Design studies for a multi-TeV γ-ray telescope array : PeX (PeV eXplorer)

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Submitted in total fulfilment of the requirements
of the degree of Doctor of Philosophy

January 14, 2013

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Contents

NOTE: Pagination from Chapter 6 of the digital copy does not correspond with the pagination of the print copy.

Abstract

This thesis presents work towards the design of a new array of Image Atmospheric Cherenkov Telescopes (IACTs) to detect multi-TeV (E $> 10^{12}$ eV) γ-ray sources. The array consists of 5 telescopes in a square layout with one central telescope, known as the *Pevatron eXplorer* or *PeX*. PeX is a PeV (10^{15} eV) cosmic ray explorer that aims to study and discover γ-ray sources in the 1 to 500 TeV range. The initial PeX design has been influenced by the HEGRA CT-System and H.E.S.S. configurations. One important feature of multi-TeV air showers is their ability to trigger telescopes at large core distance ($>$ 400 m). PeX will utilise large core distance events to improve the performance and illustrate the viability of a sparse array for multi-TeV γ-ray astronomy.

In Chapter 1, I will discuss the astrophysical motivation behind multi-TeV observations. A number of γ-ray sources have shown emission that extends above 10 TeV, for example unidentified source HESS J1908-063. A new multi-TeV detector can provide a new look at the Galactic plane and work towards uncovering the origin of Galactic cosmic ray acceleration.

In Chapter 2, I will look at the physics of air showers, which involves the interaction of protons and γ-rays with the atmosphere to form a cascade of particles. I will discuss the lateral distribution for γ-rays and show the importance of large core distance shower for multi-TeV events. Gamma-ray showers with an image *size* $> 60pe$ can be detected up to 700 m away from PeX for 500 TeV showers.

In Chapter 3, I introduce PeX in detail along with the simulation programs used to model it. I discuss the standard shower reconstruction algorithm (Algorithm 1) and an advanced shower reconstruction algorithm (Algorithm 3). I also introduce the image parameters that I will investigate while optimising PeX, which include; site altitude, image triggering conditions, image cleaning conditions, telescope separation and image *size* cut.

In Chapter 4, I have optimised the PeX cell for a low altitude (0.22 km) observational site using Algorithm 1. Parameters such as telescope separation, triggering combination, cleaning combination and image *size* cut have been varied over a range of values to provide the optimum results for PeX.

In Chapter 5, I have optimised the PeX cell for a higher altitude (1.8 km) observational site using Algorithm 1. The same parameter variations considered in Chapter 4 have been used in Chapter 5. It appears that scaling the H.E.S.S. values to appropriate values for PeX provides the near optimum results. A comparison between the site altitudes suggests that a

0.22 km altitude provides the slightly better performance for energy > 10 TeV.

In Chapter 6, a new time cleaning cut has been investigated. The arrival time between photons in two adjacent pixels in the camera is used to apply an extra cut which helps mitigate night sky background. To illustrate the robustness of the time cleaning cut, various level of night sky background have been considered. These levels include: off-Galactic plane, on-Galactic plane and towards the Galactic centre. The most important result is that PeX performance with a time cleaning cut improves results when a high level of night sky background is present. For a Galactic centre level of night sky background there is a factor of 1.5 improvement in angular resolution, effective area and quality factor when a time cleaning cut is applied compared to using no time cleaning cut.

In Chapter 7, Algorithm 3 has been considered. A smaller sample of parameter variations has been simulated to confirm that the same trends found in Chapters 4 and 5 appear for Algorithm 3. The site altitude and time cleaning cut have also been considered. Algorithm 3 provides a direction reconstruction improvement over Algorithm 1 especially for large core distance events which are important for PeX.

In Chapter 8, I consider some possible enhancements to PeX. These enhancements include: varying pixel size and pixel arrangement in the camera, further cuts to rejection proton events and possible separation between proton and γ-ray pulses. Chapter 8 also provides the flux sensitivity results for multiple PeX configurations. The final configuration and flux sensitivity for PeX is presented in this Chapter. This work shows the value of a sparse array of Cherenkov telescopes to open up the > 10 TeV energy regime.

Declaration of Originality

I, Jarrad Denman certify that this work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. I give consent to this copy of my thesis, when deposited in the University Library, being made available for loan and photocopying, subject to the provisions of the Copyright Act 1968. The author acknowledges that copyright of published works contained within this thesis (as listed below*) resides with the copyright holder(s) of those words. I also give permission for the digital version of my thesis to be made available on the web, via the University's digital research repository, the Library catalogue and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

*Published works contained within this thesis:

Denman, J., Rowell, G., Stamatescu, V., Thornton, G., Dunbar, R., Clay, R., Dawson, B., Smith, A., Wild, N., Protheroe, R., 2008, American Institute of Physics (AIP) Conference Proceedings, Vol. 1085, p838

Rowell, G., Denman, J., Stamatescu, V., Thornton, G., Dunbar, R., Clay, R., Dawson, B., Smith, A., Wild, N., Protheroe, R., *In preparation*

Jarrad Denman **13th January, 2013**

Acknowledgements

Firstly I would like to thank my supervisors Dr. Gavin Rowell and Prof. Bruce Dawson for all their support, guidance and feedback over the last few years. I appreciate all the time my supervisors and Prof. Roger Clay have spent reading and correcting my thesis. I would also like the thank the rest of the *TenTen/PeX* collaboration: Dr. Greg Thornton, Dr. Andrew Smith, Tristan Sudholz, Neville Wild and Assoc. Prof. Ray Protheroe for all their helpful suggestions and comments. A special thanks to Dr. Victor Stamatescu for all the discussions we have had about different ideas and reconstruction algorithms.

I would like the thank my office-mate Dr. Vanessa Holmes for all her support and for putting up with me for all those years. I would like to thank the University of Adelaide and the School of Chemistry and Physics for the resources provided and Ramona Adorjan for the computer assistance. I would like to thank eResearch SA for the use of the super computer, which allowed me to complete my research. A special thank you to Dr. Ben Whelan, Dr. Brent Nicholas, Nigel Maxted and the rest of my friends who have provided some much needed social entertainment during my PhD.

Finally I would really like to thank my parents Helen and Peter, and my brother Christien for all the support they have given me during my years of studying. I could not have done this without them.

Public Display of Results

Here I summarise the contributions of conference posters, conference proceedings and published works of which I have been a part.

- **Conference Poster**:
  Optimising parameters for a multi-TeV IACT cell

  4^{th} Heidelberg International Symposium on High Energy Gamma-Ray Astronomy, Heidelberg, Germany (2008).

  $http://www.mpi-hd.mpg.de/hd2008/pages/news.php$

- **Conference Proceedings**:
  Optimising parameters for a multi-TeV IACT cell

  Denman, J., Rowell, G., Stamatescu, V., Thornton, G., Dunbar, R., Clay, R., Dawson, B., Smith, A., Wild, N., Protheroe, R., American Institute of Physics (AIP) Conference Proceedings, Vol. 1085, p838 (2008).

- **Conference Poster**:
  Design studies for a new multi-TeV gamma-ray telescope array

  Astronomical Society of Australia - Annual Scientifc Meeting, University of Melbourne, Melbourne, Australia (2009).

  $http://asa2009.science.unimelb.edu.au/Site/Home_Page.html$

- **Conference Poster**:
  PeV explorer (PeX): A new multi-TeV gamma-ray telescope

  Astronomical Society of Australia - Annual Scientifc Meeting, University of Adelaide, Adelaide, Australia (2010).

  $http://www.physics.adelaide.edu.au/astrophysics/asa2011/$

- **In Preparation**:
  Rowell, G., Denman, J., Stamatescu, V., Thornton, G., Dunbar, R., Clay, R., Dawson, B., Smith, A., Wild, N., Protheroe, R.