Subject: Decision on Nature manuscript 2019-07-10953
Date: Thu, 10 Oct 2019 09:02:07 -0400
From: k.ziemelis@nature.com
Reply-To: k.ziemelis@nature.com
To: chris.rogers@stfc.ac.uk

10th October 2019

* Please ensure you delete the link to your author home page in this e-mail if you wish to forward it to your co-authors.

Dear Dr Rogers,

I am writing in place of my former colleague, Gaia Donati (Gaia has sadly now left Nature to pursue other interests).

Your manuscript, "First demonstration of ionization cooling by the Muon Ionization Cooling Experiment", has now been seen by two reviewers, whose comments are attached below. In the light of their advice I am delighted to say that we can in principle offer to publish it. First, however, we will need you to revise your paper to address the points made by the referees, and to make some editorial changes to your paper so that it is as brief as possible and complies with our Guide to Authors (https://www.nature.com/nature/for-authors).

I imagine that the reviewers' comments will be self-explanatory and straightforward to address – they are mainly requests for clarification.

From an editorial point of view, the paper is already in reasonably good shape, although there are a few issues that we will need you to attend to, Before I run through our general style and format guidelines, I will highlight the main points requiring attention:

1. Length – the paper as it stands is longer than we would normally allow for any of our papers. Although we have some scope for flexibility, we will need you to adjust the balance between main text content destined for print and the online-only Methods section. We would in any case like you to add a few words to the introduction (third paragraph starting line 35) to emphasise the issue of size when it comes to future high-energy accelerators (to really make clear to readers why what you have done is potentially such a big deal). [We would like you to aim for ~3,500 words for the summary + body text; it is ~4,100 words at present.]

2. References – we try to keep the number of references for the print text to below 50 (or 55 at a push). The rebalancing mentioned above should help in that regard (there is no restriction on the number of references associated exclusively with the online-only Methods section).

3. Summary paragraph – we have no adopted a single format for all Nature papers, in which there is a fully referenced summary paragraph; this can also accommodate a bit of the introductory material with which you start

the paper (see details below).

4. Title – our usual limit is 75 characters (including spaces), which the present title exceeds. Also, we try to avoid terms such as ‘first’, ‘new’, ‘novel’ etc for the simple reason that all papers are claiming a first of some sort, and our titles could get very repetitive. Simply omitting the first three words would fix this.

5. The supplementary figure should be provided in the ‘Extended Data’ format detailed below. There should be no need for any supplementary information.

6. Subheadings – for a paper of this length, we strongly advise the use of subheadings in the main text to aid navigation.

Now for our general guidelines.

LENGTH: We estimate the current length of your paper to be ~4,100 words (summary paragraph and main text), which exceeds our usual upper limit for Articles by a considerable margin. With 5 display items as at present, the main text of the revised version should be ~3,500 words. Keep in mind that important technical details that are not central to the main message of the paper can be moved into the Methods section (see below).

TITLES: Titles should not exceed 75 characters (including spaces); they must not contain punctuation. We suggest "Ionization cooling by the Muon Ionization Cooling Experiment ".

SUMMARY PARAGRAPH: All Nature papers now 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 findings 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 https://www.nature.com/nature/for-authors/formatting-guide. 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.

MAIN TEXT: If further introductory material is necessary, the main text can begin with a short introduction expanding on the background to the work (some overlap with the summary paragraph is acceptable), before proceeding to a concise, focused account of the new research and findings, and ending with 1 or 2 short paragraphs of discussion. Sections should separated with subheadings to aid navigation. Subheadings may be up to 40 characters (including spaces).

STATISTICS: Authors should ensure that any statistical analysis used is sound and that it conforms to the journal's guidelines (see https://www.nature.com/nature/for-authors/formatting-guide for guidance).

METHODS: At the end of the main text document (after the main figure legends), there should be a section entitled "Methods", which provides a more detailed discussion of the additional methodological information that would allow other researchers to replicate the results (we define “Methods” quite broadly, so this is not limited to details of experimental protocols – supplementary discussion and analysis can also be included). The Methods section will not appear in the print version but will be fully copy-edited and appear online in the full-text HTML and PDF versions. The Methods section should be written as concisely as possible but should contain all elements necessary to allow interpretation and reproduction of the results. If there are additional references in the Methods section, their numbering should continue from the last reference in the main paper, and the list should follow the Methods section. If the methods require chemical structures, figures or tables, these
should be supplied as Extended Data (see below).

REFERENCES: As a guideline, Articles allow up to 50 references in the main text; additional references can be cited in (and listed after) the Methods section, as detailed above.

MAIN TEXT STATEMENTS: We require authors to provide a detailed Author Contribution statement immediately after the acknowledgements; the specific contributions of each author must be listed. It is also a condition of publication that authors include an Author Information statement indicating how to access information regarding reprints and permissions, stating whether or not there is a financial or non-financial competing interest, and naming the author to whom correspondence and requests for materials should be addressed. Please ensure that this section is included in the manuscript file after the Methods (but before the Extended Data legends) - it will not appear in the print version but will appear online in the full-text HTML and PDF versions. For details of "end note" style and an example see https://www.nature.com/nature/for-authors/formatting-guide.

DATA AVAILABILITY STATEMENT: All Nature papers must now include a separate Data Availability Statement (DAS) after the Methods section (and any associated Methods references), and before the Extended Data legends. A detailed document outlining the data availability policy, containing various DAS examples that authors may use or modify can be found at: https://www.nature.com/documents/nr-data-availability-statements-data-citations.pdf. For all studies using custom code or a mathematical algorithm deemed central to the conclusions, a statement must be included under the heading "Code availability", indicating whether and how the code or algorithm can be accessed, including any restrictions to access. This does not apply to standard data reduction or processing software (which should be named), but it does apply to anything that has been modelled. More information can be found at https://www.nature.com/authors/policies/availability.html#code.

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available from the authors and/or are included with the manuscript (e.g. as source data or Supplementary Information). The statement must list which data are included (e.g. by figure panels and data types) and mention any restrictions on availability. If a dataset generated or analysed during the study is publicly available and already has a unique Digital Object Identifier (DOI), we strongly encourage authors to include this in the reference list and to cite the dataset in the Methods. Certain statements that previously would be found in the Author Information section (e.g. accession numbers for any newly determined sequences, structures, microarray or zoobank data; project IDs for MG-RAST data; accession numbers for X-ray crystallographic coordinates and structure factor files, or comparable NMR or cryoEM data) should now be included only in the DAS.

FIGURE LEGENDS: These should be listed sequentially after the references in the main text and not in the figures files. Each legend should begin with a brief title for the whole figure and continue with a short description of each panel and the symbols used. Any error bars in the figures must be defined (for example, s.d., s.e.m.) and the value of n indicated; see https://www.nature.com/nature/for-authors/formatting-guide for further explanation.

DISPLAY ITEMS: We ask that you take stock of all the data that have been generated throughout the review process and ensure that only the data most central to the conclusions are presented in the main figures. Figures should be comprehensible to readers in other or related disciplines, and assist their understanding of the paper. We encourage authors who are describing complex processes to include a schematic of the main finding as part of the Extended Data to aid readers unfamiliar with the immediate discipline. Figures should be as small and simple as is compatible with clarity. All panels of a figure should be logically connected; each panel of a multipart figure should be sized so that the whole figure can be reduced by the same amount and reproduced on the printed page at the smallest size at which essential details are visible. For guidance, Nature's standard figure sizes are 89 mm (one column), 120 mm (one and a half columns), or exceptionally 183 mm (two columns) wide; the full depth of a Nature page is 247 mm. All panels of figures should be presented on a single page and assembled into a rectangular shape for publication; please indicate any essential alignments (parts horizontal, vertical, spacings of stereo pairs, etc.). Tables should be prepared using the Table menu in Microsoft Word.

FIGURE FORMATTING: Lettering in all figures (labelling of axes and so on) should be in uniform, sans-serif font, in lower-case type, and large enough to permit substantial reduction for publication (minimum font size 5 pt). Separate parts of a figure are labelled a, b, etc. Units have a single space between the number and the unit, and follow SI nomenclature or the nomenclature common to a particular field. Thousands are separated by commas (1,000). Unusual units or abbreviations are defined in the legend. Scale bars rather than magnification factors should be used.

IMAGE PRESENTATION: Authors should be aware that any image provided for publication, either in print or online (as Extended Data or Supplemental

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EXTENDED DATA: Nature is now integrating the supplemental figures and tables into the final version of most papers. Extended Data do not appear in the printed version of the paper but are included online within the full-text HTML and at the end of the online PDF. Extended Data are an integral part of the paper and only data that directly contribute to the main message should be presented. All Extended Data must be referred to in the main text, figure legends and/or Methods section, and their figure legends should be listed sequentially at the end of the main text, not in the Extended Data files. Authors should assemble the Extended Data into a maximum of ten, A4 size, multi-panelled display items, submitted as individual JPEG, TIFF or EPS files. They must be provided at the same quality as figures for print, but there are important differences in their formatting. More specific instructions are provided in the Extended Data Formatting Guide (http://s3-service-broker-live-19ea8b98-4d41-4cb4-be4c-d68f4963b7dd.s3.amazonaws.com/uploads/ckeditor/attachments/7823/3h_Extended_data.pdf).

SUPPLEMENTARY INFORMATION: Supplementary Information is online-only material published with the manuscript (https://www.nature.com/nature/for-authors/supp-info). For most papers, there should be no need for Supplementary Information beyond that already provided as Methods and Extended Data, the aim being to avoid unnecessary fragmentation of the paper online. Exceptions to this rule include large datasets that cannot be accommodated within Extended Data; video material; and more complex “Supplemental Methods” (and any associated references) that do not readily fit within the constraints of the Methods/Extended Data formats. Please note that after the paper has been formally accepted you can only provide amended Supplementary Information files for critical changes to the scientific content, not for style. You should clearly explain what changes have been made if you do resupply any such files.

SOURCE DATA: To further increase transparency, we encourage authors to provide, in spreadsheet form, the data underlying any graphical representations used in the figures. This is in addition to our well-established data-deposition policy for specific types of experiments and large datasets. Readers of the online manuscript will be able to access the Source Data directly from the figure legend. Spreadsheets can only be submitted in .xls, .xlsx or .csv formats. One file per figure is permitted; thus, if there is a multi-panelled figure the Source Data for each panel should be clearly labeled in the csv/Excel file; alternatively the data for a figure can be included in multiple, clearly labeled sheets within an Excel file. File sizes of up to 30 MB are permitted; however, it is expected that the vast majority of Source Data files will be considerably smaller than this. When submitting these files with your manuscript, please select the file type “Source Data” and use the title
field in the file description tab to indicate the figure to which the Source Data pertain.

In the event that we are able to accept the next version of the paper, we shall need the following electronic files:

* A cover letter describing your response to any editorial comments and detailing any format changes during revision, particularly if the overall length is affected.
* A point-by-point response to any remaining issues raised by our referees.
* The final version of your text as a Word document (Word Equation Editor/MathType should be used only for formulae that cannot be produced using normal text or Symbol font). If this is not possible, please provide the manuscript as a single plain vanilla TeX or LaTeX file that includes all references and abbreviations, with no special formatting, as well as a PDF version that is uploaded as a 'related manuscript file'.
* Production-quality versions of all figures (for details see http://s3-service-broker-live-19ea8b98-4d41-4cb4-be4c-d68f4963b7dd.s3.amazonaws.com/uploads/ckeditor/attachments/7822/3c_Final_artwork.pdf). As we must be able to edit the figures so that they conform to our house style, the submission of files that are incorrectly formatted, flattened, or of insufficient resolution may delay final acceptance of your manuscript.
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We hope to hear from you within two weeks; please let us know if the process may take longer.

Yours sincerely

Karl Ziemelis
Physical Sciences Editor, Nature
Nature's author and policy information sites are at www.nature.com/nature/submit/.

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Referees' comments:

Referee #1 (Remarks to the Author):

This paper describes the first demonstration of ionization cooling by the Muon Ionization Cooling Experiment (MICE) collaboration. The result represents the first step, and a major milestone, on the road to developing accelerator systems for manipulating and producing high quality muon beams. The paper is clear and thorough. The amount of effort required was obviously huge and involved a synthesis of activities in hardware development, machine operation, software development, data acquisition, and data analysis. The adoption of techniques from High Energy Physics experiments to enable measuring the position and momentum of every muon individually passing through the beamline is truly exceptional. For all the reasons this paper deserves to be published in Nature.

I have only two technical comments:

(1) I do not understand the statement, "The correction is described in the Methods section." The draft of the manuscript that I read did not show any sections. Should this say, "... the Methods section of [some citation]" ?

(2) I am surprised that the paper does not attempt to quantify the amount of cooling or density increase. I realize that beam loss would complicate the analysis, but can't the authors find a way to quantify the amount of density increase in the beam core? I would expect this to be possible based on the data that were used to produce Figures 3, 4, and 5.

Referee #2 (Remarks to the Author):

This article reports an important achievement, the first experimental demonstration of ionization cooling, which could be an essential ingredient for a possible future muon collider.

The paper can, and should, be published after the authors have considered the following comments and questions.

In Figs. 3, the scraping effects are significant, more significant even than the cooling, while the equilibrium emittance of the cooling channel

is close to the initial emittance. Indeed, the final equilibrium emittance looks very close to what one could have achieved with scraping alone. It is a bit surprising to me that the experiment was conceived in this way, and that there is not more margin between the equilibrium emittance and the onset of scraping. Perhaps this situation deserves a brief explanation or comment. Why is there so little separation between the amplitude of scraping and the equilibrium emittance in the cooling channel, and, also, how could, or would, a real ionization cooling system for a collider achieve an orders-of-magnitude smaller emittance compared with this demonstration?

In the abstract, line 2 “Such beams have the potential … “-> “Such beams would have the potential”

Line 21, “Muon beams are created”->”Muon beams can be created” (since other methods and proposals for muon production exist)

Line 32” “High-brightness muon beams have not yet been produced at energies comparable to state-of-the-art electron and proton beams” – This sentence slightly puzzles me. Have very bright muon beams been produced at other energies?
What is the definition of a high-brightness muon beam?

Line 41, “making collisions possible” -> “potentially enabling collisions “; also an argument could be given why muon beams are ideal candidates; at first glance, the fact that the muons are unstable and decay within less than a 1000 turns does not look extremely ideal for acceleration and collisions; how should/could the energies far in excess of electron-positron colliders be attained before the muons decay? Perhaps at least a reference can be given.

In Equation (1), the emittance seems to have units of m^2/s, while in Eq. (5) and later in the text the unit is m or mm. I think there might be a factor “c “or perhaps “beta c” missing in Eq. (1).

In line 157-159, “excluding particles … in higher amplitude bins … results in a distribution that, in the core of the beam, is independent of scraping effects and aberrations…” - is this necessarily correct? For example chromatic aberrations could well affect the transverse core of the beam, for example, unless there also is a cut in momentum deviation.

Line 173, Eq. (7) is not common for accelerator physics and not easy to understand. Perhaps one more sentence of explanation would help? In addition, could one alternatively have chosen d=5 if the momentum deviation had been included as fifth dimension ?

Line 191, “4T” ->”4 T”, with a blank.

Line 233, perhaps the experimental value of beta_\perp could be given/recalled here.

Line 275 “.. in a muon collider collective effects become significant only at very low longitudinal emittance [50]” - I suspect this statement refers only to space charge effects, discussed in the reference, and not to any other type of collective effects, e.g. possible ionization-

related two-stream instabilities (hosing, self modulation, ionization-electron-driven beam breakup type of effects). The density of the ionizing material is high and the beam energy low, and the final muon beam will be bright. For example, long high-energy proton bunches suffer self modulation when passing through a plasma… could something similar happen here? Perhaps “collective effects” should be replaced by “space-charge effects”, pending further studies.

Line 328, should the term “normalised emittance” be defined?

Page 7 and figure 3, the “scraping” effect could be explained. What is it? Are muons lost or scattered when they hit an aperture? Could some of them be scattered towards the core, possibly resulting in a fake ionization cooling signal?

Line 479: The ingredients of the simulation for Fig. 4 could be indicated or a reference be given.