Abstract. We review the compelling case for establishing a capability to accelerate positrons at Jefferson Lab. The potential applications range from the study of two-photon exchange and deeply-virtual Compton scattering to exploiting the charge current weak interaction to probe the flavor structure of hadrons and nuclei. There are also fascinating ideas for using such a capability to discover new physics beyond the Standard Model of nuclear and particle physics.

Keywords: positrons, QCD, deeply virtual Compton scattering, angular momentum, nuclear structure, dark matter
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INTRODUCTION

While there are really only a few reasons for tackling the difficult and expensive challenge of providing positron beams at a laboratory like Jefferson Lab, they are compelling. In important circumstances one can use the interference with single photon exchange to clearly isolate a particular piece of physics. Examples include the study of the two-photon exchange contribution to elastic scattering and the extraction of information on the generalized parton distributions (GPDs). The charge current processes, $(e^-; \nu_e)$ and $(e^+; \bar{\nu}_e)$, uniquely isolate either positively or negatively charged quarks, respectively, and can therefore provide important information on the flavor structure of nucleons and nuclei. Finally, there are a number of interesting possibilities, including $e^+e^-$ annihilation, which have the potential to reveal physics outside of that described within the Standard Model. We set the stage for the main presentations at the workshop by outlining just a few of the possible highlights.

INTERFERENCE

One of the technical triumphs of the JLab program, based on its high duty factor, high polarization and intensity, is that one can measure recoil polarization in processes like $(e^-e^0N)$. The application of this process to elastic $e^-p$ scattering led to the discovery that, contrary to the conclusions based on using a Rosenbluth separation, the shape of the electric and magnetic form factors of the proton was very different. Indeed, the ratio $G_E/G_M$ drops rapidly towards zero as $Q^2$ increases towards 7 - 8 GeV$^2$ [1]. Extensive theoretical studies have shown that this difference is most likely a consequence of two-photon exchange, which seems to have a much bigger effect on the Rosenbluth separation than on recoil polarization [2, 3]. Experimental confirmation of this explana-
tion would be simple if one could compare $e^+$ and $e^-$ scattering, with the sign of the interference term being different in these two cases.

Turning to a different topic, the challenge of resolving the so-called “spin crisis” has been with us for more than 20 years \cite{4}. Those two decades of experimental work have provided an enormous amount of information and in many ways the crisis has now been resolved \cite{5, 6}. From accurate measurements of the proton spin structure function, $g_1^p(x)$, we now know that the quarks carry about one third of the proton spin, not zero as appeared possible back in 1988. We also know that the spin carried by polarized gluons in the proton is an order of magnitude smaller than that required to resolve the crisis through the $U_A(1)$ axial anomaly. On the other hand, crucial non-perturbative aspects of hadron structure, namely relativistic quark motion, the hyperfine interaction in QCD \cite{7} and the pion cloud required by chiral symmetry \cite{8}, all act to reduce the spin carried by the quarks. These effects account fully for the modern proton spin sum and hence resolve the spin crisis.

Of course, one really wants to confirm this theoretical explanation by independent experimental tests. Key to this is the realization that all of the mechanisms just outlined have the effect of replacing quark spin by quark and anti-quark orbital angular momentum \cite{9} and the ideal method to access that experimentally is using the GPDs \cite{10}. The GPDs are extracted from deeply-virtual Compton scattering (DVCS) through the interference between the Bethe-Heitler process and DVCS \cite{11}. This interference changes sign when one switches from $e^-$ to $e^+$ and this is critical to being sure that one has correctly recognized the interference term rather than the square of the DVCS amplitude. With its unique access to the critical valence region JLab, with its upgrade to 12 GeV, is ideally placed to determine the amount of orbital angular momentum carried by the quarks and access to high intensity beams of polarized positrons would be extremely valuable.

**Charged current measurements**

Another major technical development at JLab has been the ability to perform remarkably precise measurements of parity violating electron scattering (PVES). This has enabled the accurate determination of the strange vector current matrix elements in the proton \cite{12, 13, 14}, with the result that strange quarks contribute less than 5% of the magnetic moment or charge radius squared of the proton \cite{15, 16}. Such measurements are the QCD equivalent of the determination of the Lamb shift in QED, as the strange quarks are not part of the valence structure of the proton and contribute only through vacuum fluctuations. Calculations based on lattice QCD and modern chiral extrapolation techniques are in excellent agreement with the experimental results, albeit with errors an order of magnitude smaller \cite{17, 18} – a unique occurrence in modern strong interaction physics.

In contrast with the strange elastic form factors, the experimental determination of the difference in the $s$ and $\bar{s}$ parton distributions have proven far more difficult \cite{19}, largely as a consequence of the difficulties associated with neutrino experiments. Such a difference was anticipated more than 20 years ago on the basis of the fluctuation
Indeed, it is now known that the chiral non-analytic behavior of \( s(x) \) and \( \bar{s}(x) \) is different and hence, \( s(x) \neq \bar{s}(x) \) must be non-zero \[21\]. High luminosity electron and positron beams, preferably at a future electron-hadron collider such as ELIC proposed at JLab, would permit one to accurately map this difference, which also has consequences for the search for new physics in phenomena such as the NuTeV anomaly \[22\].

The quest to understand the role of the quark and gluon degrees of freedom in defining the properties of atomic nuclei is one of the great challenges facing modern nuclear physics. The nuclear EMC effect, which was discovered more than a quarter of a century ago \[23\], provides compelling evidence that the structure of a bound “nucleon” differs in a fundamental way from its free counterpart \[24\] and yet this evidence is largely ignored as inconvenient by the community. The quark-meson coupling (QMC) model is an extremely efficient and effective formalism with which to investigate the role of quarks and gluons in determining nuclear properties \[25, 26\], from the saturation of nuclear matter to the EMC effect. Within the QMC model, and its modern incarnation based upon the chiral symmetric, covariant, confining NJL model, developed by Bentz, Cloët and Thomas \[27\], the paradigm which has underpinned nuclear theory for over 70 years is replaced by the understanding that what occupies shell model orbits in atomic nuclei are not free neutrons and protons but quark clusters with nucleon quantum numbers whose structure has self-consistently adjusted to the local mean scalar and vector fields in the nuclear medium \[28\]. This picture has been successfully linked to conventional many-body theory through the derivation of an equivalent energy functional which yields a remarkably successful density-dependent force of the Skyrme type. Recently applications of the QMC model include an explanation of the experimental absence of \( \Sigma \)-hypernuclei \[29, 30\], the prediction of weak binding for \( \Xi \)-hypermultiplet, interesting predictions for the photo-production of hypernuclei \[31\] and new results for the properties of dense nuclear matter in \( \beta \)-equilibrium, including hyperons \[32\].

In the present context, it is especially interesting to note the discovery of the isovector EMC effect by Cloët \emph{et al.} \[33\]. In particular, even if one makes an “iso-scalarity” correction to the structure function of Fe by subtracting the structure functions of the 4 extra neutrons, one cannot eliminate so easily their effect on all of the remaining neutrons and protons. Because of the isovector repulsion between \( d \)-quarks and the attraction between \( d \)-s and \( u \)-s, the \( d \)-quarks will have a different distribution in Bjorken-x than the \( u \)-quarks. The sign of this effect is obviously the same as that associated with normal charge symmetry violation (CSV) \[36, 34\], itself an important object of study in modern hadron physics, and together these two effects (the “pseudo-CSV” associated with the isovector EMC effect and regular CSV associated with \( u \neq d \) mass differences), can account for the NuTeV anomaly. Far from being a disappointment, in the sense that there is no evidence for physics beyond the Standard Model, this support for an isovector EMC effect provides powerful support for this new paradigm for nuclear structure, itself a remarkably important issue.

The unambiguous confirmation of the difference predicted by Cloët \emph{et al.} between \( d_A \) and \( u_A \) in a nucleus with \( N \neq Z \), even after correcting for the excess neutrons (or protons), is possible using a comparison of charge current deep-inelastic scattering. Once again, a high energy, high luminosity collider such as that proposed at JLab, would be ideal. Other tests which have been proposed include the comparison of semi-inclusive \( \pi^+ \) and
π deep-inelastic scattering at 12 GeV at JLab [35] but the complications of final state interactions have the potential to complicate the interpretation there. This is not an issue for the charged current comparison.

BEYOND THE STANDARD MODEL

A comparison of the charged current cross section for electrons and positrons as function of polarization at HERA showed the potential for testing the Standard Model in this way [37]. However, lack of luminosity meant that it was never competitive with other methods. An electron-ion collider with luminosity at the level of $10^{35}$ cm$^{-2}$/sec, as proposed at JLab, may well turn this around.

Another rather different approach will be described at this meeting by Bogdan Wojtsekhowski [38]. There have been suggestions for some time that an excess of 511 KeV X-rays from the galactic center may signal the existence of a new, light $U$-boson with mass in the range of a few to tens of MeV. The most promising method to search for such a particle would be in $e^+ e^-$ annihilation using an intense positron beam, at JLab possibly at the FEL. For more details we refer to the presentation of Wojtsekhowski.

CONCLUSION

More details of the ideas presented here and a number of others will be found in these proceedings. Even from this introductory taste, it should be clear that the initiative to develop a positron capability at JLab is very well motivated scientifically. There are some very important issues that can be addressed and resolved only in this way and I am sure that these will prove compelling when it comes to finding the necessary resources.

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