CONTENTS

| | | | | Page |
|--------|--------|-----------|--|------|
| ABSTR | ACT IN | ITHAI | | I |
| ABSTR | ACT IN | I ENGLISH | | II |
| ACKNO | DWLED | GEMENTS | | III |
| CONT | ENTS | | | V |
| LIST C | F TABL | _ES | | IX |
| LIST C | F FIGL | JRES | | X |
| LIST C | F ABBI | REVIATION | IS | XXI |
| CHAP. | TER | | | |
| I | INTRO | DUCTION | ١ | 1 |
| II | RESEA | ARCH BAC | KGROUND | 3 |
| | 2.1 | Concept | and design of proton computed tomography | 3 |
| | | 2.1.1 | Position-sensitive detector | 4 |
| | | 2.1.2 | Residual energy detector | 5 |
| | | 2.1.3 | Image reconstruction | 6 |
| | | 2.1.4 | Progression of pCT | 9 |
| | 2.2 | Proton in | nteraction with matter | 9 |
| | | 2.2.1 | Interaction mechanisms | 9 |
| | | 2.2.2 | Energy loss | 12 |
| | | 2.2.3 | Proton range | 13 |
| | | 2.2.4 | Energy and range straggling of proton | 15 |
| | | 2.2.5 | Multiple Coulomb scattering | 15 |
| | | 2.2.6 | Nuclear interactions | 17 |
| | 2.3 | Track rec | onstruction | 18 |
| | | 2.3.1 | Track finding | 18 |
| | | | Track following | 19 |
| | | 2.3.2 | Track fitting | 19 |
| | 2.4 | Monolith | ic Active Pixel sensors | 20 |
| | | 2.4.1 | Semiconductor physics | 20 |
| | | | Silicon electronics structure | 20 |

CONTENTS (Continued)

| | | Depletion region |
|-----|----------|--|
| | | Charge generation |
| | 2.4.2 | The ALICE detector |
| 2.5 | Cyclotr | on |
| | 2.5.1 | King Chulalongkorn Memorial Hospital Proton Center . |
| PRC | TON TRA | CK RECONSTRUCTION: MONTE CARLO SIMULATION AND |
| ANA | ALYTICAL | MODELS |
| 3.1 | | uction |
| 3.2 | Materia | al and method |
| | 3.2.1 | Layer material properties |
| | 3.2.2 | Beam modelling |
| | 3.2.3 | Physics list |
| | 3.2.4 | Data collection and conversion |
| | 3.2.5 | Particle track reconstruction |
| | | Track following algorithm |
| | | Searching cone |
| | | Scattering angle |
| | | Radiation Length |
| | | Linked list structure |
| | | Track efficiency |
| 3.3 | Results | and discussion |
| | 3.3.1 | Beam profile |
| | 3.3.2 | Energy deposition |
| | 3.3.3 | Proton track |
| 3.4 | Summa | ary |
| PRE | LIMINARY | : THE FPGA TRIGGER CONTROL SYSTEM INTERFACING |
| THE | TELESCO | DPE WITH KCMH BEAM TEST |
| 4.1 | Introdu | uction |
| 4.2 | | al and method |
| | | Pixel sensor telescope |

CONTENTS (Continued)

| | | | | Page |
|---|-------|-----------|---|------|
| | | 4.2.2 | ALPIDE Monolithic Active Pixel Sensor | 54 |
| | | 4.2.3 | EUDAQ framework | 55 |
| | | 4.2.4 | FPGA trigger system | 57 |
| | | 4.2.5 | The first generation of trigger | 59 |
| | | 4.2.6 | Basys3 FPGA | 59 |
| | | 4.2.7 | Signal amplification | 60 |
| | | 4.2.8 | Microcontroller | 61 |
| | | 4.2.9 | GUI interface | 62 |
| | | 4.2.10 | Signal operation | 63 |
| | | 4.2.11 | Varian ProBeam proton PBS system | 64 |
| | | | Treatment room | 65 |
| | | | Control room | 66 |
| | | | Proton beam in QA mode | 66 |
| | | | PBS beam | 68 |
| | | 4.2.12 | Experiment setup | 68 |
| | 4.3 | Results a | and Discussion | 69 |
| | | 4.3.1 | Trigger signal | 69 |
| | | 4.3.2 | Background measurement | 71 |
| | | 4.3.3 | KCMH beam test | 72 |
| | 4.4 | Summary | , | 73 |
| V | DESIG | SN STUDY | OF PCT TELESCOPE WITH TRACK RECONSTRUCTION $% \left(1\right) =\left(1\right) \left($ | 76 |
| | 5.1 | Experime | ental Setup | 76 |
| | 5.2 | Beam se | tup | 77 |
| | 5.3 | | dout and conversion | 78 |
| | 5.4 | Data ana | lysis | 79 |
| | | 5.4.1 | Noise and background | 79 |
| | | 5.4.2 | Clusterization | 79 |
| | | 5.4.3 | Track reconstruction | 79 |
| | | 5.4.4 | Survival tracks | 80 |
| | | | | |

CONTENTS (Continued)

| | | | | Page |
|-------|--------|-----------|----------------------|------|
| | | 5.4.5 | Correlation | 80 |
| | 5.5 | Results . | | 81 |
| | | 5.5.1 | Noise and background | 81 |
| | | 5.5.2 | Beam profile | 82 |
| | | 5.5.3 | Cluster distribution | 85 |
| | | 5.5.4 | Track reconstruction | 85 |
| | 5.6 | Summary | / | 89 |
| VI | SUMN | ARY AND | CONCLUSION | 94 |
| REFER | RENCES | | | 96 |
| CURRI | CULUN | Л VITAE . | | 105 |

LIST OF TABLES

| Table | F | Page |
|-------|---|------|
| 2.1 | A brief overview of recent and present prototypes for proton CT | |
| | (pCT) | 10 |
| 3.1 | The radiation length of material layers of ALPIDE sensor | 41 |
| 3.2 | The simulated beam characteristics of 70 MeV pencil proton beam. | 44 |
| 3.3 | The simulated beam characteristics of 200 MeV pencil proton beam. | 45 |
| 3.4 | The mean and standard deviation (sigma) of proton particles de- | |
| | posit energy in epitaxial layer of ALPIDE sensor. | 47 |
| 4.1 | Basys 3 labeled components and descriptions | 60 |
| 4.2 | Arduino Pro Mini 3.3V (3.3V/8MHz) pins connecting to Basys3 FPGA | |
| | and the usages | 62 |
| 4.3 | Proton beam parameters in Quality Assurance (QA) | 67 |
| 4.4 | Lynx PT measured the proton spot size (sigma, mm) of the KCMH | |
| | proton center from IBA dosimetry | 68 |
| 5.1 | Proton beam parameters in Quality Assurance (QA) | 77 |
| 5.2 | The pixel numbers that are activated with 50% of the dark test | |
| | entries | 83 |

LIST OF FIGURES

| Figure | | Page |
|--------|---|------|
| 1.1 | The number of clinical proton therapy centers in Europe 2009– | |
| | 2020. Source: www.ptcog.ch | 1 |
| 2.1 | Depth-dose profiles of radiotherapy beams like photons, protons, | |
| | and carbon ions (Weber et al., 2009). | 3 |
| 2.2 | The design of the proton computed tomography system is shown | |
| | in a conceptual manner. The system includes two 2D sensitive | |
| | proton tracking modules placed before and after the patient, and | |
| | a segmented crystal calorimeter that records residual energy | 4 |
| 2.3 | The Digital Tracking Calorimeter (DTC) device which is designed | |
| | by Bergen pCT collaboration. The 50 μ m ALPIDEs are mounted | |
| | as tracking layers and 100 μ m ALPIDEs combined with absorbing | |
| | material act as calorimeter (Alme et al., 2020) | 6 |
| 2.4 | The trajectory of protons as they traverse an object is influenced | |
| | by multiple scattering events, causing their path to zigzag (de- | |
| | picted in red). The entry and exit positions and directions of the | |
| | protons are recorded. With knowledge of the object's boundary, | |
| | the points where the proton intersects with the object (points A | |
| | and B) can be determined. Although these intersection points | |
| | are sufficient for estimating the straight-line path (shown in black) | |
| | of the proton, additional information regarding the entry and exit | |
| | directions enables the estimation of the most probable path (rep- | |
| | resented by the blue line) (Li et al., 2006) | 7 |

| Figure | | Page |
|--------|--|------|
| 2.5 | The figure displays the primary methods in which protons interact | |
| | with matter. First, as illustrated in (a), they lose energy through | |
| | Coulombic interactions. Second, as shown in (b), when protons | |
| | pass near an atomic nucleus, repulsive Coulombic scattering pro- | |
| | duces a modification in their initial track. Finally, in (c), the ini- | |
| | tial proton is eliminated, and non-elastic nuclear interactions pro- | |
| | duce secondary particles such as neutrons, electrons, helium, and | |
| | gamma rays (Newhauser and Zhang, 2015). | 11 |
| 2.6 | This graph illustrates the relationship between protons' mass | |
| | stopping power (S) and energy (E) in liquid water. The graph also | |
| | shows the range (R), which is produced by taking the S values | |
| | and applying the continuous slowing down approximation (CSDA) | |
| | (Newhauser and Zhang, 2015) | 13 |
| 2.7 | This graph demonstrates the proportion of fluence Φ in a broad | |
| | beam of protons that persists at various depths z in water. Be- | |
| | cause of nuclear processes, the quantity of protons in the water | |
| | reduces progressively as they enter. Protons rapidly lose energy | |
| | and are absorbed by the medium near the end of their range, | |
| | resulting in a fast decrease in their number. The sigmoid shape of | |
| | the curve towards the range's end is caused by range straggling | |
| | or random fluctuations in the energy loss of individual protons | |
| | (Newhauser and Zhang, 2015). | 14 |

| Figure | | Page |
|--------|---|------|
| 2.8 | Energy loss probability density functions (PDFs) for water ab- | |
| | sorbers of various thicknesses. The absorber thickness is indicated | |
| | in mean free path (mfp) units, and the PDFs have been scaled on | |
| | both the x- and y-axes for clarity. The PDFs represent the energy | |
| | lost by a single event as a proportion of the total energy lost $(\Delta, \Delta, \Delta$ | |
| | across the absorber's thickness, or $(\Delta - \Delta$ av $)/\Delta$ av. Each | |
| | PDF was normalized so that the integral over all energy losses | |
| | was the same. The PDFs for thin absorbers (curves a-e) are asym- | |
| | metric and wider, and are modeled using the Vavilov (Vavilov, | |
| | 1957) or Landau (Landau, 1944) theories. The PDF for thick ab- | |
| | sorbers (curve f) is symmetric and well approximated by Bohr's | |
| | theory, which is a Gaussian distribution (Bohr, 1915; International | |
| | Commission on Radiation Units and Measurements, 1993) | 16 |
| 2.9 | This illustration shows the passage of a proton through many | |
| | Coulomb scattering events. The graphic additionally labels the | |
| | scattering angle's root mean square (rms), denoted as $	heta$, and the | |
| | projected scattering angle, denoted as $	heta$ x (Leo, 1994). $$ | 17 |
| 2.10 | This picture shows the concepts underlying the track model and | |
| | propagation. The track propagator is the function $f_{k\mid i}$, which ad- | |
| | vances the track from surface i to surface k. The mathematical | |
| | form of this function is determined by the track model, which is | |
| | the solution to the equation of motion in the detector's magnetic | |
| | field (Koch and Newhauser, 2010). | 19 |
| | This illustration shows the passage of a proton through many Coulomb scattering events. The graphic additionally labels the scattering angle's root mean square (rms), denoted as θ , and the projected scattering angle, denoted as θ x (Leo, 1994) This picture shows the concepts underlying the track model and propagation. The track propagator is the function $f_{k i}$, which advances the track from surface i to surface k. The mathematical form of this function is determined by the track model, which is | 17 |

| Figure | | Page |
|--------|--|------|
| 2.11 | (a) - The outermost shell of a silicon atom contains four elec- | |
| | trons. (b) - A valence bond is formed when two silicon atoms | |
| | come together, with each atom contributing one of its valence | |
| | electrons. (c) - The silicon atoms continue to assemble to create | |
| | a silicon crystal. With the exception of the atoms on the crystal's | |
| | outer borders, each silicon atom establishes valence bonds with | |
| | its four neighboring atoms. (Source: Max Maxfield) | 21 |
| 2.12 | The mental representation of n-type and p-type atomic struc- | |
| | tures of doped silicon. (Source: http://www.answers.com/topic/ | |
| | n-type-silicon-technology) | 22 |
| 2.13 | The illustration of n-type and p-type doped semiconductor band | |
| | structures. (Source: http://hyperphysics.phy-astr.gsu.edu) | 22 |
| 2.14 | The illustration of a depletion region formed by linking n-type | |
| | and p-type semiconductors. (Source: https://www.studypage.in/ | |
| | physics/formation-of-a-p-n-junction) | 23 |
| 2.15 | Schematic cross section of a MAPS pixel (Kofarago, 2015) | 24 |
| 2.16 | A schematic illustrating the ALICE experiment (ALICE Collabora- | |
| | tion, 2008) | 25 |
| 2.17 | A plan view of a cyclotron containing a cylindrical chamber with a | |
| | centrally positioned ion source. The chamber is vacuum-packed | |
| | and sandwiched between the poles of an electromagnet, which | |
| | provides a uniform magnetic field perpendicular to the chamber's | |
| | flat faces. The voltage is generated by an oscillator that operates | |
| | at a frequency equal to the rotational frequency of the particles | |
| | in the magnetic field. The accelerated particles travel in semicir- | |
| | cular trajectories with increasing radius (Britannica The Editors of | |
| | Encyclopaedia, 2024) | 26 |

| Figure | | Page |
|--------|--|------|
| 2.18 | The figure of ESS by using multi-wedge graphite absorbers. The | |
| | absorbers are positioned from opposing sides of the beam route, | |
| | and when they move into the path, they modify the energy by | |
| | forming a uniform layer of carbon, ensuring uniformity (Source: | |
| | Varian medical systems). | 27 |
| 3.1 | The detector geometry of MAPS telescope in GATE simulation | |
| | which has 2.5 cm of air gap between each ALPIDE. The distance | |
| | between nozzle and isocenter is about 42.1 cm that the first | |
| | ALPIDE is located at the isocenter. | 29 |
| 3.2 | Schematic cross-section of ALPIDE | 30 |
| 3.3 | The measurement of KCMH proton beam at distance from isocenter. | 31 |
| 3.4 | The diagram illustrates the sequence of steps in the tracking al- | |
| | gorithm. Hits in different layers of the detector are depicted as | |
| | blue dots. The process begins by selecting the first hit of a track | |
| | (highlighted in green) from the first layer (A). Next, candidates for | |
| | the track are searched using a cone defined by S_{max} (B). If the cal- | |
| | culated S_n for a new candidate is lower than S_{max} , the hit is added | |
| | to the track (C). If multiple hits are identified, the candidate with | |
| | the lowest S _n value is selected (D). These steps are repeated for | |
| | the subsequent layers (E) until the last layer of the detector is | |
| | reached (F). Afterward, hits belonging to this track are removed | |
| | from the pool of hits, and the reconstruction of the next track | |
| | begins (G). The algorithm continues until all identified tracks are | |
| | successfully reconstructed (H) | 36 |
| 3.5 | The cone intersects C(0,0; $lpha,\!\delta,\!	heta$) with a horizontal plane where z | |
| | > 0, the resulting shape is an ellipse. The major axis of the ellipse | |
| | aligns with the x-axis, while the minor axis aligns with the y-axis. | |
| | (Maxim et al., 2009). | 37 |

| Figure | | Page |
|--------|--|------|
| 3.6 | The angular parameters, $lpha$ and σ , define the arbitrary direction | |
| | of the cone axis, while eta represents the cone opening. The in- | |
| | tersection between the cone and a horizontal plane with $z > 0$ | |
| | forms an ellipse E $(\mathrm{z};lpha,\sigma,eta)$. The major axis of the ellipse is | |
| | inclined at an angle to the 0x axis (Maxim et al., 2009) | 39 |
| 3.7 | The linked list structure of the track reconstruction which used | |
| | for recursive algorithm and low resources consumption | 41 |
| 3.8 | The beam profile of 70 MeV pencil proton beam in 200000 events. | |
| | The color bar of the histogram shows the entries of proton hit on | |
| | specific point of ALPIDE sensor. | 43 |
| 3.9 | The 70 MeV pencil proton beam modeled by Gaussian distribu- | |
| | tion. The fitting parameters are calculated as shown in Table 3.2. | 44 |
| 3.10 | The beam profile of 200 MeV pencil proton beam in 200000 | |
| | events. The color bar of the histogram shows the entries of pro- | |
| | ton hit on specific point of ALPIDE sensor | 45 |
| 3.11 | The 200 MeV pencil proton beam modeled by Gaussian distri- | |
| | bution. The fitting parameters are calculated as shown in Table | |
| | 3.3 | 46 |
| 3.12 | The distribution of proton energy deposition in epitaxial layer of | |
| | ALPIDE sensor with 70 MeV pencil beam source | 47 |
| 3.13 | The distribution of proton energy deposition in epitaxial layer of | |
| | ALPIDE sensor with 200 MeV pencil beam source | 48 |
| 3.14 | 3D hit data of simulations | 49 |
| 3.15 | The contour plot of track efficiency on various $\boldsymbol{S}_{\text{max}}$ and cone | |
| | angle. The color bar of these plots show the reconstruction effi- | |
| | ciency of tracking algorithm | 50 |

| Figure | | Page |
|--------|---|------|
| 3.16 | GATE/GEANT4 simulation of 400 primary proton track routes. The | |
| | tracks connect all candidates from layer 0 to the last layer, in | |
| | which the last candidates of each track are discovered | 51 |
| 3.17 | The track efficiency for proton sources at 70MeV and 200MeV de- | |
| | pends on the number of primary protons employed in the GATE/ | |
| | GEANT4 simulation. | 52 |
| 4.1 | The pixel sensors telescope which consists of six ALPIDE sensor | |
| | and DAQ boards. (a) Each DAQ connects to single ALPIDE chip | |
| | and wired to external trigger signal and the power. (b) The DUT | |
| | is set to the layer 0 and the rest are references | 54 |
| 4.2 | The monolithic active pixel sensor ALPIDE | 55 |
| 4.3 | Block diagram of the ALPIDE pixel cell | 56 |
| 4.4 | The EUDAQ network typically consists of several components, | |
| | including the central command and control server known as | |
| | Run Control, the Data Collector, which is responsible for creating | |
| | global events and storing them on disk, the Log Collector, which | |
| | manages and displays log messages, and the monitor application, | |
| | which allows for real-time monitoring of data quality (Spannagel, | |
| | 2016) | 56 |
| 4.5 | This figure shows a board for data collecting. The external signal | |
| | from the trigger system is received through the trigger-in port. The | |
| | same signal is used as an output in the trigger-out. The Alterla | |
| | FPGA is included in the board and is used to operate the EUDAQv2 | |
| | firmware | 57 |
| 4.6 | The trigger control system scheme for FPGAs. The GUI accepts | |
| | frequency values from the user. The microcontroller converts | |
| | frequency to a binary value and sends it to the FPGA along with | |
| | the register address. Finally, the FPGA sends a trigger signal to the | |
| | ALPIDEs through the DAQ board | 58 |
| 4.7 | The Basys3 board layout and labels | 60 |
| 4.8 | SN74HC08N | 61 |

| Figure | | Page |
|--------|--|------|
| 4.9 | The microcontroller part that consists of Pro Mini 328 board and | |
| | USB programming module | 62 |
| 4.10 | The Graphical User Interface (GUI) of FPGA trigger | 63 |
| 4.11 | FPGA trigger operational signal of registering the frequency value | |
| | to FPGA buffer along its 2-bit address | 64 |
| 4.12 | FPGA trigger operational signal with turning ON Switch signal | 65 |
| 4.13 | The treatment room at KCMH where the experiment setup is placed. | 66 |
| 4.14 | The control room has monitors for requiring users to adjust pa- | |
| | tient bed position, parameterise proton beam and creating treat- | |
| | ment plan | 67 |
| 4.15 | For the KCMH beam test, the experiment configuration of the | |
| | FPGA trigger controlling system interfaced with ALPIDEs telescope. | |
| | While the telescope was inside, the power source and trigger were | |
| | wired out of the dark box. The telescope was likewise linked to | |
| | the power supply | 69 |
| 4.16 | The simulation signal used to write a frequency value to an FPGA | |
| | register. A particular address is assigned to each of the various | |
| | 1-bit input values | 70 |
| 4.17 | The generating trigger simulation signal. The frequency is set to | |
| | 291E of Hexadecimal | 70 |
| 4.18 | The WaveRunner 8254 oscilloscope | 71 |
| 4.19 | The FPGA trigger pulses of regular and amplified signals measured | |
| | by the Waverunner 8254 | 72 |
| 4.20 | The mean of activated pixels of background measurement in 6907 | |
| | events | 72 |
| 4.21 | The number of activated pixels of individual event that is pro- | |
| | vided FPGA trigger as pulse signal | 73 |

| Figure | | Page |
|--------|---|------|
| 4.22 | The 2-dimensional hitmap of six ALPIDE planes with 70 MeV pro- | |
| | ton source in 10 MU by applying 10000 events of trigger | 74 |
| 4.23 | The 2-dimensional hitmap of six ALPIDE planes with 200 MeV pro- | |
| | ton source in 10 MU by applying 10000 events of trigger | 75 |
| 4.24 | The histogram of EUDAQv2 output for 70 MeV and 200 MeV of | |
| | KCMH proton beam on 10000 trigger events | 75 |
| 5.1 | a) the KCMH telescope test with a collimator in the treatment | |
| | room with its b) schematic picture | 76 |
| 5.2 | The 36 cm acrylic collimator. | 77 |
| 5.3 | The flowchart demonstrates how multi-threading software works. | |
| | The Software runs from interested event 0 to interested event n. | |
| | The central theme monitors the export's.root file in an endless | |
| | loop. Upon finding the main thread .root file, the main thread | |
| | will compel the worker thread to terminate EUDAQv2 monitor. | |
| | Finally, the exporting program gathers all ROOT files before re- | |
| | peating the process. The last task is to repeat the procedure | |
| | while increasing the number of events. | 78 |
| 5.4 | The flowchart of the track reconstruction process that the track | |
| | following algorithm description can be found in section 3.2.5, the | |
| | track efficiency was calculated as track survival in section 5.4.4, | |
| | and the correlation of the reconstruction definition will be men- | |
| | tioned in Section 5.4.5 | 80 |
| 5.5 | The illustration of average activated pixel count of each event for | |
| | every ALPIDE planes in the telescope during the dark test. The | |
| | red line indicates the standard deviation of activated pixels | 81 |
| 5.6 | The cluster size distribution of every ALPIDE layers which generate | |
| | noise and background signal in the dark test | 82 |

| Figure | | Page |
|--------|--|------|
| 5.7 | These histograms represent the distribution of pixel activations | |
| | from the initial sensor layer, positioned 5 cm behind the isocenter. | |
| | The treatment beam passes through an acrylic collimator | 84 |
| 5.8 | The figure shows a) the spot sigma of six ALPIDEs and b) the num- | |
| | ber of activated pixels from all ALPIDEs | 84 |
| 5.9 | The illustration of cluster size samples which can be detected by | |
| | the telescope with 70 MeV of proton energy | 86 |
| 5.10 | The illustration of cluster size samples which can be detected by | |
| | the telescope with 200 MeV of proton energy | 87 |
| 5.11 | The distribution of cluster sizes for collimated beam energies of | |
| | 70 MeV and 200 MeV. These distributions were observed across | |
| | 6 ALPIDE chips. In the top right corner of each figure, you can | |
| | find the mean and standard deviation values for the cluster size | |
| | distribution | 88 |
| 5.12 | The correlation between the typical cluster size of proton beams | |
| | traveling through the collimator and the typical energy deposited | |
| | in the ALPIDE chip is illustrated graphically. The graphic contains | |
| | information for proton beam kinetic energies between 70 MeV | |
| | and 200 MeV. The mean cluster size values on the plot are sur- | |
| | rounded by error bars that show the standard deviation of the | |
| | cluster size distribution | 89 |
| 5 13 | Illustration of the reconstruction efficiency of various S values | 90 |

| Figure | | Page |
|--------|---|------|
| 5.14 | The averaged R ² value of track reconstruction using a cone search | |
| | angle of $\Delta 	heta$ (upper) after fitting the location correlation of hit | |
| | data on each ALPIDE layer in the telescope. The saturated curve | |
| | (lower) is found by determining the average correlation of the X | |
| | and Y axes between the first layer and the last layer | 91 |
| 5.15 | The distribution of the number of reconstructed tracks in the tele- | |
| | scope | 92 |
| 5.16 | The visualization of track reconstruction from the experiment with | |
| | the acrylic collimator in 70 MeV and 200 MeV of proton energy | |
| | within single event | 92 |
| 5.17 | The visualization of track reconstruction from the experiment with | |
| | the acrylic collimator in 70 MeV and 200 MeV of proton energy. | |
| | The number of events which are chosen from the total data | |
| | events is 10 events. | 93 |

LIST OF ABBREVIATIONS

pCT Proton Computed Tomography

PT Proton Therapy

CT Computed therapy

DTC Digital Tracking Calorimeter

PSD Positioned Sensitive Detector

RED Residual Energy Detector

YAG:Ce Yttrium aluminum garnet activated by cerium

NaI(Tl) Thallium-activated sodium iodide
CsI(Tl) Thallium-activated cesium iodide

Si strip Silicon Strip Detector

Sci Fi Scintillating Fiber

MAPS Monolithic Active Pixel Sensor

ALPIDE ALICE Pixel Detector

ALICE A Large Ion Collider Experiment

ITS Inner Tracking System

KCMH King Chulalongkorn Memorial Hospital

FPGA Field-programmable gate array

MeV Mega Electron Volt

MC Monte Carlo

CMOS Complementary Metal Oxide Semiconductor

PBS Pencil Beam Scanning

PDG Particle Data Group

DAQ Data Acquisition

QA Quality Assurance

MU Monitor Unit

GUI Graphical User Interface