PROCEEDINGS OF SCIENCE

Issues in Hadronic Physics*

A. H. Mueller†‡
Department of Physics Columbia University New York, NY 10027, USA
E-mail: amh@phys.columbia.edu

Highlights from DIS-2014 are covered. A personal view of the status and prospect for hadronic physics is given.

XXII. International Workshop on Deep-Inelastic Scattering and Related Subjects,
28 April - 2 May 2014
Warsaw, Poland

*Summary talk given at DIS 2014, Warsaw, April 28 – May 2, 2014
†Speaker.
‡This work is supported in part by the US Department of Energy.

© Copyright owned by the author(s) under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike Licence.

PoS(DIS2014)011

1. Introduction

This talk is an attempt to summarize the issues dominating current QCD and hadronic physics. The plenary talks at this conference have already done this rather well. Here I will not try to cover all the interesting work which is going on, both theoretical and experimental, but instead attempt to touch on the main themes covered by this work. This will be a personal summary in that I will focus on themes that I feel are important for the field and where I believe (hope) progress can be made in the not too far future.

The field is currently very rich in both experimental and theoretical activities on an extremely broad set of topics. There are at the same time straightforward, but interesting, calculations and measurements to be done as well as puzzles and mysteries to be understood and resolved.

Finally this is a talk, as close to the actual talk given at DIS–14 as I can do, not a review. Thus I will not try to be complete or give a long list of references.

2. Proton Structure

What are we looking for in proton structure studies? A precise and detailed description of the proton's wave function is terms of quarks and gluons, the fundamental dynamical variables of QCD.

Deep inelastic lepton-proton scattering (DIS) [1] gives quark and gluon densities, $xq(x,Q^2)$ and $xG(x,Q^2)$, in the proton as a function of the fraction of the proton's momentum carried by the quark or gluon, x, and the scale, Q, at which the quark or gluon can be viewed as point-like. However, DIS structure functions carry no information on the spatial distribution of partons, quarks and gluons, in the proton. The transverse spatial distribution of valence quarks in the proton will come from deeply virtual Compton scattering (DVCS) experiments with the 12 Gev beam at the Jefferson laboratory and from the COMPASS experiment at CERN. Determination of the spatial distribution of sea quarks and gluons in the proton will require a higher energy electron machine like the proposed electron ion collider (EIC) [2].

2.1 Spin

Experiments studying how the spin of the proton is distributed among quark spin, gluon spin, quark orbital angular momentum and gluon angular momentum have been going on for quite some time and steady, if slow, progress is being made [3]. Currently it is believed that quark spin makes up about 30 to 40 percent of the proton's spin with gluon spin about half that amount, although the gluon spin determinations still have very large uncertainties. Suppose these values are about right. Then quark and gluon orbital angular momentum would be expected to make up the other half of the proton's spin. This all seems very reasonable. So why has there been so much intense discussion about this over the past 25 or so years? I think the reason is two fold. First, although the above apportionment of the proton's spin is not very radical it is difficult to accommodate in the constituent quark model and, secondly, the original EMC results gave a much more radical sharing of the proton's spin.

The constituent quark model identifies all the proton's spin as carried by constituent, not partonic, quarks. The constituent quark model very well gives the counting and structure of baryon

PoS(DIS2014)011

and meson spectra. It also gives very good answers for baryon magnetic moments and for the weak decay constant, G_A. It is natural for it to also describe the $SU(3)$ flavor singlet counterpart of G_A which is $\Delta u+\Delta d+\Delta s$, the part of the proton's spin carried by quark spin. There are relativistic corrections which modify constituent quark model predictions. One way to estimate them is to compare the experimental value of G_A which is about 1.25 with the quark model prediction, $5/3$. This would suggest a downward correction to the quark model predictions of about a third could be expected from relativistic corrections and so one might expect $\Delta u+\Delta d+\Delta s$ in the range of 0.6 to 0.7. The current experimental result is about half that amount and so it seems the quark model does not work very well for the proton's spin. It should be emphasized that there is nothing fundamentally wrong here. The quantities Δu, Δd and Δs refer to partonic (bare) quarks and not to constituent quarks. However, in G_A, and in magnetic moment comparisons, one identifies bare and constituent quarks for these static quantities so it seems we have to conclude that the constituent quark model does not work very well for the flavor singlet part of the axial vector current matrix element of the proton, that is for the proton's spin.

The original EMC experiment lead to an even stronger and more radical conclusion, that strange quark spin was about (negative) twenty percent of the proton's spin but that the sum $\Delta u+\Delta d+\Delta s$ was near zero. This was indeed radical. The constituent quark model failed completely and more surprisingly, it suggested that one could not understand proton structure without taking strange quarks into account. It is this latter issue, strange quarks in the proton that I now want to discuss in some detail.

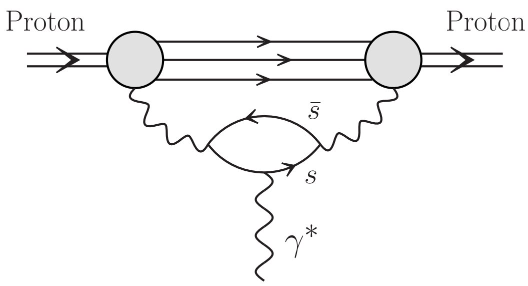

Figure 1: DIS.

We know there are about half as many strange quarks in the protons sea as there are up and down quarks [4]. However, the important issue is not how many quarks of a given flavor are in the sea but whether they have anything to do with the structure of the proton. To illustrate the issue here note that at a sufficiently large scale of hardness the charm sea becomes quite large. But no one really believes charm quarks are necessary to describe static, or quasistatic, properties of the proton. The charm-anticharm pairs are very short time fluctuations in the proton. They do not live long enough, nor are they distinct enough from the gluon from which they came, to interact with the longer lived parts of the proton and so they cannot contribute to such static quantities as mass, magnetic moment or spin of the proton. What about the strange quark? While Δs values have come down very much from the original EMC numbers there is no general agreement at present as to how small Δs actually is. However, the HAPPEX experiment [5] at the Jefferson Laboratory has given strong evidence that strange quarks play little role in proton structure. HAPPEX measures

PoS(DIS2014)011

the strange contribution to the electromagnetic form factor of the proton and find no contribution at all. This does not mean there are no strange quarks in the proton, but it does suggest that the spatial distribution of strange quarks is identical to that of strange antiquarks thus allowing them to cancel in their electromagnetic form factor contribution. This is indicated in Fig. 1 where a gluon splits into an $s\bar{s}$ pair which, during its lifetime, does not interact with the rest of the proton. An electromagnetic current will couple in an identical way to the s and $\bar{s}$, except for a sign change, leading to cancelling contributions. This cancellation would not happen if the s and $\bar{s}$ interact, in different ways, with the rest of the proton. This strongly indicates that as new data emerge and analyses become better one will find that $\Delta s \simeq 0$ and that will, I think, be the very end of the "spin crisis". In time, lattice gauge theory calculations should also be able to determine the size of strange quark effects on proton structure. I conclude that HAPPEX already gives strong evidence that the proton, and presumably non strange mesons, would change very little if strange quarks were removed from QCD. Their presence in the proton appears to be merely as spectators to the up and down quarks and gluons which determine the proton's structure.

2.2 DIS vs DVCS vs form factors

Let me now turn to determining the spatial distribution of partons, quarks and gluons, in the proton. First a bit of theory. Partons are only clearly visible (manifest) in a calculation in QCD when using light cone gauge or using other "physical" gauges, such as Coulomb gauge, in a frame where the proton momentum is very large, that is in an infinite momentum frame. This gives a peculiarity in the way in which we are able to describe the spatial distribution of partons in a proton. Partons can be assigned a transverse position in the proton but they cannot be given distinct longitudinal positions. That is, there is only one layer of partons in the longitudinal direction. It seems most efficient in describing spatial parton distributions to use a mixed representation, that is to label a quark or gluon by a longitudinal momentum (or a longitudinal momentum function of the proton's momentum) and a transverse coordinate. The transverse "size" of the parton is determined by the hardness of the reaction being used so that if the hardness scale is much less than a fermi the parton can be assigned a fairly precise position in the proton. Using the longitudinal momentum fraction as the other variable acknowledges the lack of relative longitudinal position of partons in the proton as well as making contact with a standard variable used in DIS experiments.

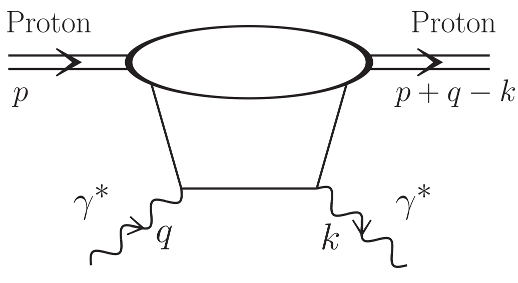

Figure 2: DVCS.

The basic DVCS process is shown in Fig. 2. It differs from DIS in several aspects. First the outgoing photon is real. Secondly, one is interested in the amplitude $\gamma^* + \text{proton} \to \gamma + \text{proton}$ is DVCS while the DIS process $\gamma^* + \text{proton} \to \text{anything}$ is related to $\gamma^* + \text{proton} \to \gamma^* + \text{proton}$

PoS(DIS2014)011

through the optical theorem. In DIS the forward virtual photon plus proton goes to virtual photon plus proton amplitude is a theoretical tool; it is not measured. What is measured in DIS is that the γ^*, coming from an electron scattering, interacts inelastically with the proton. In DVCS, on the contrary, the process is elastic. This allows a momentum transfer, $\Delta_\perp$, between the initial and final protons to be measured. It is the Fourier transform with respect to $\Delta_\perp$ that allows one to determine the transverse position $x_\perp$, conjugate to $\Delta_\perp$, of the struck quark to be measured.

We have seen a little earlier that form factors also give information on the spatial distributions of quarks in the proton. Indeed, the early elastic electron-proton scattering experiments by Hofstadter gave significant information on the charge distribution in the proton, and as we have seen, the HAPPEX experiment has given crucial information on the distribution of charge carried by strange quarks (or antiquarks) in the proton. What is the advantage of DVCS experiments over elastic form factor measurements? In DVCS experiments one can fix the Q^2 of the initial virtual photon to be large enough to be a good point like probe and fix the momentum fraction of the struck quark also to have a particular value x. Then at fixed x and Q^2 different momentum transfers $\Delta_\perp$ can be measured. A Fourier transform, converting $\Delta_\perp$ to $x_\perp$, then gives the transverse spatial distribution of quarks, at a given x and with a spatial resolution $\Delta x_\perp \sim 1/Q$. In elastic form factors, on the other hand, the hardness of the reaction and the momentum transfer are not independent variables. Form factors contain useful information, but they do not have the flexibility of DVCS measurements. The upcoming programs at COMPASS and at Jlab promise to be very interesting and should give a good picture of the transverse spatial distributions of the up and down valence quarks in the proton. For a spatial imaging of the gluon and sea quarks an EIC will be necessary to probe the moderately small x regime of partons.

3. Higher order calculations and event generators

Recent years have seen remarkable technical progress in learning how to do more precise higher order calculations and how to put these higher order calculations [6] into event generators [7] . Much of this work has been driven by the desire to be able to do precise Higgs measurements in a hadronic collider context. At the moment NLO calculations have been successfully merged with parton showers and there is current work toward NNLO calculations and even attempts to do estimates for N^{3}LO effects. The details of recent progress is summarized in the plenary talks of D. De Florian and L. Lonnblad.

4. Heavy ion physics

Heavy ion collisions, along with the related areas of proton and deuteron-ion collisions, is rich with data and with theoretical activity [8].

On the experimental side the flow of heavy flavor is still mysterious. In particular the elliptic flow of D-mesons appears comparable to that of light mesons and it is very hard to understand how enough momentum can be transferred from the medium to make a heavy particle like the D have the same velocity as the lighter particles of the QGP-fluid. In particular for very heavy flavors this certainly cannot happen. So it seems, as far as the QGP is concerned, charm particles act more like light hadrons than like truly heavy particles.

PoS(DIS2014)011

Another exciting phenomenon which is being actively studied experimentally is the apparent similarity between A-A events, p-A events and even, for high multiplicity cuts, p-p collisions. In particular the flow seems similar in all these cases. While it may not be so surprising that there could be collective effects in p-A and even p-p collisions it is surprising that the flow patterns would be similar. In particular the system produced in a high multiplicity p-p collisions should begin to have a spherical expansion, and then rapidly fall apart on the same time scale as the collective effects set in. Anyway, this is very exciting stuff and it will be interesting to see how the experimental results evolve in time.

There seems to be a growing, but certainly not yet complete, consensus that the transport coefficient, $\hat{q}$, is not too far from perturbative estimates, $\hat{q} \simeq 1-2\,\mathrm{GeV}^2/\mathrm{fm}$ [9]. This conclusion comes from combined jet quenching studies at RHIC and at the LHC. This is perhaps not so incompatible with the QGP looking, in many respects, like a strongly coupled system. After all $\hat{q}$ is a local quantity, in space and time, evaluated at a scale which is typically much larger than the temperature T. It is hard to see how could be other than perturbative. I think the real task for theorists is to understand how microscopically perturbative physics can lead to large scale collective physics which appears to be strongly coupled.

In fact there is a lot of theoretical effort trying to understand large scale QGP physics starting from a perturbative, nonequilibrium but high occupancy initial condition, the type of initial condition corresponding to a gluon saturated heavy ion wave function (CGC). Two separate groups are trying to do numerical solutions of classical Yang-Mills field theory using initial conditions appropriate to those of a heavy ion collision with the ions wave functions given by McLerran-Venugopolan (MV) high occupancy initial conditions. Such initial conditions are probably very appropriate for RHIC while for heavy ion collisions at the LHC small-x evolved MV initial distributions would be more appropriate. In the Saclay calculation Epelbaum and Gelis [10] begin their numerical evaluation of the classical Yang-Mills equations immediately after the classical fields corresponding to the MV wave functions of the ions, which are highly Lorentz contracted, pass through each other. The passage of the Y-M fields through each other can be done in an analytic calculation to give the initial distribution for the classical evolution. After the numerical evolution of the Y-M equations are completed a Gaussian average over all possible MV initial conditions must be done. Remarkably the Epelbaum-Gelis calculation gives a pattern of longitudinal and transverse pressures which strongly resembles strong coupling calculations done in the AdS/CFT context.

The Heidelberg-Brookhaven [11] calculation, on the other hand, starts the numerical evolution at a later time, in order to avoid instability growths, and uses a weaker coupling than the Saclay calculation. The final results look very much like the “Bottom-up” picture of thermalization and strongly resemble perturbation theory. Apart from starting at a larger time the main difference in the Heidelberg-Brookhaven calculation is that they take initial field conditions which are not coherent over large regions of longitudinal momentum. Their belief is that at late times the evolution should lose knowledge of the precise initial conditions and reach a universal behavior.

I find both of these calculations very exciting and impressive, however, I believe one should view them as still exploratory and not yet try to compare them with real heavy ion phenomena. What I hope we will get out of these calculations is a general picture of how an initial highly occupied gluon system goes toward equilibrium and, indeed, how dependent the evolution is on the

PoS(DIS2014)011

precise forms of the initial conditions which are taken.

5. QCD perturbative evolutions

There are three different types of evolution in QCD, DGLAP (renormalization group) evolution, BFKL evolution and Collins, Soper, Sterman (CSS) or Sudakov evolution. In a given high energy process various, even all, of these types of evolution may come in. These three types of evolution are conceptually very different although there is a kinematic domain where DGLAP and BFKL evolution become the same in a certain approximation. Let me go over these different evolutions in turn then in the next section I will discuss the physics associated with BFKL evolution in more detail.

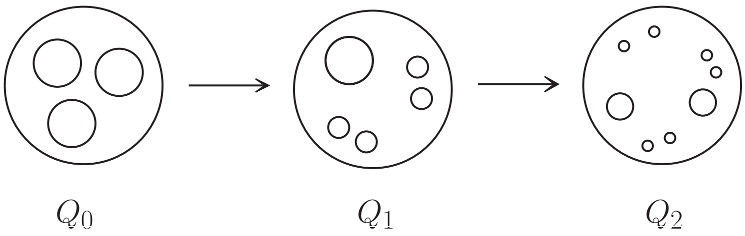

Figure 3: DGLAP.

DGLAP evolution is an evolution of a hard scale and so it is intimately connected with renormalization. It is perhaps useful to recall how DGLAP evolution appears in the quark distribution measured, say, in DIS. $q_f(x,Q^2)$ is the density, in the Bjorken-x variable, of quarks of flavor f measured with a transverse resolution $\Delta x_\perp \sim 1/Q$. Suppose we keep x fixed away from the small-x domain and increase Q^2. What happens? Increasing Q^2 sharpens the spatial resolution at which we measure quarks. Increasing Q^2, from Q_0^2 to Q_1^2 say, may show that what looked like a quark at Q_0^2 is actually a quark and a gluon or a quark along with an additional quark-antiquark pair when measured with resolution $\Delta x_\perp \sim 1/Q_1$. So long as $Q^2/\Lambda^2_{\rm QCD} \gg 1$ these changes are calculable perturbative in QCD. Thus as we sharpen the resolution scale of our measurement we normally find more quarks and gluons so that when Q^2 is very large there can be many quarks and gluons in the proton. However, despite the growing numbers of quarks and gluons in DGLAP evolution the partons in the proton are in fact becoming more dilute, that is the quantum occupancy in the proton's wave function is decreasing. Let me illustrate this by a concrete example. Suppose one starts with a single gluon at scale Q_0. The probability that the gluon is actually at least two gluon when viewed at a scale Q_1, is given by

$$\frac{\alpha_s N_c}{\pi} \ln \frac{Q_1^2}{Q_0^2}. \tag{5.1}$$

Thus in order to be reasonably sure that there are at least two gluons at scale Q_1^2 we must take Q_1 at least as big as

$$Q_1^2 = Q_0^2 e^{\pi/\alpha_s N_c}. \tag{5.2}$$

For $\alpha_s \simeq 0.4$ this means $Q_1^2/Q_0^2 \sim 15$. Since the area occupied by a gluon at scale Q is proportional to $1/Q^2$ we see that although an additional gluon has been "created" in going from Q_0^2 to Q_1^2 the

PoS(DIS2014)011

system has become more dilute, by a factor of 7, since the two new gluons occupy much less area than the original gluon. One often illustrates this pictorially as shown in Fig. 3. DGLAP evolution can be enhanced by using the longitudinal phase space for gluon emission when the emitted gluons are soft but this is the overlap region with BFKL which we shall come to shortly.

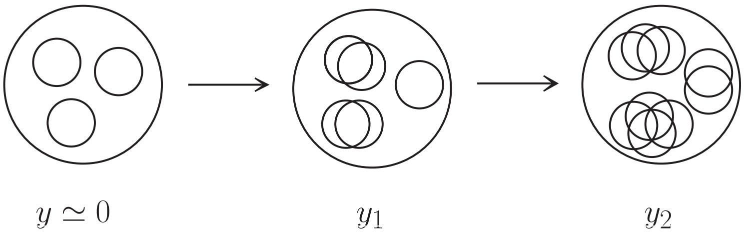

Figure 4: BFKL.

In contrast to DGLAP evolution BFKL evolution is essentially a single scale process as far as the size of partons are concerned. Suppose our measuring apparatus can only resolve time scales as small as t_0 with all time scales smaller than t_0 being averaged over in a smooth way. Scattering on a proton at rest is an example where the proton target only resolves scales greater than one fermi. Again, as in the DGLAP case begin with a single gluon as scale Q_0 and with rapidity on the order of one. If we now "boost" the gluon, give it a large rapidity, more of its fluctuations live longer than t_0 because of time dilatation. Thus as a parton, or hadron, gets higher and higher rapidity a growing number of fluctuations, that is of extra gluons, become visible at time scale t_0. An explicit calculation shows that in the leading logarithmic approximation

$$N_{\text{gluons}}(t_0, y) \propto e^{(\alpha_P - 1)y} \tag{5.3}$$

where $\alpha_P - 1 = 4\alpha_s N_c \ln 2/\pi$ is the BFKL intercept. There are large higher order corrections to this explicit formula so one should not take the exact values too seriously, but the *phenomenon* of BFKL evolution should be clear; a rapid growth of gluons with rapidity and all the gluons having a comparable transverse size. This is illustrated in Fig. 4. Finally, we note that if both the rapidity is increased and the scale of measurement, Q, is increased one gets an especially large increase in parton numbers. This is, the overlap region between BFKL and DGLAP evolution. However, in this double logarithmic region the system becomes more dilute unless the rate of increase in Q^2 is very slow compared to that in y in which case we are back to standard BFKL evolution.

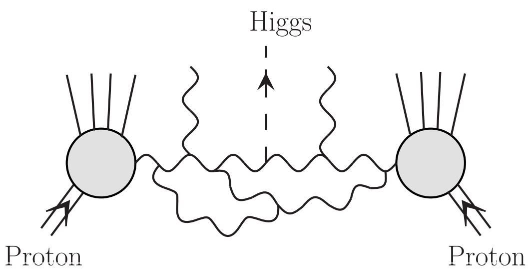

Figure 5: Higgs.

Finally, let's turn to CSS evolution or, equivalently, Sudakov effects. I think this phenomenon (evolution) can be best illustrated by the example of Higgs production illustrated in Fig. 5 where

PoS(DIS2014)011

two additional gluon emissions and two virtual gluons are illustrated in addition to the classic $g+g \to$ Higgs transition. If the measurement simply consists in verifying that a Higgs has been produced the extra gluons will cancel, a real-virtual cancellation, unless some of them are of a hardness compared to the Higgs mass in which case they correspond to higher order corrections to the hard scattering part. However, if one measures the transverse momentum of the Higgs to be $q_\perp$ then double logarithmic corrections of size $\alpha_s(M^2)\ln^2(M^2/q_\perp^2)$ emerge because of an incomplete real-virtual cancellation. As far as the leading double logs are concerned CSS evolution simply gives the standard exponentiation of the lowest order term. Subdominant terms, single logs, constants, etc. can be systematically evaluated. The Sudakov factors do not affect total production rates but simply transfer low transverse momentum production into a higher transverse momentum region. In particular the typical transverse momentum of the Higgs has been calculated by Jianwei Qiu to be $q_\perp \simeq 15\,\mathrm{GeV}$ [12], and this rather large value is due to CSS (Sudakov) evolution.

6. Small-x physics

In the last section I have reviewed the three different kinds of evolution which occur in high energy QCD, namely DGLAP, BFKL and Sudakov. DGLAP and Sudakov (CSS) evolution are easy to see and play prominent roles in the various domains of DIS and hard scattering. On the other hand BFKL evolution has not been definitively and directly seen. This conference had considerable discussion on trying to isolate BFKL effects [13]. A recent calculation by Ducloué, Szymanowski and Wallon [14] gets very good fits to the CMS azimuthal decorrelation data for Mueller-Navelet jets if BLM scale setting is used. On the other hand similar studies using event generators which are said to contain no BFKL evolution seem to get good fits also. It may be a little difficult to know exactly what physics goes into a well-tuned event generator. In addition to the many parameters that go into the tuning there are significant pieces of physics, for example on energy dependent "infrared" cutoff on momentum transfers, which *could* be connected with saturation but which would seem to have no place in a genuinely DGLAP based dynamics.

Why all the fuss? Why are we so interested in studying BFKL evolution? As I have discussed in some detail in the previous section it is only BFKL evolution which leads to high quantum occupancies and to a new nonlinear domain of QCD. The study of such high occupancy systems, when freed, is the domain of heavy ion physics. Indeed, the approach of such systems to equilibrium is the only laboratory where one can study relativistic nonequilibrium many body physics. The mechanism by which these high occupancy systems are created is BFKL evolution, at least at LHC energies. Thus it is natural to try to study BFKL evolution in the (relatively) simple proton-proton scattering environment.

Experimentally there are potentially many places to look for small-x physics at the LHC. As theorists we have to find more observables which make use of the exceptionally high energies at the LHC and at the same time sharply focus on the essential issues in small-x physics. Thus the real challenge for small-x physicists is to understand proton-proton and pA forward processes well enough to extract small-x quantities from things that can be measured.

PoS(DIS2014)011

7. The near future for hadron physics

There is quite a lot going on now at accelerator facilities around the world and for the next, say, ten years this should continue to be the case. The 12 GeV beam at the Jefferson Laboratory should begin operation in the next few years and with it data that should tell us the transverse spatial distribution of valence quarks in the proton. A competitive program will be carried out by the COMPASS collaboration at CERN. pp, pA and AA collisions will continue at CERN with very rich data for hadronic and heavy ion physics. As I have emphasized several times already I believe the real challenge here is to develop the theory to the point that we can take advantage of the extremely small x-values that are available in pp and pA collisions at the LHC. At Brookhaven we can look forward to a lot of new spin data using W's to resolve the spin of the quarks (and antiquarks) in the proton. RHIC should still have a pretty vigorous heavy ion program which will be complimentary to that of the LHC. All in all, datawise the next ten years or so should not suffer from lack of material.

8. The farther future

It is, of course, harder to see what will come beyond the next ten years. The hadronic physics community in the US is actively pursuing an electron-ion collider (EIC) which, if approved would likely end up either at the Jefferson Laboratory or at Brookhaven. With the new long range plan for nuclear physics just beginning in the US we likely will have a good indication in the next year of whether an EIC will be built. An EIC of the type being contemplated by Jlab and BNL would be an excellent facility for studying the spatial distribution of sea quarks and gluons. It would also go to small enough x to give definitive answers on the distribution of the proton's spin among quark and gluon spin and their angular momenta. It would also have x-values reasonably well matched to determine gluon distributions of large nuclei relevant for the central region of heavy ion collisions at the LHC. Diffractive vector meson production at an EIC, on both protons and nuclei, would be also quite interesting.

One hears rumors of the possibility of a very high energy collider which as a component would have electron-proton and electron-ion collisions far beyond the energies of the Jlab-BNL proposals. Wonderful if it should happen.

References

[1] For a historical review see the talk of J. Friedman at this conference.

[2] D. Boer, M. Diehl, R. Milner, R. Venugopalan, W. Vogelsang, D. Kaplan, H. Montgomery and S. Vigdor *et al.*, arXiv:1108.1713 [nucl-th].

[3] J. Qiu, plenary talk at this conference.

[4] K. Wichmann, plenary talk at this conference.

[5] Z. Ahmed *et al.* [HAPPEX Collaboration], Phys. Rev. Lett. **108**, 102001 (2012) [arXiv:1107.0913 [nucl-ex]].

[6] D. De Florian, plenary talk at this conference.

PoS(DIS2014)011

[7] L. Lonnblad, plenary talk at this conference.

[8] K. Grebieszkow, plenary talk at this conference.

[9] K. M. Burke, A. Buzzatti, N. Chang, C. Gale, M. Gyulassy, U. Heinz, S. Jeon and A. Majumder *et al.*, arXiv:1312.5003 [nucl-th].

[10] T. Epelbaum and F. Gelis, Phys. Rev. Lett. **111**, 232301 (2013) [arXiv:1307.2214 [hep-ph]].

[11] J. Berges, K. Boguslavski, S. Schlichting and R. Venugopalan, Phys. Rev. D **89**, 114007 (2014) [arXiv:1311.3005 [hep-ph]].

[12] E. L. Berger and J. -w. Qiu, Phys. Rev. D **67**, 034026 (2003) [hep-ph/0210135].

[13] The summary of working group 2 "small-x, diffraction and vector mesons" as well as the plenary talk of P. Van Mechelen at this conference.

[14] R. Ent, plenary talk at this conference.

PoS(DIS2014)011