INTRA-BEAM IP FEEDBACK STUDIES FOR THE 380 GEV CLIC BEAM DELIVERY SYSTEM

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Abstract

In its currently-envisaged initial stage, the Compact Linear Collider (CLIC) will collide beams with a 380 GeV center of mass energy. To maintain the luminosity within a few percent of the design value, beam stability at the interaction point (IP) must be controlled at the sub-nanometer level. To help achieve such control, use of an intra-pulse IP feedback system is planned. With CLIC's very short bunch spacing of 0.5 ns, and nominal pulse duration of 176 ns, this feedback system presents a significant technical challenge. Furthermore, as part of a study to optimize the design of the beam delivery system (BDS), several L* configurations have been studied. In this paper, we will review the IP feedback simulations for the 380 GeV machine for two L* configurations, and compare luminosity recovery performance with that of the original L* configuration in the 3 TeV machine.

INTRODUCTION

As part of the planned phased commissioning of the CLIC facility, an initial stage with an electron-positron collision energy of 380 GeV is under investigation. Being a new lattice with new requirements, the 380 GeV machine must be studied in detail, particularly in regards to the capabilities of the machine to deliver the required luminosity to the particle physics program.

In order to deliver maximal luminosity, a feedback (FB) system is required which interacts directly with the machine to correct perturbations of the beam from the nominal orbit. The beam delivery system (BDS), located in the region immediately adjacent to the interaction point of the collider, contains an IP feedback system (shown in Fig. 1, from [1]) which is capable of iteratively correcting the beam position several times within a single train, increasing the luminosity with each iteration.

There are several versions of the new 380 GeV lattice, two of which will be discussed in this paper. These versions differ in the distance between the final quadrupole and the IP, a distance called L*. In one version, the L* is 4.3 meters (identical to the 3 TeV lattice design from 2010 [1]). In the other, this distance has been increased to 6 meters.

In this paper, the authors will investigate the ability of the intratrain IP feedback system to recover the luminosity lost due to five different models of ground motion (GM). These results will be compared to those previously obtained by Resta López, et. al. [1, 2].

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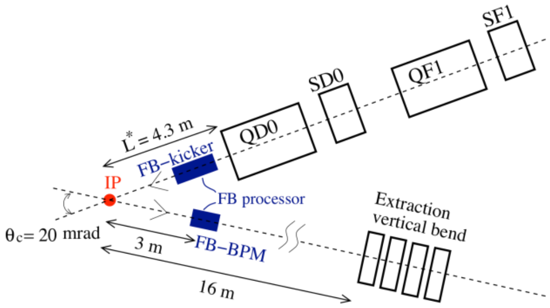

Figure 1: IP Feedback system at CLIC. L* is indicated.

BACKGROUND

In the previous studies for the 3 TeV system, the effects of 4 models of ground motion (A, B, C, and K) were investigated [3]. At this energy, the length of the train of particles was optimized to be 156 ns. Additionally, a BPM resolution of 1 μm was used for the simulations.

Using the simulation programs PLACET and GUINEA-PIG [4-6], 100 random seeds of ground motion were applied to the BDS and the luminosity recovery due to the IP feedback system was simulated. The FB BPM would detect the outgoing offset angle, which is directly related to the incoming position offset (see [1] for a full discussion). This signal is then sent to the electronics of the FB system, and the kick required to correct the beam offset is calculated and applied at the FB kicker, located upstream of the IP. Due to particle time of flight and electronic delays, a system latency of 37 ns is assumed [1]. Given this latency, and the 156 ns train length, the IP feedback system is capable of applying four iterations of corrections to the beam within a single train.

Figure 2 (from [1]) shows the average luminosity loss recovered at various IP kicker gain settings when 100 random seeds of GM model C are applied to the BDS. The error bars shown are the standard deviation divided by the nominal luminosity. The peak of this plot shows that the system can be corrected to better than 45% total luminosity loss from the initial 70% loss caused by the ground motion.

Figure 3 (from [1]) shows the performance of the IP FB system with the application of a single seed of GM model C to the BDS. In this case, the gain is chosen at the peak of the curve in Fig. 2. The nominal luminosity of this 3 TeV system is 6.223 × 10^{34} $cm^{-2}s^{-1}$. The first iteration shows the greatest recovery in luminosity, which each successive iteration continuing to improve, but by smaller amount.

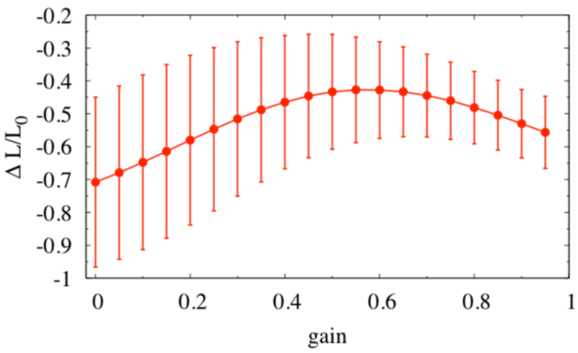

Figure 2: Relative luminosity loss vs. kicker gain

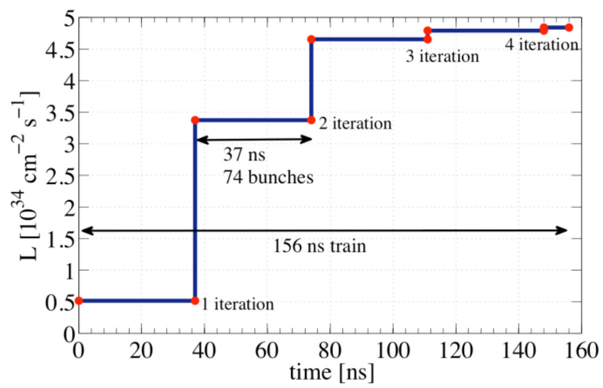

Figure 3: Luminosity recovery for single seed of GM

CURRENT INVESTIGATION

Using the LinSim [7-9] framework of PLACET and GUINEA-PIG, 5 GM models were investigated. In addition to the four models investigated previously, model D has been included in the study. Model D is a variation of model B with an amplified peak to match technical noise, and should be the worst case that the CLIC project would experience. However, in order to compare the previous studies with the present, the more extreme ground motion model C will be the focus of this work.

Determination of Gain

In a manner similar to that shown in Fig. 2, the value of the gain applied to the IP kicker is determined by simulating 100 random seeds of ground motion for each model. The value, or range of values, which shows the greatest luminosity recovery is used as the IP kicker gain setting for the final simulation of the IP feedback system.

Figure 4 shows the results of this gain scan for the 4.3 meter L* configuration in the 380 GeV machine under the application of GM model C. For this configuration, the maximum total luminosity is 1.82×10^{34} cm^{-2}s^{-1}. The highest luminosity recovery for this case is found at a gain setting of 0.4, which corresponds to a recovery of better than 42% luminosity loss from the initial loss of nearly 75%. For the 6 meter L* configuration under the application of GM model C, one can see from Fig. 5 that the peak luminosity recovery, corresponding to better than

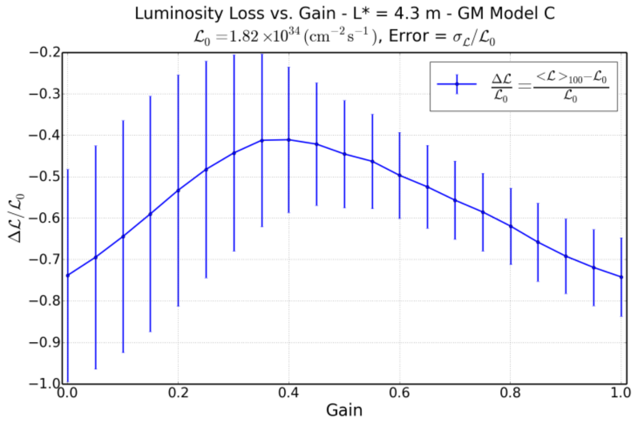

Figure 4: Relative luminosity loss vs. kicker gain for the 380 GeV BDS with an L* of 4.3 meters.

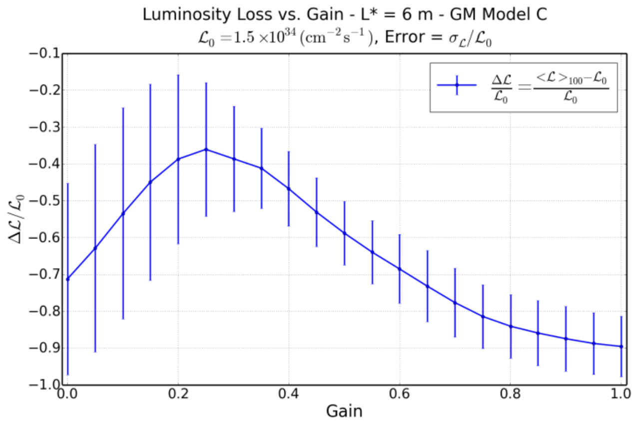

Figure 5: Relative luminosity loss vs. kicker gain for the 380 GeV BDS with an L* of 6 meters.

35% luminosity loss from the initial 72%, occurs at a gain of 0.25. The maximum total luminosity for this configuration is 1.5×10^{34} cm^{-2}s^{-1}.

A similar process is performed for each of the ground motion models. For a more in-depth discussion regarding the determination of the IP kicker gain strength, including the mathematics and conversions required, please refer to the discussion in reference [1].

Luminosity Recovery

Using the gain value which corresponds to the highest recovery of lost luminosity, one can plot the luminosity against the time in the timeframe of one bunch train. This shows the effects of each correction iteration, just as in Fig. 3. However, rather than plotting the luminosity recovery for a single seed of applied GM model C, the average luminosity recovery from 100 random seeds of the same model are shown in Figs. 6 and 7. Furthermore, the shaded band around the average value represents the error on the mean. Figure 6 shows the recovery for the 4.3 meter L* configuration, where four distinct iterations can be seen within the length of one bunch train. Each iteration corresponds to an increase in luminosity. Figure 7 is the analogous plot for the 6 meter L* configuration. This procedure was completed for all five models of ground motion. The results are summarized in Table 1.

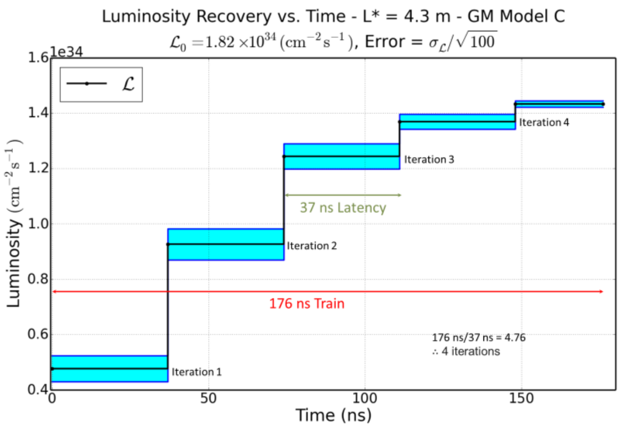

Figure 6: Luminosity recovery vs. time for the 380 GeV BDS with an L* of 4.3 meters.

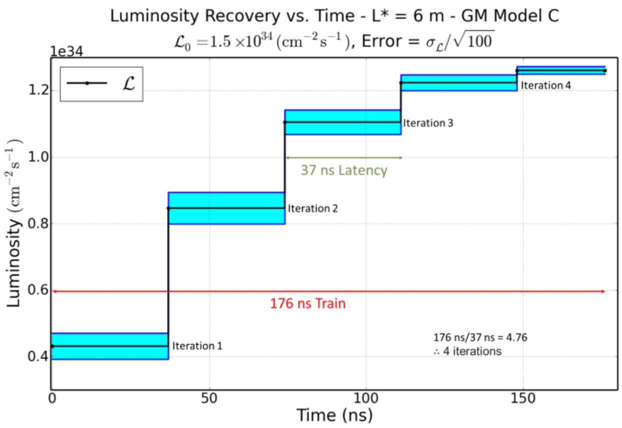

Figure 7: Luminosity recovery vs. time for the 380 GeV BDS with an L* of 6 meters.

Table 1: Comparison of Luminosity Loss After IP Feedback Correction for 5 GM models

GM Model	3 TeV L* = 4.3 m (2010)	380 GeV L* = 4.3 m	380 GeV L* = 6 m
A	0.1%	0.1%	0.1%
B	3%	3%	3%
C	45%	42%	35%
D	No Data	9%	6%
K	35 %	20%	18%

RESULTS

Table 1 summarizes the results for the simulations of the IP feedback system for all 5 models of ground motion as applied to both configurations of the 380 GeV beam delivery system. It also compares these results to those from the 3 TeV study performed previously. All of the percentage values shown represent the total relative luminosity loss after recovery from the application of ground motion. The average luminosity recovery is better than the value shown.

Generally, the luminosity recovery due to the IP feedback system is able to achieve similar results for both 380 GeV configurations. Furthermore, these results are generally as good or better than those achieved in the 3 TeV study. The most marked improvement is in the case of GM model K, where both 380 GeV configurations improved by over 15% when compared to the 3 TeV luminosity recovery. Additionally, the 6 m L* configuration achieved more than a 10% improvement for GM model C over the 3 TeV system.

CHALLENGES

There are several challenges which must be addressed prior to expanding these studies. Two of these are:

- At times, the system converges to a near-maximal luminosity rapidly, and then continues to try correcting, leading to a decrease in luminosity. This has been observed in several models. Likely, this is due to the selection of a gain value which is slightly too high or too low. An extra step in the simulation process will be added to narrow down the proper gain setting prior to performing the luminosity recovery study.
- The beam distribution at the IP is not always an ideal case. The IP feedback system attempts to steer the beam offsets to the zero position. This will only achieve maximum luminosity under the assumption that the beam is distributed at the IP in a near-ideal manner. If the beam distribution is significantly different from the ideal case, collisions occurring with a slight offset could result in higher luminosities than collisions with a zero beam offset. To address this, the feedback system would need to have a method to steer to positions obtaining maximum luminosity rather than the zero position, or the beam would need to be tuned to a more-ideal distribution. Addressing this issue is a more complex challenge than the previous.

FUTURE WORK

The authors intend to expand upon this work in the future by addressing several challenges. Combining misalignments and adding more complex perturbations and realistic conditions are the obvious expansions to the current studies. However, correcting the electron and positron beamlines independently presents a much larger task, and will be addressed. Furthermore, more complex correction schemes, which are capable of greater corrections to the beam in a fewer number of iterations, shall be investigated.

ACKNOWLEDGEMENT

Many thanks to Javier Resta López for his time and assistance in this work. Additional thanks to the CLIC project and the Feedback On Nanosecond Timescales (FONT) project.

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ANNEX B:
IEEE REFERENCE STYLE GUIDE AS APPLIED TO JACoW PAPERS, PERIODICALS AND OTHER WORKS

Referencing JACoW Proceedings

The format for published JACoW proceedings papers can be readily deduced from [1-3].

Author Listing Careful attention should be given to the placing of commas and the use of 'and' in the author list. In particular, for the case of three or more authors (as in [3]), a comma also follows the penultimate author. The preference for *et al*. takes precedence when the number of authors becomes large (e.g., ≥ 6).

Paper Title As is modern practice in references, the title of the paper is written in sentence case, i.e., only the initial letter of the first word in the title is capitalized. Proper nouns, however, also have a capital. Capital letters appearing in acronyms likewise remain unaltered.

Conference Proceedings The proceedings title is written in title case in italics using standard abbreviations, such as *Int.* and *Conf.* The preposition, "in", in normal font, precedes the proceedings title. The location, i.e., city, state (if USA), and country of the conference venue, the month (three-letter abbreviation) and the year the conference took place, is then listed. Finally, details pertaining to the paper itself, such as the conference paper ID and mandatory page numbers are given. The conference paper ID is optional, and may be included in the interest of facilitating a search through internet search engines. The complete or abbreviated form for citations, as shown in the following section, is recommended. The former is more informative to readers outside the immediate conference sphere. Both forms, however, ensure a proper import into digital libraries and information sources such as INSPIRE, Scopus, and Google Scholar. To this end, the minimal form is also listed for convenience. Although this form is not advocated, it nevertheless remains acceptable. Authors are also reminded to make a distinction between papers published in JACoW proceedings (which will always have page numbers) and those papers that may have been presented at past JACoW conferences but were not published [4]. References to contributions presented at the same conference should be written as shown in [5]; the wording "this conference" may be optionally appended.

Referencing Periodicals and Other Sources

The IEEE style is also shown for periodicals [6-11], online sources [12], books [13, 14], internal reports [15], theses [16], manuals or handbooks [17], patents [18] and unpublished material [19, 20]. Examples of correctly formatted references can be found at the JACoW website, under 'Formatting Citations' which is reached through the 'for Authors' link.

Alignment of References

Entries to the References section follow a hanging indent structure. In this way, reference numbers in the first line of each reference entry are right aligned, while subsequent lines within a given reference are indented by a specified amount. The indentation values for Word are shown in Table 1 and depend on whether the number of references exceeds single digit values.

In the LaTeX template, \bibliography{9} is used for when the total number of references is less than ten. This should be changed to \bibliography{99} if the number of references is ten or more.

Table 1: Formatting of References

Font	**Left Indent**	**Hanging Indent**	**Space Before**	**Space After**
		No. References ≤ 9		
9 pt, justified	0.00 cm 0.00 in	0.52 cm 0.20 in	0 pt	3 pt
		No. References ≥ 10		
Refs. 1 to 9				
9 pt, justified	0.16 cm 0.06 in	0.52 cm 0.20 in	0 pt	3 pt
Refs. 10 onwards				
9 pt, justified	0.00 cm 0.00 in	0.68 cm 0.26 in	0 pt	3 pt

PAPER PUBLISHED IN A CONFERENCE PROCEEDINGS

Complete Form

[1] A. Alpha and B. T. Beta, "An interesting paper", in *Proc. 1st Int. Particle Accelerator Conf. (IPAC'10)*, Kyoto, Japan, May 2010, paper MOP057, pp. 567-569.
[Conference Proceedings, two authors; optional paper ID]

[2] A. Alpha *et al*., "A fascinating paper about FELs", in *Proc. 35th Int. Free-Electron Laser Conf. (FEL'13)*, New York, NY, USA, Aug. 2013, paper WEP033, pp. 27-29.
[Conference Proceedings, for six or more authors use *et al.;* paper ID is optional]

[3] A. Alpha, B. T. Beta, C. Gamma, and D. Delta, "An overview of control systems", in *Proc. 13th Int. Conf. on Accelerator and Large Experimental Physics Control Systems (ICALEPCS'11)*, Grenoble, France, Oct. 2011, paper TUP014, pp. 89-91.
[Conference Proceedings, four authors; optional paper ID]

Abbreviated Form

[1] A. Alpha and B. T. Beta, "An interesting paper", in *Proc. IPAC'10*, Kyoto, Japan, May 2010, paper MOP057, pp. 567-569.
[Conference Proceedings, two authors; optional paper ID]

[2] A. Alpha *et al.*, "A fascinating paper about FELs", in *Proc. FEL'13*, New York, NY, USA, Aug. 2013, paper WEP033, pp. 27-29.
[Conference Proceedings, for six or more authors use *et al.;* paper ID is optional]

[3] A. Alpha, B. T. Beta, C. Gamma, and D. Delta, "An overview of control systems", in *Proc. ICALEPCS'11*, Grenoble, France, Oct. 2011, paper TUP014, pp. 89-91.
[Conference Proceedings, four authors; optional paper ID]

Minimal Form

[1] A. Alpha and B. T. Beta, in *Proc. IPAC'10*, pp. 567-569.
[Conference Proceedings, two authors]

[2] A. Alpha *et al.*, in *Proc. FEL'13*, pp. 27-29.
[Conference Proceedings, for six or more authors use *et al.*]

[3] A. Alpha, B. T. Beta, C. Gamma, and D. Delta, in *Proc. ICALEPCS'11*, pp. 89-91.
[Conference Proceedings, four authors]

UNPUBLISHED PAPER PRESENTED AT A PREVIOUS CONFERENCE

Complete Form

[4] A. Alpha and B. T. Beta, "An interesting talk", presented at the 5th Int. Particle Accelerator Conf. (IPAC'14), Dresden, Germany, Jun. 2014, paper MOP057, unpublished.
[Unpublished paper; conference name in normal font; paper ID may only be given if material supplementing the proceedings exists on the JACoW website, e.g., PDF of talk]

Abbreviated Form

[4] A. Alpha and B. T. Beta, "An interesting talk", presented at IPAC'14, Dresden, Germany, Jun. 2014, paper MOP057, unpublished.
[Unpublished paper; conference name in normal font; paper ID may only be given if material supplementing the proceedings exists on the JACoW website, e.g., PDF of talk]

PAPER PRESENTED AT THE CURRENT CONFERENCE

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[5] A. Alpha and B. T. Beta, "An interesting talk", presented at the 7th Int. Particle Accelerator Conf. (IPAC'16), Busan, Korea, May 2016, paper MOAB01, this conference.
[Current conference; conference name in normal font; the wording "this conference" is optional]

Abbreviated Form

[5] A. Alpha and B. T. Beta, "An interesting talk", presented at IPAC'16, Busan, Korea, May 2016, paper MOAB01, this conference.
[Current conference; conference name in normal font; the wording "this conference" is optional]

PAPER PUBLISHED IN, OR SUBMITTED TO, A PERIODICAL

[6] P. Mercury *et al.*, "Title of paper published in journal", *Phy. Rev. Lett.*, vol. 114, no. 5, p. 050511, Feb. 2014.
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[Periodical, paper accepted for publication by Phys. Rev. Lett.]

[11] G. D. Read, "Title of paper submitted for publication", submitted for publication.
[Paper submitted for publication; the name of the periodical does not appear]

ONLINE SOURCE

[12] JACoW, `http://www.jacow.org`
[online source; no hyperlink, no period at end of URL unless there is a trailing "/" as shown below. A monospace font, such as Lucida Sans Typewriter (size 8 pt), is used in Word, while the 'url' package in LaTeX uses the Latin Modern Typewriter font]

[12] JACoW, `http://www.jacow.org/`.
[online source; no hyperlink, period after traling "/" in URL allowed. A monospace font, such as Lucida Sans Typewriter (size 8 pt), is used in Word, while the 'url' package in LaTeX uses the Latin Modern Typewriter font]

CITATIONS TO BOOKS

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[Thesis]

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[Handbook/Manual, no hyperlink, no period after URL]

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UNPUBLISHED WORK AND PRIVATE COMMUNICATION

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[Unpublished]

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[Private communication]

ANNEX C: THE DILIGENT AUTHOR'S CHECKLIST

Common Oversights

In order to lessen the load on a small team of editors and to help expedite publication of the Proceedings, authors are kindly asked to give themselves an extra few minutes to go over the following points, which highlight the most common errors, before uploading their paper. By providing a properly formatted JACoW paper, the Proceedings Office is able to benefit from an autodistill process which automatically converts the author's PDF file into a version that adheres to the JACoW-compliant PDF standard. The process further ensures that all fonts required to view the entire document are embedded, rendering a final PDF that qualifies technically for publication.

Author and Affiliation Listing

The names of authors and their affiliations should be in 12 pt uppercase and lowercase letters, with standard, roman fonts (i.e., not italics). When there is more than one author, the submitting author should be first, followed by the co-author. Co-authors should be grouped by affiliation and then be listed alphabetically. Please refer to **ANNEX A** for further details and examples, particularly for the case where authors have multiple institutes.

Title, Abstract, and Author Listing in the SPMS

Authors are prompted to verify that the title, the abstract and the author/institute listing, previously submitted to the SPMS, has been updated to match that now appearing in the final manuscript. In particular, primary authors are reminded that it is their responsibility to check the accuracy of the co-authors entered in the SPMS database. These should be an exact match to that appearing in the paper. This is required to ensure the proper indexing of authors to papers in the published proceedings.

Subsection Headings

Subsection Headings use 12 pt *italic* lowercase and uppercase. The initial letter of every principle word is capitalized, and the heading is left aligned in the column.

Figure Captions

Figure captions should be placed *below* the figure and centred if on one line, but justified if spanning two or more lines:

Figure 1: A one line figure caption is centred.

Figure 2: A lengthy figure caption that spans two lines is justified.

Note the colon ":" after the figure number and the period "." at the end of the caption.

When referring to a figure from within the text, the convention is to use the abbreviated form, i.e., Fig. 1, *unless* the reference to the figure is at the start of the sentence:

Figure 1 shows a schematic view of...

... as shown in Fig. 1.

Table Headings

Table captions should be placed *above* the table and centred if on one line, but justified if spanning two or more lines:

Table 1: Table Heading

Table 2: A Particularly Long Table Heading Spanning Two Lines

Note the colon ":" after the table number, that the initial letters of the principle words in the table heading are capitalized, and the absence of a period at the end of the caption.

When referring to a table from within the text, the convention is NOT to abbreviate, i.e., Table 1.

Equations

If a displayed equation requires a number, it should be placed flush with the right margin of the column. Please leave sufficient space immediately before and after the equation, i.e., in Microsoft Word, 12 pt before and after.

Units

An unbreakable space should always precede a unit. Examples are: 3 keV, 4 GeV, 100 kW, 7 μm.

References

References are written in 9 pt size and should be neatly presented in a consistent format with reference numbers aligned. Please refer to **ANNEX B** for the preferred format and proper alignment.

Please also ensure that references in the text are cited in sequential order.