Calculation of the Supersymmetric top quark mass at CLIC

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Abstract

In this project I calculate the mass of the Supersymmetric top quark in CLIC experiment at $\sqrt{s}=3$ TeV in $e^ e^+$ collisions. I assume the following decay for the top squark $\tilde{q} \to q \chi_0$, and I focus on the fully hadronic channel of decay i.e $\tilde{q} \to q \chi_0 \to Wb\tilde{\chi}_1^0$. The mass was found to be $m_{\tilde{t}}=861\pm19$ GeV using the Boosted Descision Trees Multivariate Analysis and $m_{\tilde{t}}=812\pm20$ GeV using the Gradient Boosted Descision Trees Multivariate Analysis.

Declaration

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Acknowledgements

Put your acknowledgements here. Thanking your supervisor for his/her help is standard practice, but you don't have to do this...

This template is is modification of the one for the MSc in High Performance Computing, which is apparently descended from a template developed by Prof Charles Duncan for MSc students in Meteorology. His acknowledgement follows:

This template has been produced with help from many former students who have shown different ways of doing things. Please make suggestions for further improvements.

Some parts of this template were lifted unashamedly from the Edinburgh MPhys project report guide, with little or no modification. I have no idea who wrote the first version of that...

You don't have to use LaTeX for your dissertation. You can use Microsoft Word or Apple Pages if you wish, but it's *much* easier to typeset equations in LaTeX, and references look after themselves. Whatever you use, your dissertation should have the same general structure, and it should look similar to this one – especially the front page.

Introduction

On July 2012 the discovery of the Higgs boson was announced at CERN's Large Hadron Collider (LHC). This marked the begining of a new era for experimental High Energy Physics motivating the design of new experiments for further and deeper exploration of the Higgs boson itsel but also, addressing the questions/problems that arose with it.

One of these experiments is Compact Linear Collider (CLIC), a high-luminosity linear $e^ e^+$ collider. It is designed for a staging scenario of three main centre of mass energies at $\sqrt{s}=380$ GeV, $\sqrt{s}=1.5$ TeV and $\sqrt{s}=3$ TeV targeting optimal physics output based on the current land-scape. The main difference of CLIC with LHC is that in the latter, protons collide which are non fundamental particles as they consist of quarks and gluons bound alltogether. One of the disadvantages of LHC is the inability to know beforehand the initial state of the colliding particles as quarks exist in a "sea of gluons" making it impossible to know their momenta. This sets some restrictions with respect to the precision that it can probe various observables.

On the other hand, CLIC is designed to invastigate the interactions of elementary particles, an important advantage since initial states of the colliding particles is known. In advance, LHC suffers from energy loss due to Synchrotron radiation since protons are accelerated in a 27 km circular accelerator whereas CLIC, being linear does not.

The main targets of CLIC are dependent of the energy stage. In the first it will focus on prescision standard model physics such as Higgs and Top quark measurements and in the two subsequent, among others, there will be searches for new physics [1]. One of the theories that aspires to give solutions to many of the problems of Standard Model is Supersymmetry (SUSY). In

this theory every particle has a Supersymmetric partner that differs in the spin by 1/2, thus relating bosons with fermions and fermios with bosons.

In the Minimal Supersymmetric Standard Model, the top squarks \tilde{t} decay almost all the times into a top quark t and a dark matter candidate, the neutralino $\tilde{\chi}^0_1$. In this project I will use Multivariate Analisis to discriminate the best it can be achieved between signal and background with the goal to measure the top squark mass at $\sqrt{s}=3$ TeV in the CLIC accelerator environment.

CLIC

2.1 Outline of the experiment

CLIC is a proposed $e^ e^+$ linear collider optimised to perform in three centre of mass stages at $\sqrt{s} = 380 \text{ GeV}$, $\sqrt{s} = 1.5 \text{ TeV}$ and $\sqrt{s} = 3 \text{ TeV}$. The purpose of the different energy stages is to fully exploit its scientific potential including precision measurements and searches for physics Beyond the Standar Model.

Specifically, at $\sqrt{s} = 380$ GeV and with an integrated luminosity of $\mathcal{L}_{int} = 500 \text{ fb}^{-1}$, prescision measurements can be made in the Higgs and the top quark sector. At this enegy stage the Higgsstrahlung process $(e^+e^- \to ZH)$ alongside the WW fusion $(e^+e^- \to H\nu_e\tilde{\nu}_e)$ are the dominant and can shed light to properties of the Higgs boson in a model independent way [1]. Furthermore at the next two stages leading role will play the propsed scenarios for physics BSM with most importantly Supersymmetry at $\sqrt{s} = 3$ TeV and with $\mathcal{L}_{int} = 2000 \text{ fb}^{-1}$. This is because CLIC has the potential for direct particle detection up to the kinematic limit of $\sqrt{s}/2$ but also through indirect detection of observables that are sensitive to BSM scenarios exploiting the full energy potential.

Given the linear nature of CLIC, there are no energy losses induced by Synchrotron radiation which appears in circular colliders, but due Beamsstrahlung radiation. As the colsliding bunches get closer to the vertex, the strong electromagnetic fields (up to 10 Tesla) created by the opposing beam cause deflection of the partices trajectories resulting to emit Synchrotron radiation. The effect is energy-dependent with huge impact at higher energies [2] as it can be seen in the following image [3].

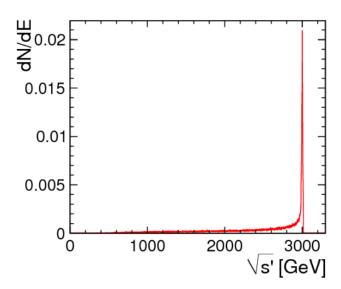


Figure 2.1: The luminosity spectrum for CLIC operating at $\sqrt{s}=3$ TeV, where $\sqrt{s'}$ is the effective centre-of-mass energy after beamstrahlung and initial state radiation

Supersymmetry

This section should be written in standard scientific language. Standard techniques in your research field should not be written out in detail. In computational projects this section should be used to explain the algorithms used and the layout of the computational code. A copy of the actual code may be given in the appendices if appropriate.

This section should emphasise the philosophy of the approach used and detail novel techniques. However please note: this section should not be a blow-by-blow account of what you did throughout the project. It should not contain large detailed sections about things you tried and found to be completely wrong! However, if you find that a technique that was expected to work failed, that is a valid result and should be included.

Here logical structure is particularly important, and you may find that to maintain good structure you may have to present the explorations/calculations/computations/what in a different order from the one in which you carried them out.

You might sometimes want to include multiple equations in one place

$$E = ma^2 (3.1)$$

$$E = mb^2 (3.2)$$

$$E = mc^2 (3.3)$$

You might want to include multiple equations in one place without numbering them

$$E = ma^2$$

$$E = mb^2$$

$$E = mc^2$$



Figure 3.1: The University Crest

You might want to include multiple equations in one place without numbering all of them

$$E = ma^{2}$$

$$E = mb^{2}$$

$$E = mc^{2}$$
(3.4)

You might also want to include diagrams. The example shows the use of the special command which allows existing postscript files to be included. You would normally keep your figures separate from the text. These pictures might be images or pdf output from some program.

Below I create a figure which is centred and stretched to 30% of the width of the page {0.30\hsize} and with the height stretched by the same amount {!} to preserve the aspect ratio. If you omit the extension (ie .eps, .ps or .pdf) on the file name then LaTeX will pick up the postscript copy whereas pdflatex will automatically pick up the PDF version.

You should find the file crest.pdf on this wiki.

You can use a label on a figure to refer to it later. The university crest is in Figure (3.1). Note that you should not use phrases like "the figure above" or "the following figure" since LATEX may move the figure relative to the text if it cannot be fitted onto the current page.

Another Chapter Title

4.1 Number of Chapters

You may vary the number of chapters. The Introduction and Background Theory chapter are essential, although you may choose a different title for the latter. These two introductory chapters are usually followed by a chapter on what you did yourself, with a title such as Design and Development, although you can choose any title you wish. After that, you might to have another chapter, or you may go straight to the Results and Conclusions chapter.

After the Introduction, you are free to use any chapter titles you wish.

Results and Analysis

This section should detail the obtained results in a clear, easy-to-follow manner. It is important to make clear what are original results and what are repeats of previous calculations or computations. Remember that long tables of numbers are just as boring to read as they are to type-in!

Use graphs to present your results wherever practicable.

Results or computations should be presented with uncertainties (errors), both statistical and systematic where applicable.

Be selective in what you include: half a dozen *e.g.* tables that contain wrong data you collected while you forgot to switch on the computer are not relevant and may mask the correct results.

5.1 Some results

Here are some results.

5.1.1 More results

When showing results you are likely to use tables and graphs. You can create tables easily in LaTeX.

If you want to produce fancier tables than shown in Table 5.1 refer to the LATEX manual or ask Google.

One of the simplest ways to produce simple graphs is to use gnuplot which produces LaT_FX output. Graph (5.1) was produced using gnuplot with output

File names	Satellite	Resolution
worldr	Meteosat	5km
worldg	Meteosat	$5 \mathrm{km}$
worldb	Meteosat	$5 \mathrm{km}$

Table 5.1: This is a simple table. More complicated tables can have headings which pass over more than one column

designated as LATEX so that a LATEX output file is produced which you can include directly or keep separate and refer to using the *include* command.

Another approach is to draw simple figures using xfig which allows you to export diagrams in LATEX picture format so that the diagram can be included directly.

Perhaps the most robust way to include graphs is to convert them to PostScript or PDF and include them in the same was as was done in Figure 3.1 for the University Crest. You can usually do this with most packages, including Microsoft ones; one trick for producing PostScript is to print to a dummy PostScript printer.

5.2 Discussion of your results

This section should give a picture of what you have taken out of your project and how you can put it into context.

This section should summarise the results obtained, detail conclusions reached, suggest future work, and changes that you would make if you repeated the project.

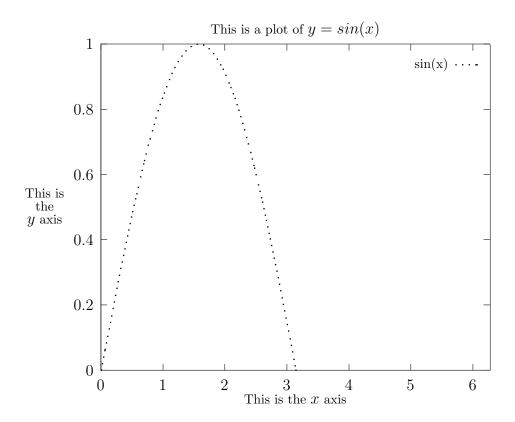


Figure 5.1: Simple Gnuplot example

Conclusions

This is the place to put your conclusions about your work. You can split it into different sections if appropriate. You may want to include a section of future work which could be carried out to continue your research.

The conclusion section should be at least one page long, preferably 2 pages, but not much longer.

Appendix A

Stuff that's too detailed

Appendices should contain all the material which is considered too detailed to be included in the main body of the text, but which is important enough to be included in the thesis.

Perhaps this is a good place to mention BibT_EX.

You can do references in the simple way explained in the introduction, or you can use ${\rm BiBT}_{\rm E}{\rm X}.$

$\mathbf{A.1}$ BIBT_EX

It is convenient to use BibTeX to compile your bibliography. First you need to create a .bib file e.g. you may call it ref.bib Then you can put all your references into the file with entries such as

```
@Book{ob:bornwolf,
    author = "Born, M and Wolf, E",
    title = "Principles of Optics",
    publisher = "Cambridge University Press",
    year = 1999,
    edition = {7th},
}

@Article{jr:ashkin,
Author = {A. Ashkin and J.M. Dziedzic and J.E. Bjorkholm and S. Chu},
Title = "Observation of a single beam gradient force optical tap for dielectric particles",
```

```
Journal = "Optics Letters",
Volume = 11,
Pages = "288-290",
Year = 1986}

@INPROCEEDINGS{seger,
  author = {J. Seger and H.J. Brockman},
  title = {What is bet-hedging?},
  editors={P.H. Harvey and L. Partridge},
  booktitle = {Oxford Surveys in Evolutionary Biology},
  year={1987},
  page={18},
  publisher={Oxford University Press},
  place={Oxford}}
```

for a book, an article in a journal or an article in a proceedings volume respectively.

Inside your LATEX file you should include

```
\bibliographystyle{unsrt}
and
\bibliography{ref}
```

The first command determines the reference style, here plain and unsorted. With this referencing style a numerical referencing system (which is now the most common in physics literature) is used and the numbering of references will be the order in which they appear in the document. Alternatively, you could use a customised 'style file' but there is no real need. The second command just inputs your .bib file Note that only the references cited in the text will appear in the bibliography so you can have spare references in your .bib file.

You use the name you have given to an entry (e.g. for the book example above the name is ob:bornwolf) to cite the relevant article by using the cite command in your LATEX file e.g. [?]

A.2 Producing your documents using pdflatex

To use pdflatex your figures need to be in pdf format. You can convert almost any image file to pdf using convert. e.g. convert myfigure.png myfigure.pdf.

The first time you should type:

pdflatex ProjectReport
bibtex ProjectReport
pdflatex ProjectReport
pdflatex ProjectReport

This first time you runpdflatex it will produce a ProjectReport.aux. The BIBTEX command reads in the bibliography file and makes the files ProjectReport.bbl and ProjectReport.blg files. These files are read in the next pdflatex command, but you'll still have "undefined cross-reference" errors which are sorted out by the last pdflatex command.

Subsequently, you should only need to do one (or two) pdflatexs, or pdfbibtex followed by pdflatex twice if you change any references.

You may also use plain latex instead of pdflatex. This requires you to use postscript graphics instead of pdf.

Appendix B

Stuff that won't be read by anyone

Some people include in their thesis a lot of detail, particularly lots of tables containing raw results, figures of intermediate results, or computer code which no-one will ever read. You should be careful that anything like this you include should contain some element of uniqueness which justifies its inclusion.

Bibliography

- [1] The CLIC, MJ Boland, U Felzmann, PJ Giansiracusa, TG Lucas, RP Rassool, C Balazs, TK Charles, K Afanaciev, I Emeliantchik, et al. Updated baseline for a staged compact linear collider. arXiv preprint arXiv:1608.07537, 2016.
- [2] Giovanni Bonvicini, E Gero, R Frey, W Koska, C Field, N Phinney, and A Minten. First observation of beamstrahlung. *Physical review letters*, 62(20):2381, 1989.
- [3] H Abramowicz, A Abusleme, K Afanaciev, N Alipour Tehrani, C Balázs, Y Benhammou, M Benoit, B Bilki, J-J Blaising, MJ Boland, et al. Higgs physics at the clic electron–positron linear collider. *The European Physical Journal C*, 77(7):475, 2017.