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**PhD course of National Interest in Technologies for  
Fundamental Research in Physics and Astrophysics**

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## Annual report

**Name and surname:** Ammad Ul Islam  
**Cycle and a.a.:** XXXIX 2024-2025  
**Supervisor:** Andrea Fabbri

- **Research activity carried out during the year**

### 1. Summary

This annual report provides a comprehensive overview of the academic and research activities carried out during the second year as a Ph.D. student. The year was characterized by a crucial pivot from foundational coursework to direct, hands-on involvement in the TAO experiment. The primary goal of these activities was to secure access to real-time data from the experiment, which is the basis for the development and validation of thesis project. The key highlights include the successful completion of coursework, productive research visits to the Institute of High Energy Physics (IHEP) in China, and significant contributions to the installation and commissioning of the TAO detector, particularly the low-voltage system.

### 2. Introduction

The objective of the project is to address a fundamental challenge in high-energy physics: the real-time detection of photons in complex, high-noise environments. The proposed solution involves the development of an Artificial Intelligence (AI) based pattern recognition technique, which will be implemented on a Field-Programmable Gate Array (FPGA). This report details the progress made in the second year, with a particular importance on the practical work carried out at the TAO experiment, which was essential for transitioning from theoretical concepts to practical, data-driven research.



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**3. Academic and Theoretical Progress (Year 2)**

The first part of the second year was dedicated to completing the required coursework. The curriculum was carefully selected to provide the necessary theoretical and technical background for the thesis. Key areas of study included advanced topics in:

- **Artificial Intelligence and Machine Learning:** I have taken two courses i.e. “Machine Learning for Physics” and “Advanced scientific Programming in MATLAB” which helped me developing the understanding of various AI models, including neural networks, and their application to pattern recognition.
- **Digital Signal Processing (DSP):** By working on some tasks based on DSP, helped me Gaining expertise in signal filtering, data manipulation, and noise reduction techniques, which are critical for processing raw data from the detector.
- **FPGA and Hardware Design:** I have studied the course “Programmable System on Chip (SoC) for Data Acquisition and Processing” which helped me in Learning the principles of hardware description languages (HDLs) and real-time system design to enable the efficient implementation of the AI algorithm on a physical chip.
- **Particle Physics and Detector Technology:** I have studied the course “High Energy Particle Physics Detectors in Space” which was focused on studying the principles of high-energy physics, detector operation, and the unique challenges of high energy physics experiments.
- **Management of Scientific Projects:** In parallel with all the courses mentioned I also studied the course “Management of Scientific Projects” understanding the Project Life Cycle, different phases of a project, from initiation and planning to execution, monitoring, and closure. I also got a basic concept of techniques for creating a Work Breakdown Structure (WBS), developing a timeline, using Gantt charts, and estimating task durations. The course also covered Resource Management, Risk Management, Communication and Collaboration, Data and Quality Management, an introduction to



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agile and iterative approaches, and how they can be adapted to the unpredictable nature of scientific research. This course provided the essential framework for transitioning from individual research to managing a complex project, ensuring it stays on track and delivers valuable results.

This academic foundation provided the essential tools for a successful research visit and prepared me to tackle the practical complexities of the TAO experiment and will be helpful for me to complete my PhD in the defined timeline.

#### **4. Practical Contributions and Research Activities**

The focus of the 2nd year was the two research visiting periods at the Institute of High Energy Physics (IHEP) in China from 2025/07/07 to 2025/08/25 and from 2025/03/22 to 2025/06/18. These periods were helpful in moving the project forward by providing direct access to the TAO experiment and its operational environment. The main activities performed there can be categorized as follows:

##### **4.1. Detector Installation and Infrastructure Work**

- **PS Testing and Configuration:** Carried out careful testing of individual Power Supply (PS) units for low voltage system and their configurations. This involved one-by-one testing, pair testing, and checking the output under various conditions. Initially had a contribution in sorting out the issue of the low voltage splitter board. “User Manual” and “Low Voltage System Test Procedure” were composed which provides the complete details of the system and the testing procedure.
- **Cabling and System Preparation:** Participated in the complex process of cabling the Low Voltage (LV) system, High Voltage (HV) system and data acquisition system to detector flanges. This required careful planning and execution to ensure electrical integrity, proper signal routing and proper labeling.



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- **Infrastructure Management:** Contributed to the practical infrastructure tasks, including the dismantling of LV, HV, and Signal cables, the cleaning of the main detector tank with ethanol, and the shifting of all the hardware to the new cleanroom. Also got a hand on setting up and managing the new cleanroom. Played a key role in the installation of the Polyurethane (PU) and thermal insulation layers, which are critical for maintaining a stable operating temperature within the detector. I also assisted in the installation of the High-Density Polyethylene (HDPE) shielding and the bottom shielding with lead, which both provide crucial protection against external background radiation, ensuring the purity of the data collected by the detector.

#### **4.2. Commissioning and Troubleshooting**

A significant portion of the time was spent on commissioning the detector to prepare it for data acquisition. This was a critical phase that involved:

- **Dry Run Initial Tests:** Conducted multiple dry run tests (Initial 1, 2, and 3) to identify and rectify any issues in the system's readiness. I also contributed to the documentation of all test results and procedures for the collaboration.
- **Troubleshooting Faulty Channels:** Systematically identified and resolved issues with faulty channels, ensuring the integrity of the detector's data acquisition pathways. Documentation was maintained for all identified issues and their resolutions.
- **General System Troubleshooting:** This part was one of the challenging parts where we addressed various other critical issues, including resistance complications, grounding issues and leakage from the central detector during air purging. A very critical incident of water leakage happened during the installation, which required quick and effective problem-solving skills. All issues were handled carefully, leading to the successful rebuilding of the system in complete working condition. Throughout this process, I thoroughly documented all complex troubleshooting procedures, detailing the problems encountered and the final solutions implemented.



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- **Final Commissioning:** The final stage involved putting all the components back onto the racks and conducting the final commissioning tests to prepare the system for full-scale operation.

#### **4.3. Specific System Development**

- **Low-Voltage System Installation and Commissioning:** Played a crucial role in the physical installation and subsequent commissioning of the low-voltage system. This work was essential for providing stable and reliable power to the detector's electronics. This involved carefully connecting 14 PSUs organized in pairs to the detector's 8 signal flanges and two LV PCBs per flange. I also played a key role in the cabling and configuration, ensuring that the system cables and connections for each PSU pair were correctly mapped according to the system's design. The Low Voltage System were completely managed by me.
- **Development of a Control System GUI for the LV System:** This part was one of the essential part, as it was needed to control the 16 PSU from a single application, the commercial software provided by the manufacturer were able to control only 8 PSU at a time and was not responsive and lagging during the control operations. The commercial software integration with DCS was not possible and we were not able to record the runtime data. To tackle this issue I developed a dedicated Graphical User Interface (GUI) for the LV control system using Python libraries like smbus2, pandas, and openpyxl. The GUI provides a real-time table of PSU status, showing critical parameters such as voltage, current, and temperature, along with I2C bus and address information. The GUI also includes safety features such as a "Paired PSU Synchronization" function that automatically shuts down a paired PSU if its counterpart goes offline, preventing unsafe overloads. The application also automatically logs all live data to an Excel spreadsheet every 30 seconds for analysis. I



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continue to contribute regularly to improving the reliability and performance of this system, working remotely with the on-site team.

## **5. Collaboration and Dissemination**

Participation in key events was also a major part of the second year's activities:

- **The 2nd ECFA-INFN Early Career Researchers Meeting, 2024:** Attended this meeting in September 2024 at the Laboratori Nazionali di Frascati (Rome), Italy. This event provided a unique opportunity to engage in discussions about the future of high-energy physics and to present my research in a poster session to a broad audience of peers and senior researchers.
- **PhD meeting at the Gran Sasso National Laboratories, February 2025:** Presented a poster on my research, providing an opportunity to discuss my work on "pattern recognition using AI and its development on FPGA" with experts in underground physics and astroparticle physics.
- **JUNO Analysis Workshop, Dongguan University of Technology (DGUT), July 2025:** This workshop was a focused event for the JUNO collaboration, providing a platform for in-depth discussions on key physical analysis topics, including detector commissioning, reconstruction, and calibration. This was a direct extension of my hands-on work at the TAO experiment and was essential for clarifying the next steps in data analysis.
- **The 26th JUNO Collaboration Meeting, Kaiping, China:** Attended this major collaboration meeting in July 2025. This event brought together researchers from around the world to discuss the overall progress of the JUNO experiment, including the commissioning of the main detector and the initial data-taking phase. This meeting was crucial for understanding the larger context of my work within the international collaboration.



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- **TAO Meetings:** Attended the TAO meetings. These meetings provided an opportunity to present progress, discuss challenges with other researchers, and gain insights into the latest developments in the field. These interactions were invaluable for networking and refining the research direction.

## **6. Link to Thesis and Research Impact**

The activities performed during this period are directly linked to the core objectives of the thesis. The hands-on experience in the installation and commissioning of the TAO detector provided a deep understanding of the experiment's operational environment, including potential sources of noise and data complexities. The work on the LV system and the GUI was not just a service to the experiment but a direct way to understand the hardware-software interface and the flow of data.

Beyond the direct technical contributions, the extensive networking and collaboration during the various workshops and meetings were invaluable. Engaging with peers and senior researchers at the ECFA-INFN and JUNO meetings provided a critical platform for presenting my work and receiving constructive feedback. These interactions not only helped me to refine my research approach but also exposed me to new ideas and methodologies from different fields within high-energy physics. The connections established during these visits will be crucial for future collaborations, professional growth, and ensuring the continued visibility and impact of my research within the broader scientific community.

Most importantly, this practical work was performed with the explicit purpose of preparing the detector to generate the real-time data required for further analysis. This data will be the training and testing set for the AI-based pattern recognition technique. The experience of working on-site will be invaluable for designing an AI algorithm that is robust enough to handle the "harsh environment" mentioned in the thesis title. The contributions made are not only





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significant for my Ph.D. research but also for the wider scientific community, as the insights gained will benefit future research in high-energy physics.

### **7. Future Plans (Year 3)**

The third year will be a critical period focused on the core development and writing of the thesis. The work plan is as follows:

- **Data Analysis and Pre-processing:** The first step will be to thoroughly analyze the real-time data acquired from the TAO experiment which is expected to be available at the end of this year. This will involve cleaning, pre-processing, and organizing the data to make it suitable for training an AI model.
- **AI Algorithm Development:** The primary task will be to develop and train the AI-based pattern recognition technique. This will involve selecting the appropriate machine learning model, optimizing its architecture, and training it on the acquired data to accurately identify and classify photon signals.
- **FPGA Implementation:** The trained and optimized AI model will be developed on an FPGA(KU15P). This requires expertise in programming FPGAs using HDLs like Verilog or VHDL to ensure the algorithm can run in real-time with low latency, a critical requirement for high-energy physics experiments.
- **System Validation and Benchmarking:** The implemented AI-FPGA system will be tested on new, unseen data to validate its performance. This will include benchmarking its speed, accuracy, and efficiency against traditional methods.
- **Thesis Writing:** The final months of the year will be dedicated to writing the thesis, systematically documenting the research methodology, results, and conclusions.

This plan ensures a straight and rational progression from the foundational work of the second year to the core research of the third year, concluding in a completed and validated thesis.





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## **8. Conclusion**

The second year of Ph.D. research was highly productive, successfully combining academic coursework with a hands-on research visit that provided critical data and practical experience. My direct contributions to the TAO experiment have been invaluable, both for the project itself and for my personal research. The groundwork has been laid for a successful third year, which will see the development and implementation of a novel AI-based technique for photon detection. The progress made in this year demonstrates a strong commitment to the project and a clear path toward the successful completion of the Ph.D. thesis.



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- **List of attended courses and passed exams**

- Programmable System on Chip (SoC) for Data Acquisition and Processing
- High Energy Particle Physics Detectors in Space
- Management of Scientific Projects
- Machine Learning For Physics
- Advanced scientific Programming in Matlab(Attended)

- **List of attended conferences, workshops and schools, with mention of the presented talks**

- The 26<sup>th</sup> JUNO Collaboration Meeting, Kaiping, China
- JUNO Analysis Workshop, Dongguan University of Technology(DGUT) July 2025
- PhD meeting at the Gran Sasso National Laboratories February 2025: Poster Presentation
- 2nd ECFA-INFN Early Career Researchers Meeting, 2024

- **List of published papers/proceedings**

- As Corresponding Author: “Real-Time Monitoring and Control of Renewable Energy Systems Using Wireless Telecommunication and Signal Processing Techniques for Smart Grids with Energy Storage”, Spectrum of Engineering Sciences (2025)
- Development and Performance of Silicon Photomultipliers Readout System and Front-End Electronics for Reactor Neutrino Detection at the JUNO-TAO Experiment (writeup)

- **Thesis title (even temporary)**

- Pattern recognition development on FPGA through AI in harsh environment

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*Amjad Islam*

Date, ... 9/28/2025

Signature...

*Kudrew Edhi*

Seen, the supervisor