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Editor, *Nature*

Dear Editor(s) of *Nature*:

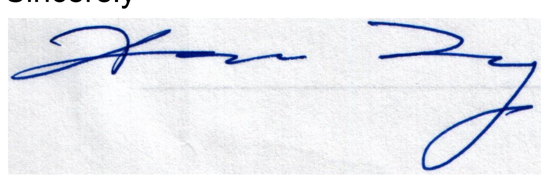
Thank you and the referees for reviewing our manuscript titled “Quarks Through the Looking-Glass – New Measurement of Parity Violation in Electron-Quark Scattering”. We are excited to know that it has been considered for publication. Starting on page 2 of this letter, we will specifically address all comments and suggestions from the editor and the referees.

We are submitting the revised manuscript with this cover letter. The list of files included in this resubmission is shown below. The overall length of the manuscript remains almost unchanged.

1. The main text as a PDF file. We have removed the abstract per Nature guidelines. (The first paragraph unfortunately is now split between two pages, but otherwise it should satisfy all Nature requirements.)
2. The Methods section as a separate Supplementary Method PDF file as suggested by the editor.
3. The two Supplementary Tables in a single PDF file.
4. EPS files for the two figures in the main text. We have re-worked both figures. All Nature artwork requirements are met except that the files are in RGB mode due to lack of conversion tools. We plan to check the color rendering in the proof stage and we hope the simple color scheme of these figures will cause little or no problem in the conversion from RGB to CMYK.
5. A high-quality image as a potential cover illustration. The image does not contain any symbols for physical variables as we have focused more on its aesthetic appeal (as suggested).

We look forward to additional reviews and further editorial comments. Please do not hesitate to contact us if there are technical difficulties in using our submitted files.

Sincerely



Xiaochao Zheng
Associate Professor in Physics

Here are point-by-point response to comments from the editor and all issues raised by referees. Our responses are shown in indented paragraphs.

Response to Editor's comments (partial):

Please note that the title of the paper may not contain punctuation or exceed 90 characters (including spaces). We suggest simply "Measurement of Parity Violation in Electron-Quark Scattering".

> *Response:* We adopted the editor's suggestion and will use the title “New Measurement of Parity Violation in Electron-Quark Scattering".

Letters begin with a fully referenced paragraph, ideally of about 200 words, aimed at readers in other disciplines. This paragraph starts with a 2- to 3-sentence, basic introduction to the field; continues with a 1-sentence statement of the main conclusions starting 'Here we show' or an equivalent phrase; and finally, concludes with 2 to 3 sentences putting the main findings into general context so it is clear how the results described in the paper have moved the field forward. A downloadable, annotated example is available at www.nature.com/nature/authors/gta/index.html#a1.2. Summary paragraphs can be up to 300 words long if necessary to explain complex material for readers in other fields. The extra length, however, is for introduction and context, and not for additional technical information.

> *Response:* We have combined the abstract and the first paragraph from the original manuscript. In the revised text, the first paragraph contains 220 words. It starts with a 4-sentence basic introduction to the field, continues with a 1-sentence statement starting “We report here ...”, followed by the main findings, and ends with two sentences that put the results into the general context of particle physics research.
>
> Comparing the style of our first paragraph to the requirement of Nature, the only exception is the 4-sentence introduction to the field. We feel that the extra sentence is necessary to introduce the basics of parity violation to the broader audience, in particular given the fact that particle physics has less exposure in Nature than other fields. We hope that this exception can be accepted, given that the overall length of the introductory paragraph is very close to the suggested 200 words. On the other hand, we will be happy to make changes if they are mandatory to the final publication.

Further introductory material in the main text of the paper should not be necessary. Any discussion at the end of the paper should be brief, and not repeat what is written in the initial summary paragraph. There are no subheadings.

> *Response:* Our manuscript satisfies the above requirements.

Authors should ensure that any statistical analysis used is sound and that it conforms to the journal's guidelines (see www.nature.com/nature/authors/gta/index.html#a5.6 for guidance).

> *Response:* Research in particle and nuclear physics is based primarily on statistical analysis. Our analysis is sound in this aspect. Some representative

illustrations of the statistical quality of the measurement were published in our NIM paper which reported on our data acquisition system (but did not include any physics results), in Ref.[14] of the main text.

Please ensure that all references contain final page numbers. Footnotes are not permitted, so please incorporate item 27 within the main body of the text.

Response: We have moved item 27 into the main text as suggested. We have checked carefully and made sure all references have the final page numbers. We removed some of the arxiv information that was accidentally included in the previous version.

(The rest of the editor's comments are related to file and formatting requirements of the re-submission and will not be addressed here).

Response to Referees' comments:

Referee #1 (Remarks to the Author):

The paper entitled "Quarks Through the Looking Glass - New Measurement of Parity Violation in Electron-Quark Scattering" presents an important experimental result, which opens up a new program of study from an old field of physics, and certainly deserves publication. The collaboration that performed this measurement consists of leaders in the field of polarized electron scattering, and the road to future measurements at higher energy has begun. Given the great success of the polarized electron scattering program at Jefferson Lab with its 6 GeV beam energy, and the many technical accomplishments that have been realized over the years, there is little doubt as to the robustness of the present measurement. The re-establishment of measurements of parity violation in the deep inelastic scattering after nearly 35 years is an attractive accomplishment and bodes well for the future of the parity violation program.

> *Response:* We thank the referee for the positive assessment of our experiment. The successful completion of this experiment relied on recent developments in the production and the control of high-quality polarized electron beams, a result of collaborative efforts that went beyond the collaboration of this experiment and even the Jefferson Lab community.

Although the experiment is notable, reliable and publishable, the challenging issue is whether the result is of such significance that it justifies publication in Nature, where the scientific criteria is that the paper be "of extreme importance to scientists in the specific field" and "to be acceptable, a paper should represent an advance in understanding likely to influence thinking in the field. There should be a discernible reason why the work deserves the visibility of publication in a Nature journal rather than the best of the specialist journals." For example, is this publication of such impact that Physical Review Letters is not adequate enough exposure?

> *Response:* We believe that our paper meet the above criteria. First and the most importantly, it is addressing the measurement of a fundamental quantity in the Standard Model. The access to the coupling C_{2q} in PVDIS is relatively clean and unambiguous compared to other physical processes. The results should be made known within the specific field. Secondly, this experiment has successfully addressed the issue of high background contamination in typical deep inelastic scattering experiments through the use of a specialized data acquisition system. Our data collection method was never utilized before and is a technical advance by itself. Thirdly, the various systematic uncertainties have been studied and we have paved the path for measurements of higher precision in the future. Lastly, the manuscript is written in a style that is accessible to people outside the specific field. For all above reasons, we believe our manuscript meet the publication criteria of *Nature*.

The authors present the following key features to justify the overall significance of the results.

It is the first measurement of parity violation in deep inelastic scattering in the past 35 years.

For testing a combination of the electroweak constants, C2q's, the measurement is five times more precise than what was done previously. The results yield the first non-zero determination of the electroweak coupling constants C2q's, predicted by the Standard Model. And, the results put a new constraint on the existence of Λ+- parameters probing the 4 to 5 TeV scale, surpassing limits on similar constants from HERA at DESY and providing comparable sensitivity to that probed by the ATLAS experiment at CERN.

The difficulty is the impact of the measurement on fundamental physics. The result puts constraints on new physics comparable to the ATLAS test of the left-left isoscalar model. However, the ATLAS measurement was published in Physical Review D and, though important, it is one of many constraints on potential new physics channels and did not fundamentally advance the field beyond what was expected. Overall, it is fair to conclude that the ATLAS result and the parity violation measurement presented in this paper are of comparable impact on physics searches, and therefore could be published in equivalent level journals.

> *Response*: As a leading high energy physics collaboration, ATLAS provides many precision tests of the Standard Model and many searches for new phenomena. ATLAS has published 266 papers to date, some possibly could have been submitted to and published in Nature.
>
> In addition, it is worth noting that the measurement reported by our work is a direct and unambiguous measurement of the C_{2q} couplings, that allows tests of the Standard Model complementary to what is happening at the LHC.

However, there is an additional difficulty in this paper concerning the interpretation of the measurement. The beam energy is very low and as a result, the kinematic range is limited. There is one measurement at Q2 = 1 GeV2 and a second measurement at Q2 = 2 GeV2. The concern is the existence of higher twist effects. In the last sentence the paper states that "our results on C2u,2d are largely not affected by this effect at the present precision." But, it is arguable whether these low Q2 are in a region where higher twist effects can be safely ignored and not have even a significant impact on the overall new physics sensitivity.

Take the following case. Assume that the result implies a violation of the Standard Model and a potential discovery of new physics. The first line of attack on the measurement would be that the Q2 was too low and that the results disagree with the Standard Model due to higher twist effects. The only way to respond to this criticism would be to perform measurements at higher Q2, which is, indeed, already in the long-term plan of the Jefferson Lab program. In fact, the search for higher twist effects is by itself an important study with implications towards understanding nucleon spin structure. But, if these effects are large, they weaken the case that the measurements are sensitive to new particle physics phenomena at higher energy scales.

The two measured asymmetries, at comparable Q^2 , are probably not adequate to constrain potential deviations coming from higher twist effects. Unfortunately, theoretical calculations on higher twist effects are difficult and generally not reliable numerically.

> *Response:* The referee has raised a very important topic. The Higher Twist (HT) effects, being a non-perturbative effect resulting from gluon exchanges among

quarks, deserves detailed discussions on its own. Originally, there was hope that HT would even shed light on our understanding of confinement, a long-standing issue of QCD.

Concerning the size of HT in parity-violating deep inelastic electron scattering (PVDIS) asymmetry: Theoretical studies on this topic date back all the way to the SLAC E122 experiment over 30 years ago. The first discussion was presented by Bjorken, where it was argued that "for deuterium, A/Q^2 at y=0 is, to a good approximation, independent of Q^2 ..." [this is equivalent to saying that HT is very small for the a_1 term in the asymmetry as shown in Eq.(2) of the main text]. The latest discussions on HT in PVDIS, some particularly focused on the experimental program at JLab, were done for example in the work of Mantry, Ramsey-Musolf and Sacco; Belitsky, Manashov and Schafer; and Seng and Ramsey-Musolf. All calculations indicated that the HT contribution to the a_1 term is at the order of half a percent at Q^2 =1 GeV^2 and the Bjorken x range of our measurement. The HT contribution to the a_3 term of the asymmetry is bounded by the neutrino H_3 data, as already described in the Methods section.

Overall, we believe a combination of theoretical bounds and experimental data indicates that the HT effect on the PVDIS asymmetry is below 1% for both kinematic points. The resulting uncertainty in the extracted C_{2q} is quite small compared to experimental uncertainties.

We realized that our current discussion regarding HT, as presented in the last paragraph(s) of the Method Summary and the Method section, wasn't quite clear in conveying the above reasoning. We have revised these particular paragraphs. In the revised version we have focused on the following: 1) we provide more details on the theoretical estimation of HT in PVDIS, in particular the most recent calculations. 2) we include in Eq.(6) an uncertainty in C_{2q} that accounts for the HT effects. All subsequent results on the mass limits and the two figures have been updated. As one can see that the change is quite small and does not change the mass limit results because the limits are quoted with only two significant figures. The change is also nearly invisible in the figures.

The experiment is groundbreaking in that it opens up a new field of study of parity violation in deep inelastic scattering. The experiment is challenging in that there is a large pion background in these measurements, and this difficulty was addressed. However, technically it is perhaps not as novel as other parity violation experiments that have been performed at Jefferson Lab, in particular those that have measured much smaller asymmetries.

Response: The technical difficulty of this experiment was indeed not in producing the high-quality polarized electron beam (which was the challenge for carrying out other PVES experiments at Jefferson Lab aiming for measuring asymmetries that are more than two orders of magnitudes smaller). As mentioned in the comments above, the main challenge of our measurement is the high charged-pion background typical to deep inelastic scattering experiments. This issue was solved by a counting data acquisition (DAQ) system that rejected pions "real-time", with very small uncertainties due to deadtime and particle identification. The design and the performance of the DAQ was published in Nuclear Instrum.

and Methods A (Ref.14 of the revised main text). The collaboration designed, built, and utilized the DAQ successfully. This data collection method is one of a kind among modern parity violation experiments.

Several minor comments:

(1) "Standard Model" should be capitalized. It is capitalized once in this paper, but appears otherwise not capitalized. It should be capitalized everywhere, which is the convention in particle physics.

Response: We have made the correction.

(2) At the end of the first introductory paragraph, there is a statement that this experiment "opens the door to even more precise measurements in the future". The paper would benefit from a discussion in the conclusion about future plans. At least one major improvement will be to run the experiment with a higher energy beam. There are a number of approved experiments that will be performed at Jefferson Lab and it would be worthwhile to mention this to the reader.

Response: We have added one sentence about the planned PVDIS experiment at the 12 GeV upgrade of Jefferson Lab. This is done in the discussion of the results presented in Eq.(6) and Fig.1. The 12 GeV experimental proposal hasn't been published in journals, thus the statement is not referenced. However all core collaborators of the 12 GeV proposal are already among co-authors of this manuscript.

(3) As noted in the comments above, the statement that the two measured asymmetries place a restrictive enough limit on potential higher twist effects so that those effects can be ignored at these Q2 values is not really convincing.

Response: Please see our response concerning higher twist effects in the previous two pages. We no longer rely on our own measured asymmetries as a bound of the higher twist contribution to PVDIS asymmetries.

(4) The section on Method Summary should be incorporated into the main text. It presently contains quite a bit of redundancy compared to what is already given in the main text. For example, there is no reason to state twice the location of the experiment (Jefferson Lab) or restate the target (deuterium) and beam used. This is a short enough publication that tightening the main text should be doable.

Response: When writing this manuscript we have carefully studied the requirements of Nature. On the Nature author information page, it states that

“If brief (less than 200 words in total), methods can be included in the main text at an appropriate place. Otherwise, they should be described at the end of the text in a ‘Methods Summary’ section of no more than 300 words.”

The difference in word count between the in-text methods and the separate method summary is not large (200 vs. 300 words), and we interpret this as an indication that the main text should focus on the scientific findings. While it is necessary to include essential information of the method as part of the publication, it's better to describe it in a separate section so readers will not be distracted from the main results.

Therefore we adopted the following approach in the original submission: in the main text we described briefly the basic information of the experiment, such as the location of the experiment and the target and the beam, and focused on the use of a novel, unique, fast-counting data acquisition system. This description was kept under 200 words. Then, in a separate Method Summary section we described other essential, but not novel or particularly challenging aspects of the experiment and the data analysis. We feel that our approach is more in-line with the style of Nature.

Nevertheless, following the referee's suggestion we have removed some redundant information from the Method Summary, such as the location of the experiment and what types of beam and target were used.

(5) There are some grammar weaknesses in the abstract that should be cleaned up. "report ON a .." ...." Five times MORE PRECISE .... (not BETTER)" "(the) quantities" → "quantities", etc...

Response: We have accommodated these suggestions.

If there is a PhD thesis on the experiment, it should be referenced for further details on the experiment. Even if all the experimental details are kept, as is, they should appear upfront in the section where the experiment is described to avoid repetition.

Response: There is one Ph.D. student on this experiment: Diancheng Wang (the first author). Dr. Wang has successfully defended his thesis on Nov. 25th, 2013. His thesis will become available as soon as it is finalized (by Dec. 1st) and this manuscript is published (to avoid conflict with Nature policy). In addition, we plan to write a long archival paper on the details of the analysis, which is typical for Jefferson Lab experiments.

The credit to previous work is appropriate.

Referee #2 (Remarks to the Author):

This is a publication which scientific community has been waiting for a long time. Jefferson Laboratory very accurately measured parity violation in electron-quark scattering, provided new tests of the Standard Model and limits on new physics beyond the Standard Model. This is one of the most important experimental works in elementary particle physics, and it certainly deserves to be published in Nature.

> *Response*: We thank the referee for the positive assessment of our experiment. Again we would like to emphasize that the successful completion of this experiment relied on recent developments in the production and the control of high-quality polarized electron beams, a result of collaborative efforts that went beyond the collaboration of this experiment and even the Jefferson Lab community.

Referee #3 (Remarks to the Author):

This is an interesting, albeit expected, result. It represents the first improvement (by about a factor of 5) in parity violating deep-inelastic polarized electron-deuteron scattering since the classic SLAC E122 experiment by Prescott et al in 1978. That important experiment confirmed the electroweak sector of the standard model at a time when it was in doubt and made a relatively precise measurement of the weak mixing angle. It probably should have been awarded a Nobel prize.

This paper concentrates on parity violating effects due to the quark weak neutral axial-vector current of the standard model. It confirms expectations at the 95% confidence level and uses the results to constrain new contact interactions (beyond standard model expectations) to be > O(5TeV), if they exist. That is a reasonably competitive bound (but not the best). Future measurements at higher JLAB energies hope to further significantly improve the results.

The paper is fairly clear, but relies heavily on details presented in the Supplementary Information that would be linked online to the article. The analysis appears straightforward. However, I was surprised to not see an error stated for the standard model predictions that were compared with. An error must result from truncation of the perturbative series and neglect of some QCD effects. The authors should state clearly in the Text the approximate theory error and what has been neglected. They may find that QCD is more important in modifying the prediction than they seem to think and suggest.

> *Response:* We have added descriptions of various theoretical uncertainties in the revised version, including those for the Standard Model expectation of the asymmetry, and for the sensitivity to the C1,2 couplings. For both cases the uncertainty is dominated by that from parton distribution functions (PDFs). The uncertainty due to other effects such as QED vacuum polarization and gamma-Z box diagrams are quite small compared to that from PDFs.
>
> Since we added a separate uncertainty due to the higher twist effects to the C2 result, we listed the uncertainty due to PDFs separately as well.
>
> If the comment is about particular QCD effects that are not included in our revised discussions, please specify which effect(s) and we will be more than happy to address them in a future communication.

Some of the physics terminology is confusing, if not incorrect. For example, in the Abstract and Text, the authors suggest that quark chirality flipping is being measured in the scattering asymmetry via an axial-vector interaction. However, all gauge interactions studied, vector and axial-vector conserve chirality for both the electron and quarks. Chirality flipping usually suggests an interaction that changes left to right and vica-versa. No such interactions are in play here. Those comments should be modified or if the authors feel they are correct, an explanation of exactly what is meant should be given.

> *Response*: We thank the referee for pointing out that our terminology is unsuitable. To clarify, we did not mean that the virtual photon or the Z^0 boson flips the quark chirality. We meant that the quark chiral state is flipped when we flip the physical world, as in a parity transformation. To avoid confusion, we have changed the expression as follows:

1) In the abstract, changed to “particularly on those due to reversing the quark chirality”;
2) In the definition of C1,2, changed to :”$C_{1u(d)}$ is the axial-vector-electron vector-quark (AV) coupling, i.e. it probes parity violation caused by the difference in the Z^0 coupling between left- and right-handed electron chiral states; $C_{2u(d)}$ is the vector-electron axial-vector-quark (VA) coupling that is sensitive to parity violation due to the different quark chiral states.”

We hope the above changes resolved the confusion.

Some of the way literature is cited seems peculiar. For example, how can one discuss parity violation without mentioning Lee and Yang. Instead, the paper simply gives credit in the text for the discovery of parity violation to C.S. Wu (with no mention of others, even collaborators) for parity violation. Another example is the suppression of higher twist effects where work by Bjorken should have been cited.

Response: We added the reference to Lee and Yang. We apologize for the incomplete reference in the original submission. The reference to Bjorken's higher twist work is now added to the Methods section as part of our extended discussion on higher twist effects (see response to Referee #1).

Readers may be confused by the extrapolation of the results down to Q^2=0 in for example eq(6) and the subsequent discussion, since such an extrapolation is not needed either for the weak mixing angle determination (at the Z mass) or for the constraints on contact interactions.

Response: The referee is correct that the extrapolation is not needed for the extraction of $\sin^2\theta_W$ or the constraints on contact interactions. The extraction can be done at any Q^2, however a natural choice would be at zero.

In addition, one reason we would like to keep the terminology is the following: Electroweak radiative corrections relevant for the vector-axial or axial-vector couplings, and for other electroweak observables, are quite complicated. The community must adopt a consistent way to quote the measured results if we want to advance this type of measurements to higher precision and to compare results from different types of experiments. We hope the introduction of the “zero-Q^2” definition will set a standard for similar measurements of the $C_{1,2}$ couplings in the future.

Some of the equations have unusual normalization that looks peculiar. For example, why is the 6/5 in eq(3) not factored out in eq(2) and simpler definitions of a_1 and a_3 used. Also, why not mention that the formulas are given in a valence quark approximation although the analysis includes sea quark effects.

Response: The factor 6/5 comes from the structure function ratio and *is part of* $a_{1,3}$, thus should not be present in Eq.(2). This can be seen from Eq.(13) of Supplementary Information: the factor 5 comes from the e_q^2-weighting of the parton distribution function in the denominator (the 2/3 of the up quark squared plus the -1/3 of the down quark squared). The factor 6 comes from the factor 2 in the $a_{1,3}$ definition and the cancellation between the e_q^2-weighting of the denominator and the e_q-weighting of the numerator (which gives a factor 3 from the quark charges being multiples of 1/3). Since we are using an isoscalar target, the parton distribution functions themselves, such as u(x) and d(x), do not show up in the 6/5 factors.

To be accessible to a wider audience, the authors should make the title and text crisper and explain in a bit more detail why the experimental results are particularly important.

Although the results are novel and worthy of publication, I do not see the need to publish in Nature. In fact, a more technical article that incorporates and expands the Supplementary Information into the text would be much more useful, particularly if it the analysis and assumptions were thoroughly explained. A Nature article should be reserved for stronger evidence than a (less than) 2 sigma effect, or for an unexpected finding of dramatic consequence. In addition, it should be of interest to a more general, wider audience of Scientists than specialized workers in the field.

Perhaps this paper can be made more exciting in tone, motivation and implications in a way that would make it more suitable for Nature. For example, a crisper, more provocative title might be: "Unveiling Quark Properties Through a Parity Violating Looking Glass". Also, to be of wider interest, it might incorporate some of the early history and mystery of parity violation while also elaborating the discussion of elegant experimental technique. One might also mention the importance of (rather large) quantum corrections probed by this experiment and some history of their evolution and successes.

Response: We like the idea of reviewing some early history of the proposition and the discovery of parity violation and electroweak unification, however it will lengthen the introduction and will not be in-line with the concise style of Nature Letters. [We have been careful to include history that is essential only to the introduction of our measurement (PVDIS)]. As for the title, we have adopted the suggestion from the editor.