Workshop Summary
Physics and Instrumentation with 6-12 GeV Beams at Jefferson Lab.

D. F. Geesaman
Argonne National Laboratory

August 14, 1998

1 Introduction

That we are we here today discussing the Physics and Instrumentation of experiments with 6-12 GeV at Jefferson Lab is, in large part, a measure of how well the physics program of the laboratory is flourishing. We have had a first look at the science we have been working for more than a decade to bring to fruition. We know a lot more now than in 1988: new experimental results, advances in theory and real progress in the accelerator capability that makes higher energy beams “only” a matter of money. The laboratory's success in demonstrating the high gradients of the superconducting cavities means higher beam energies can happen sooner rather than later.

To take advantage of the near-term evolutionary increases in accelerator energy, we have to plan now. A major proposal for new experimental equipment to the funding agencies in 1999 is unlikely to receive significant funding until FY2000, which makes completion in FY2002 the earliest reasonable time scale for large new upgrades. At the same time we want to develop an integrated strategy to create in a cost-effective manner the right experimental tools for the major accelerator upgrade to 12 GeV planned for 2003. At the end of my talk I will give one such strategy which would allow us to carry out each of the experimental examples I discuss.

Higher beam energies allow us to make both qualitative and quantitative changes in our physics reach. The qualitative changes are easy to enumerate:

- Extend convincingly into the deep inelastic regime.
- Attain sufficient cross section for meson photoproduction with polarized photon beams for 2 to 3 GeV mass mesons to carry out thorough searches to identify new particles.
- Cross charm production threshold at $\sim$ 8 GeV.

2 Deep Inelastic Scattering

Figure 1 shows the electron energy loss, ν, and electron four momentum transfer squared, Q^2, ranges for deep inelastic scattering accessible with 12 GeV beams. Experiments such as measurements of the polarized spin asymmetry of the neutron on polarized ${}^3\vec{H}e$ targets [1] can be extended to x values of 0.7 with small (.05) errors (See Figure 2). This is the physics of the valence quarks that people think they understand, but when pushed one realizes that the predictions of models vary wildly depending on how one breaks SU(6) symmetry. The present experimental results run out of steam at x of 0.4.

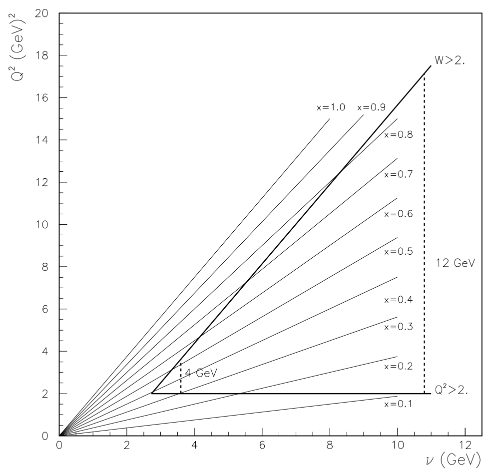

Figure 1: Kinematics regions in electron energy loss, ν, and electron four momentum transfer squared, Q^2, accessible with 4 and 12 GeV beams. The deep inelastic regions are the triangles defined by $Q^2 > 2$ GeV^2, $W > 2$ GeV and the scattered electron energy greater than 10% of the beam energy. The thin diagonal lines represent constant values of Bjorken x.

The high-x-low-to-medium-Q^2 of Jefferson Lab is ideal for probing other quark-gluon correlation functions by measurements of the higher-twist contributions to the structure functions (expansion in powers of $1/Q^2$ of the deep inelastic structure functions). The first correction to the inclusive structure functions comes at twist 4 ($1/Q^2$). One should remember that phenomenological analyses [2] of the F_2 structure function suggest that at x of 0.8 the twist four contribution is approximately twice the leading order twist two contribution at $Q^2 = 1$ GeV^2. In the case of polarized structure functions, twist three terms ($1/Q$) can contribute. Again the ${}^3\vec{H}e$ polarized spin structure function experiment provides an excellent example because the g_2 transverse spin structure function has a twist 2 contribution which can be calculated from the g_1 distribution and one is left with the twist three (1/Q) contributions. Extracting the higher twist contributions is most naturally done in considering

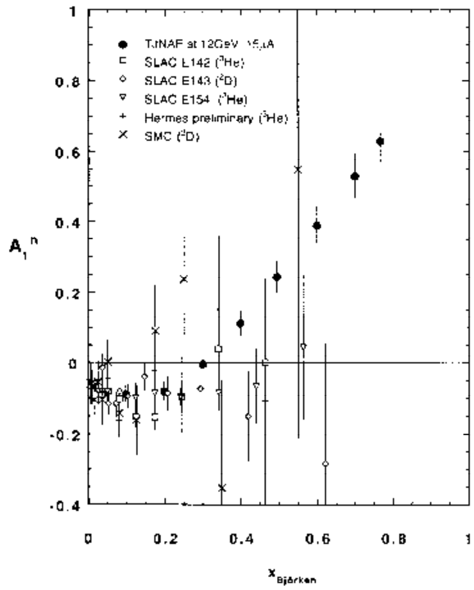

Figure 2: The polarized neutron asymmetry obtained in the deep inelastic scattering of polarized electrons from polarized ^{3}He. The solid points illustrate the quality of measurements that could be made with a 12 GeV electron beam at Jefferson Lab [1].

the moments of the structure functions, and the higher x moments are rapidly dominated by the valence quark region.

3 Hadron Spectroscopy

If one looks at the detector complement at JLAB, the CLAS is ideal for baryon spectroscopy. With higher energies comes a new opportunity for meson spectroscopy. To obtain intense polarized beams with sufficient energy to probe meson masses up to 3 GeV requires a 12 GeV electron beam. What is particularly exciting is that calculations, for example those of Afanasev and Page [3], indicate the cross sections for photo-production of meson states with exotic quantum numbers (quantum numbers not allowed for a pure $q\bar{q}$ pair) are large. The physics explanation at the cartoon level is that the low-lying exotics tend to have the quarks in relative spin one states, so there is a major advantage to starting with a spin one object compared to a spin zero object such as a psuedoscalar meson.

The experimental facilities needed to carry out this program, to do the partial wave analysis to identify the expected but to-date-missing quark-antiquark states and to find states with exotic quantum numbers, is a polarized photon beam and a hermetic detector with extremely well understood acceptance. Several workshops have taken place in the past year to identify the right experimental equipment and have led to the proposal for a new experimental hall, Hall D. Alex Dzeriba and rest of the Hall D collaboration demonstrate in their presentations [4] that they understand the care and precision needed for this task to provide convincing evidence for new meson states that the world will believe.

In 1994 at a workshop in Brookhaven National Laboratory, Nick Samios asked, "Where should I put my money to see an exotic in my lifetime? Accelerators? Detectors? Where?". From the audience I cried out "Medical Technology, so you will live longer." Knowing what I know now, today I would answer, "Plane tickets to Jefferson Lab."

4 Exclusive Reactions

The quantitative changes in our physics reach are equally important as we continue to search for failures in our standard model of nuclear physics. The prototypical reactions which stretch our understanding of coherent QCD phenomena to the shortest distance scales are exclusive reactions. In JLAB E91-26, Makis Petratos and his collaborators [5] have pushed measurements of elastic scattering from the deuteron to momentum transfers of almost 6 GeV^2 corresponding to distance scales of less than 0.1 fm. Figure 3 presents their preliminary results for the combination of deuteron form factors usually denoted as $A(Q^2)$. Surprisingly, hadronic calculations can account for the data quite well (though there is no shortage of name-brand hadronic models that fail to describe the data). However $Q^{20}A(Q^2)$, which is the quantity plotted in Figure 3 appears to have reached the scaling plateau expected from the constituent counting rules. The new JLAB data of Roy Holt and his collaborators on the $d(\gamma,p)n$ and $d(\gamma,d)\pi^0$ reactions have taught us the fragility of conclusions based on assumed approaches to scaling [6, 7]. With 10 GeV beams one can extend these elastic scattering results to momentum transfers of 8 GeV^2. Figure 4 shows what could be done on the ^{4}He elastic form factors with higher energy beams.

5 Generalized Parton Distributions

I am especially enthusiastic about physics where I see important theoretical advances that give the experimenters a much more focused aim at the important issues. In this workshop, non-forward-parton-distributions have repeatedly rose to the front, particularly in discussions of virtual Compton scattering [8] and vector meson production [9, 10]. Exclusive reactions like these are amenable to perturbative QCD treatment once we understand the right place to factorize the perturbative physics from the presently uncalculable non-perturbative, but process-independent physics. It is this separation in deep-inelastic scattering that make parton distributions such an important quantity to measure. Non-forward-parton-distributions are a major generalization of the parton distribution concept to unequal parton momenta in the initial and final verticies of the "hand-bag" diagram that serves as the basis for our theoretical picture.

For the theoretically simplest non-forward process, Virtual Compton Scattering (VCS), there is a minor experimental issue; the diagram you wish to study interferes with a QED Bethe-Heitler diagram which is usually much larger. But with the polarized beams of Jef-

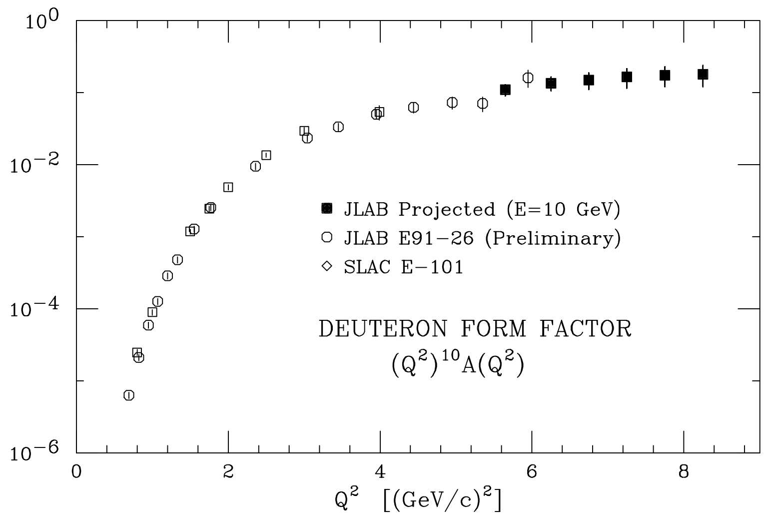

Figure 3: Preliminary JLAB results for the Deuteron elastic form factor $A(Q^2)$ from E91-26 compared to previous SLAC results. The solid boxes show the quality of measurements that could be made with a 10 GeV electron beam at Jefferson Lab [5].

ferson Lab, this is not a problem, this is an amplifier to make the VCS signal larger. The idea is to use the so-called "fifth structure function" with polarized beam. The experimental asymmetry is

$$A \propto Im\left(\frac{2VCS^{*}BH + BH^{*}BH)}{|BH|^2}\right)$$

and since the Bethe-Heitler amplitude is purely real, the asymmetry measures Im(VCS/BH).

6 Hadrons in the Nuclear Medium

If we can convincing show that our standard model of nuclear physics has deficiencies and that hadronic properties and interactions change inside the nucleus, we will have made what I consider to be the most important paradigm shift in nuclear physics since the observation of the EMC effect. Tony Thomas illustrated the progress [11] in consistent calculations of nucleon and nuclear properties at the quark level. My prejudice is that comparing results at the hadron and parton levels is the litmus test for theories of nuclei. That is why I firmly believe that Jefferson Lab is the most important facility for our field. Even in the first experiment to run at JLAB [12], our (e,e'p) measurements in Hall C, we are able to use the Q^2 dependence of the results to set tight levels on possible modifications of the nucleon form factors in nuclei. If you interpret our results as limits on the allowable change of the parameterization of a dipole form of the proton magnetic form factor in the nucleus, our data would imply that the proton magnetic radius has decreased by 5 ± 2% on average in

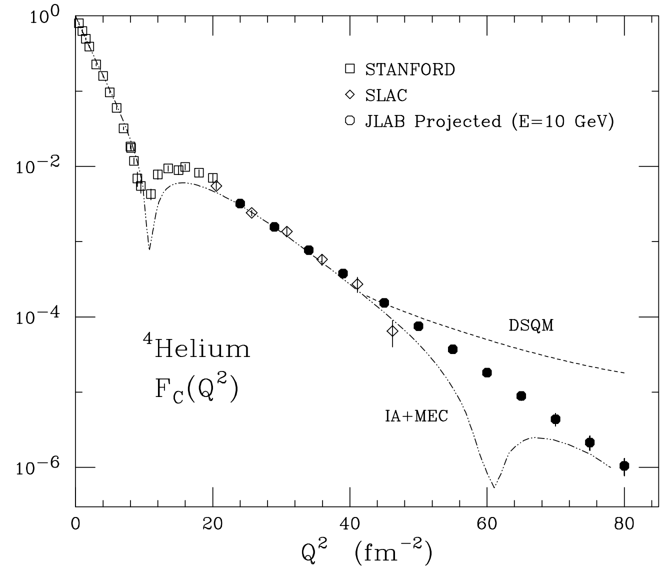

Figure 4: Current data on the ^{4}He elastic form factor $A(Q^2)$ from Stanford and SLAC. The solid dots show the quality of measurements that could be made with a 10 GeV electron beam at Jefferson Lab [5].

C, Fe and Au. There are several assumptions one should question before accepting this as the final answer, but the sensitivity to hadron structure in the nucleus is clearly there.

At higher energies we can extend these measurements to momentum transfers of 17 GeV^2, almost a factor of 3 from our current results (See Figure 5). Here we have the kinematic range and the precision to firmly ground the expectation of color transparency in exclusive reactions. This use of the nuclear medium as a ruler to determine length scales which characterize the strong interaction dynamics provides a complementary tool to unravel the mechanism of exclusive reactions to the high Q^2 exclusive results discussed above.

7 Experimental Equipment Concepts

From the discussions leading up to the workshop and the presentations here, a possible strategy for advanced instrumentation has emerged. At present this includes:

- Evolutionary detector upgrades in Halls A and B.

  Do not read evolutionary as "minor" or "cheap". Some real advances in physics require powerful new instrumentation. What this means is that the primary equipment in Hall A may likely continue to be the two high resolution spectrometers and the primary equipment in Hall B will continue to be CLAS.

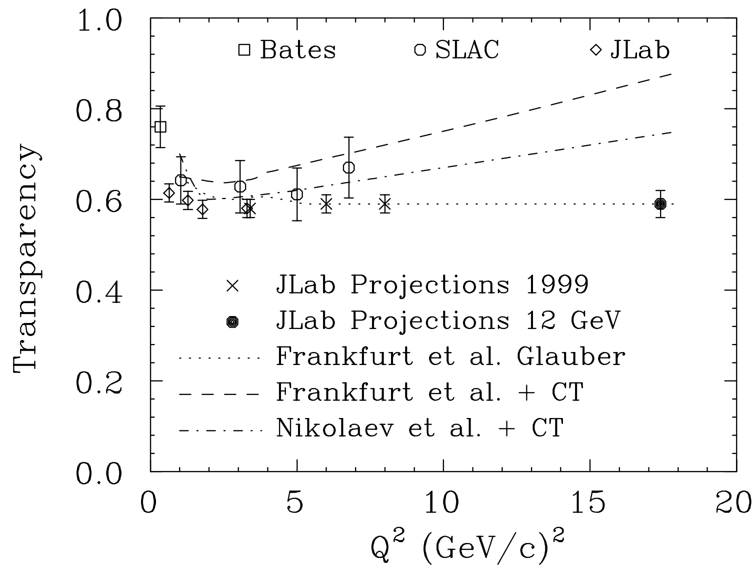

Figure 5: Nuclear Transparency defined as $\sigma_{exp}/\sigma_{PWIA}$ for protons in the $C(e,e'p)$ reaction. The dotted line is the result of a Glauber calcuation and the dashed and dot-dashed lines are two predictions of the effects on the Glauber calculation of color transparency. The solid point shows the quality of measurements that could be made at higher Q^2 with a 12 GeV electron beam at Jefferson Lab.

- A 12 GeV Super High Momentum Spectrometer (SHMS) in Hall C to provide a high energy coincidence pair in conjunction with the existing 8 GeV HMS spectrometer.
- A new experimental hall for high energy photon beams, Hall D, with a hermetic detector optimized for meson spectroscopy.

I want to emphasize that this is just a snapshot of one approach in the current thinking and by no means should be considered a settled issue. To me, this approach does make sense. All of the physics I have discussed here can be addressed with this experimental equipment. It appears consistent with the 40 Million dollar estimate of the cost of new base equipment that is included in the price tag of the 12 GeV upgrade. It capitalizes on our current investment and indeed shows the wisdom of the original equipment choices as they retain their value at the higher energy. It also emphasizes the importance of running simultaneously at three different energies which is one of CEBAF's most powerful features. We cannot forget that there are important experiments at lower energies required to complement the higher energy experiments. For example in conjunction with the higher momentum transfer measurements of the $A(Q^2)$ deuteron form factor, we want to push the magnetic form factor squared of the deuteron, $B(Q^2)$, to as high a momentum transfer as possible. Projected results [5] show that the ratio of the $B(Q^2)$ to $A(Q^2)$ can be extended to Q^2 of 6 GeV^2 by backward angle measurements in Hall A with $\sim$ 2 GeV beam energies.

8 Instrumentation

The instrumentation sessions of the workshop left me drooling to think of what I could do with

- Position resolution of a few microns,
- Electromagnetic calorimeters which resolutions of $\frac{2\%}{\sqrt{E}} + 0.5\%$,
- Low masses vertex trackers,
- Complete π, K and p separation in one device.

What I took away from these sessions is that we may not have been bold enough yet in pushing the limits of the technology, certainly not on a five year time scale. But I will bet after hearing these ideas here, a number of you soon will be. That is why I expect the final instrumentation plans for higher energy to continue to evolve. Some of these ideas will make new physics accessible in the nearer term, before the major energy upgrade.

9 Summary

That should be your marching orders. Your mission, and I know you will accept it, is to turn these ideas into the scientific and instrumentation proposals that will make this physics happen at Jefferson Lab and bear the standard for nuclear physics in the next decade. I thank you all for an exciting conference and lots of wonderful physics.

10 Acknowledgments

The organizers of this workshop, Steve Dytman, Phil Roos and Howard Fenker, did a wonderful job assembling a stimulating cast of charactors, stage managing a fertile environment, and in every way creating a workshop in which it was a joy to participate. The Users would like to express their heartfelt thanks. The conference staff, Greg Adams, Mary Dickinson, Kari Heffner, Karen Hokansson, Shauna Keffell, Samina Khawaja, Nga Pham, Lori Powell, Gladys Smith, Kimberly Thomas and Shannan Walsh of the User Liaison Office, Ruth Bizot, Marty Hightower and Cynthia Sloane of Conference Services and Judy Myrick of the University of Maryland provided the set, the props, the ticket takers and the "roadies" that made it all come together. As a member of the audience, and a member of the cast, I would like to express all our appreciation for their essential contributions to the workshop.

This work is support by the U.S. Department of Energy under Contract W-31-109-Eng-38.

References

[1] Z. Meziani, Contribution to this Workshop.

[2] M. Virchaux and Alain Milsztajn, Phys. Lett. B**274**, 221 (1992)

[3] A. Afanasev and P. R. Page, JLAB Preprint JLAB-THY-9746, (1998)

[4] A. R. Dzierba, Contribution to this Workshop. See also the Eight+ Working Group Website: http://dustbunny.physics.indiana.edu/∼dzierba/Eightplus/

[5] M. Petratos, Contribution to this Workshop.

[6] JLAB E89-12 Collaboration, C. W. Bochna et al., to be published.

[7] JLAB E89-12 Collaboration, D. Meekins et al., to be published.

[8] X. Ji, Phys. Rev. Lett. **78** 610 (1997); A. V. Radyushkin, Phys. Lett. B **380**, 417 (1996).

[9] M. Vanderhaeghen, P. A. M. Guichon and M. Guidal, Phys. Rev. Lett. **80**, 5064 (1998).

[10] J. Collins, L. Frankfurt and M. Strikman, Phys. Rev. D **56**, 2982 (1997)

[11] A. Thomas, Contribution to this Workshop.

[12] D. Abbott et al. Phys. Rev. Lett. **80**, 5072 (1998)