange quark content of the nucleon. Complex kinematical circumstances make the precise determination of any quantity in neutrino scattering dependent upon highly correlated factors involving this quantity. Indeed, this issue is the limiting factor in the determination of the Weinberg Angle from neutrino- nucleon scattering.[17]

The only feasible means of measuring this quark parton density function is by an analysis of neutrino interactions in which there are two muons in the final state where the process is presumed to proceed through the intermediate production and decay of a heavy charmed meson. Progress both in the global determination of the parton distributions and in reliably deducing the Weinberg Angle from DIS depends on a satisfactory understanding of the mechanism for producing charmed quarks from light strange and down quarks. The first problem is of increasing importance at SSC because at the higher energies of that machine, the fraction of strange quarks in the nucleon will be more than at the present energies due to QCD evolution. The second problem is important in that the 21st century understanding of the Standard Model's success as a field theory will come from comparisons of experiments performed in the 1990's.

Until recently, the theoretical machinery was based entirely on the naive parton model and was inadequate for the precise extraction of the strange quark distribution. Recent work of Aivazis, Olness and Tung[16] now provides the theoretical basis for a NLO analysis. We propose to apply this more precise formalism to the experimental determination of the strange quark content – both by re-examining the existing data (Brock), and by studying the new CCFR data (Mishra). In particular, Brock is exploring extensive simulation of all past determinations of the strange sea as well as a modeling of the Weinberg Angle analyses. Our experiences in both the experimental and theoretical approaches is essential to a successful conclusion of this project. If the large NLO contributions found by the theoretical calculation[16] are translated into significantly different phenomenology as currently available, this will have a ripple effect throughout many high energy physics programs which depend on an accurate knowledge of the strange quark density.

A4) The Establishment of a Global Database:

The authors of [2] and [3] established a database for global analysis of parton distributions which contains *complete* information on data entries: *i.e.*, in addition to the central values and statistical errors, point-to-point systematic errors as well as correlation information, whenever available, are included. This is important, as shown recently,[18] that by neglecting experimental systematic errors the allowed range of the fitting variables is artificially and incorrectly constrained leading to global fit results that are incorrect both in central value and in error assignment. This database so far only includes major experiments on deep inelastic muon- and neutrino- scattering and Drell-Yan experiments; it must be expanded to include complete entries for other relevant processes such as direct photon, heavy flavor, W- Z-production cross- sections, and jet production results. The database will be maintained and updated by this collaboration and made available to the community at large.

It is also extremely important to determine and understand exactly what modifications and/or corrections have been performed on the raw data of each experiment so as to be able to correctly combine its results with those from other experiments on the same physical process. Significantly different treatments of data and application of very different "corrections" to the data among related experiments can often be found in the literature, yet these differences have also been routinely overlooked in many phenomenological analyses.[3] The existence of a systematically compiled and maintained database can help to alleviate incorrect use of existing data, thus avoid producing wrong results in phenomenological work.

A5) The Development of Sophisticated Fitting Techniques:

The global fits performed to extract the parton distribution functions will eventually involve thousands of data points from five or six different physical processes, each with statistical and systematic errors as well as correlation information. The number of free fit parameters, including relative normalizations, can easily number more than 20. With a statistically rigorous treatment of systematic errors. each of the fits could take 100 or more AMDAHL hours if done by the brute force method. To minimize the CPU time and effectively handle these large multiprocess fits, with their huge data samples and variable arrays, will require the implementation of sophisticated Maximum Likelihood techniques and extremely efficient software processors. Several of the collaboration members have had experience with these fits and are beginning to study the modifications necessary to confront the problems outlined above.

A6) Software Development for QCD and Electro-Weak (EW) Calculations

QCD and EW formulae beyond the leading order are often very complicated for many high energy processes. Although most existing NLO calculations have been implemented in numerical programs, three prevalent problems exist: (i) whereas the possibility for mistakes is very real due to the complexity of these results (as proved by several known cases where cross- checks have been made), for some processes, the widely used program(s) may not have been independently checked; (ii) the existing program(s) often are so computer-time consuming that it is totally impractical to use them in large-scale numerical calculations of the type needed in global fitting procedures; and (iii) the various available independently developed programs for different processes often use diverse conventions, formats, and techniques which make it difficult to pool them together to do global analysis.

Thus, the orderly progress in this field can be facilitated a great deal by taking stock on existing software programs on next- to-leading order QCD and Electro-weak calculations; and assessing possible plans to: (i) develop independent checks on the accuracy of these programs, (ii) standardize on conventions and formats, (iii) make serious efforts to improve the efficiency of the most time-consuming programs, and (iv) ultimately produce new self-consistent object-oriented modular programs to perform quantitative QCD calculations which can be systematically expanded. Members of this collaboration have developed many of the existing programs for QCD applications. It is possible to start a project to address these urgent needs.

A7) Identification and Completion of Relevant New Higher Order Calculations.

One of the many benefits of a collaboration such as the one being proposed is the increased degree of coordination which can be obtained amongst researchers located at different sites. Higher order calculations for standard model processes are complex and very time consuming. An important role for our collaboration will be to optimize the use of our resources by determining which calculations are most needed at a particular time and then arranging for teams of people to work on them. It is important to have a certain degree of redundancy in order to insure that the final results are correct, but too much duplication of effort is to be avoided.

A8) Resummation of Large Logarithms

Perturbative calculations are expansions in powers of a nominally small running coupling α_s. such calculations cease to be directly useful when there exists more than one large scale in a physical problem, since coefficients of the perturbation expansion typically behave like powers of the logarithm of ratios of the scales. Examples are: the small-x region in various processes (DIS, DY, etc.), the moderate to low transverse momentum region of W-, Z- and DY production. Methods to resum these large logarithms are necessary, and they provide an extension of the applicability of the perturbative qcd formalism to new kinematic ranges. For some processes, resummation methods already exist in the literature, notably for the transverse momentum distribution of vector boson production.[19]

A particularly important case, because of the large cross sections involved, is the small-x region. In general, this is where

$$\text{hadron scale} \ll \text{scale of hard scattering} \ll \text{total cm energy}.$$

bottom quark production at existing colliders and at the SSC or top quark production at the SSC are cases of this. J.C. Collins, in collaboration with R.K. Ellis, has embarked on a project to handle the small-x regime. The aim is to derive generalized factorization theorems that are valid both at small x and large x and to apply them phenomenologically. The results will allow one to include nonleading logarithmic corrections – i.e., higher order corrections in α_s – to allow the use of the full accuracy of the many existing calculations of higher order graphs.

Once a resummed result is obtained, it is also important to formulate practical and reliable implementation of it in the analysis of data. This has not been done in any serious fashion so far in QCD phenomenology.

G. Sterman has been examining a situation typified by the Drell- Yan cross section, where the hard scattering has logarithms of $1 - z$, where z is the ratio of the lepton pair mass squared to the overall partonic invariant mass squared. As such, z is usually integrated over a range of values, and predictions depend upon the detailed nature of the parton distributions involved. Moreover, for a large range of energies, the parton distributions themselves often favor values of z close to unity ("threshold"), that is, in a region where the finite corrections become large. This requires a resummation of such effects to all orders in perturbation theory. Such a resummation shows the importance of higher order corrections for certain tests of the theory. The other limit, z near zero ("semihard" region), also becomes important at very high energies; it is an important part of calculations the small-x region explained earlier.

There is thus a need for a systematic evaluation of the role of higher-order corrections in perturbative QCD. To achieve accurate predictions for jet and heavy quark production, even at high energy, it is crucial to formulate the resummation of threshold corrections in a manner that is applicable to a large set of processes, and to create a formalism which treats large corrections in both the threshold and semihard limits. The use of redefined parton distributions, not based directly on deeply inelastic scattering, should also be considered in this context.[20]

A9) Study of Higher-twist Effects

1) Theory:

Higher twist (HT) effects are by definition suppressed at very high energy. Nevertheless they can be important in high energy experiments[21] when the summation of higher order terms lead to formally nonconvergent perturbative corrections. As this example shows, nonleading twist is at the boundry of perturbative and nonperturbative regiemes. The exploration of the relationship between leading and nonleading twist in hadronic cross sections has only just begun. For example, an understanding of jet and particle transverse momenta is important as a testing ground for perturbative QCD. The experimentally observed A-dependence in such cross sections with nuclear targets has yet to receive the theoretical attention it deserves. It has been argued[22] that effects of this kind should be thought of as higher twist phenomena in the context of perturbative QCD, and progress on a systematic understanding of higher twist effects has been reported recently[23]. In deeply inelastic scattering, higher twist effects have been reformulated from the point of view of the parton model, by introducing multiple parton distributions.[24] Further work is necessary to extend this interpretation to hadron-hadron scattering, and to create a unified theoretical framework for both leading and nonleading behavior.

2) Phenomenology:

An impressive amount of DIS data from electron, muon, and neutrino experiments is available. When attempting to determine perturbative QCD parameters with DIS data, the maximal variation of the strong coupling constant with respect to the momentum transfer and thus the most sensitive region for its determination is at small Q^2 – precisely the region affected with the unknown HT contribution. Traditionally, one imposes a cut on Q^2 (or the square of the invariant hadronic mass) to eliminate the HT effect on evolution and determines the logarithmic slopes to determine $\alpha_S(Q^2)$, or equivalently Λ_{QCD}. Our study would now include the low-Q^2 data to *further constrain* the structure function evolution, and simultaneously *measure* the HT contribution. The structure function evolution then would adopt a form:

$$F_{phys}(x,Q) = F^{QCD}_{twist2}(x,Q)\left[1+\frac{\alpha(x)}{Q^2}\right],$$

where the term $\alpha(x)$ would quantify the HT contribution. The data will be divided into various x-bins, and the HT parameter $\alpha(x)$ would be determined in each bin. A high statistics neutrino experiment naturally lends itself to such a study, since the Q^2-range spans, for example in CCFR experiments: $1 \le Q^2 \le 700 GeV^2$. The BCDMS study[25] of HT contribution conducted with the evolution of $F_2(x,Q^2)$ using the combined SLAC data ($1 \le Q^2 \le 20 GeV^2$) and the BCDMS data ($25 \le Q^2 \le 200 GeV^2$) leads both to an improvement in Λ_{QCD}, and to the intriguing result that , for $x \le 0.4$, the contribution of HT is negligible down to Q^2 of the order of 1 GeV^2. However, it should be pointed out that the treatment of systematic errors, when combining two experiments, is non-trivial.

B) Pedagogical Projects:

A strong motivation for forming this collaboration is to help bridge the gap between theory and experiment which has developed in the past decade or more. Although the use of QCD permeates all of high energy physics, more must be done to educate experimental graduate students and postdocs in the basic theory so that they might carry out meaningful phenomenological analyses of the experimental results or understand their theoretical implications. At the same time, most theory students are trained in abstract theories far removed from the standard model, let alone experiments, hence are ill-equipped to work on phenomenological problems even when the opportunity arises. Three tasks of a pedagogical nature which will address this problem have been identified by the collaboration:

B1) Handbook on Quantitative QCD Phenomenology

The extensive literature on QCD (and EW) calculations on a wide range of high energy processes, although much needed for doing practical phenomenology, is often too diverse, too difficult and too confusing to digest and to use by practitioners of the QCD parton model. The non-trivial renormalization scheme and renormalization/factorization scale dependence of the hard-scattering cross-sections and the parton distributions beyond the leading order make it difficult for all but the experts to critically compare published results and to use them in a systematic and consistent manner in applications.

Of considerable value to the community would be a systematic and critical review of existing higher order QCD calculations and phenomenological application of these calculations, focusing on consistency and clarity of presentation, and aiming at making these results more readily accessible to phenomenologists and experimentalists. This will also serve as the basis for assessing the need of further work to resolve existing ambiguities and to initiate new calculations. (Cf. Section A7.)

B2) Summer School on Quantitative QCD Phenomenology and the Standard Model

We propose to organize and run a yearly summer school targeted to experimental graduate students and postdocs, but open to all physicists, that has a strong pedagogical emphasis on the phenomenology and calculational aspects of the Standard Model and their theoretical basis.

There are presently several summer schools that are designed to educate young experimentalists and theorists. However, they are either of a topical nature (i.e. emphasize the most currently fashionable topics) or deal with theory on a fundamental level, hence do not directly address the need which concerns us. We believe a low-browed approach, emphasizing the physics related to current experiments, is the best way to fill the gap described earlier. Our school would aim to help experimentalists to gain much better understanding of the physics behind what they are measuring on the one hand, and help theorists trained in formal theory to come into contact with real physical processes on the other. Some lectures on experimental analysis can also be useful to theorists in understanding the reliability of measured quantities, based on an evaluation of the statistical and systematic errors assigned to the measurement. The summer school would consist of a series of lectures spread over 1 - 2 weeks. These lectures would be given mainly, but not exclusively, by members of this collaboration. Students will be strongly encouraged to interact closely with the lecturers and the other students during the entire time of the school. In discussions with colleagues throughout the community we find there is general agreement that such a summer school is long overdue.

The location of the school has not yet been determined. The ideal location, while most students are currently located at Fermilab, would have it close enough to Fermilab so that travel costs would be minimal, but far enough away from the lab so that the lectures would have the undivided attention of the participants. Since travel support for graduate students and postdocs is usually difficult to obtain, we feel it essential to be able to offer partial financial support to those that need it. Our budget request for this school reflects this goal.

Several of the present collaboration members have experience in organizing conferences and summer studies. They would be considerably augmented by an offer of Fermilab to contribute the time and experience of their symposium/school organizers.

B3) Textbook on Perturbative QCD

There are already published a number of books and review articles on perturbative QCD. However, none of them, to our mind, are suitable for learning the subject from scratch, given only a knowledge of quantum field theory and of general elementary particle phenomenology. For the effective use of the SSC many perturbative QCD calculations are necessary, so physicists must be well acquainted with the methods of perturbative QCD.

To remedy this situation John Collins and Dave Soper are considering writing a textbook on the theory and application of perturbative QCD. We would treat not only the methods of perturbative QCD – as needed to perform calculations – but also the conceptual foundations. It is important that the book (or books) contain a large number of good problems.

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Budget Information Document (Page 1)

TEXAS NATIONAL RESEARCH LABORATORY COMMISSION

Research and Development Program First Year Consortium Budget

(See Reverse for Definitions and Instructions)

Please Print or Type

ORGANIZATION: Illinois Institute of Technology

PRINCIPAL INVESTIGATOR (P.I.) / PROJECT DIRECTOR (P.D.): Wu-Ki Tung

PERIOD COVERING
FROM: 1/1/91
TO: 12/31/91

FOR COMMISSION USE ONLY
PROPOSAL NO:
AWARD NO:

A. SENIOR PERSONNEL: PI/PD, FACULTY AND OTHER SENIOR ASSOCIATES	FUNDED PERSON-MOS	FUNDS REQUESTED BY APPLICANT
1. See Budget Detail for each		$ -
2. Member fo the Consortium		
3.		
4.		
5.		
6. ( ) TOTAL SENIOR PERSONNEL		170,277
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)		131,301
1. ( ) POST DOCTORAL ASSOCIATES		
2. ( ) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)		
3. ( ) GRADUATE STUDENTS		
4. ( ) UNDERGRADUATE STUDENTS		
5. ( ) SECRETARIAL-CLERICAL		
6. ( ) OTHER		
TOTAL SALARIES AND WAGES (A + B)		301,578
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)		43,964
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)		345,542
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM ON SEPARATE PAGE)		
TOTAL EQUIPMENT		124,100
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)		40,000
2. FOREIGN		
F. OTHER DIRECT COSTS		
1. MATERIALS AND SUPPLIES		
2. PUBLICATION COST/PAGE CHARGES		
3. CONSULTANT SERVICES		
4. COMPUTER (ADPE) SERVICES		
5. CONTRACTS AND SUBGRANTS		
6. OTHER		
TOTAL OTHER DIRECT COSTS		78,843
G. TOTAL DIRECT COSTS (A THROUGH F)		588,485
H. APPLICANT'S COST SHARING		136,457
I. TOTAL AMOUNT OF THIS REQUEST (ITEM G LESS ITEM H)		452,028

PI/PD TYPED NAME: Wu-Ki Tung, Project Director	DATE: 10/31/90
PI/PD SIGNATURE: Wu-Ki Tung	
INST. REP. TYPED NAME: Darsh T. Wasan, VP for Research & Technology	DATE: 10/31/90
INST. REP. SIGNATURE: D. T. Wasan	

BUDGET INFORM. ON DOCUMENT (PAGE 2)

Texas National Research Laboratory Commission

Research and Development Program

Summary By Budget Period* (Entire Consortium)
Please Print or Type

Categories	Budget Period 1	Budget Period 2	Budget Period 3	Budget Period 4	Budget Period 5	Budget Periods 1-5	Total Project Perio
A. Senior Personnel Totals	170,277	178,791	187,730	197,117	206,973	940,888	940,888
B. Other Personnel Totals	131,301	237,866	249,759	262,247	275,360	1,156,533	1,156,533
C. Fringe Benefit Totals	43,964	66,162	69,470	72,944	76,591	329,131	329,131
Total of A, B & C	345,542	482,819	506,959	532,308	558,924	2,426,552	2,426,552
D. Equipment	124,100	130,305	50,000	52,500	55,125	412,030	412,030
E. Travel 1. Domestic	40,000	42,000	44,100	46,305	48,620	221,025	221,025
2. Foreign							
F. Other Direct Costs	78,843	82,785	86,924	91,271	95,834	435,657	435,657
G. Total Direct Costs (Item A through Item F)	588,485	737,909	687,984	722,384	758,503	3,495,265	3,495,265
H. Applicant's Cost-Sharing	136,457	143,280	150,444	157,966	165,864	754,011	754,011
I. Total Amount of Request (Item G. Less Item H.)	452,028	594,629	537,541	564,418	592,639	2,741,255	2,741,255
Duration of Budget Period	1/1/91 Mo/Day/Yr to 12/31/91 Mo/Day/Yr	1/1/92 Mo/Day/Yr to 12/31/92 Mo/Day/Yr	1/1/93 Mo/Day/Yr to 12/31/93 Mo/Day/Yr	1/1/94 Mo/Day/Yr to 12/31/94 Mo/Day/Yr	1/1/95 Mo/Day/Yr to 12/31/95 Mo/Day/Yr	1/1/91 Mo/Day/Yr to 12/31/95 Mo/Day/Yr	1/1/91 Mo/Day/Yr to 12/31/95 Mo/Day/Yr

PI/PD TYPED NAME & SIGNATURE
Wu-Ki Tung, Project Director Wu-Ki Tung
DATE 10/31/90

INST. REP. TYPED NAME & SIGNATURE
Darsh T. Wasan, VP for Research & Technology D. T. Wasan
DATE [illegible]

EXPLANATION SHEET FOR 5-YEAR BUDGET

Year 1991: Sum of individual institution 1991 budget.

Year 1992: Inflationary increment of 1991 budget except for:

Other Personnel: Increase of 2 postdoc positions and 2 graduate students from the 1991 figues due to the late start in 1991.

Equipment : We anticipate purchasing a Silicon Graphics computer (or equivalent) for $120,000. The rest is maintainance and upgrading.

Year 1993: Inflationary increment of 1992 budget except for:

Equipment : Decrease in computer purchase. Only upgrades and the addition of a few workstations are anticipated.

Year 1994: Inflationary increment of 1993 budget.

Year 1995: Inflationary increment of 1994 budget.