FACULTY OF INFORMATION TECHNOLOGY CTU IN PRAGUE

ASSIGNMENT OF MASTER'S THESIS

Title:	Web Application for Discoveries with the ATLAS Forward Proton Detector at CERN
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Instructions

ATLAS, the largest experiment at the Large Hadron Collider (LHC) at CERN and the ATLAS Forward Proton (AFP) detectors took large scale data in 2017. The search for an Axion-Like-Particle (ALP) is being performed.
The first task is to familiarize with the existing analysis software.
Then, get familiar with the source of data and it's API. Based on the amount and structure of relevant data, develop an appropriate solution for storing and processing the data. The web application should be designed to allow the user to visualize the data, applying selection requirements. The web application should be able to determine the statistical significance of the expected ALP signal.
The project tasks include implementing specific requirements on the web application regarding a multiuser environment with security layers and authentication matching the ATLAS data access rules. The database should be designed for large datasets and be flexible for updates and extensions.

References

Will be provided by the supervisor.

Ing. Michal Valenta, Ph.D.
Head of Department

doc. RNDr. Ing. Marcel Jiřina, Ph.D.
Dean

Prague October 22, 2019

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Master's thesis

Web Application for Discoveries with the ATLAS Forward Proton Detector at CERN

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Department of Software Engineering
Supervisor: doc. Dr. André Sopczak

February 14, 2020

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In Prague on February 14, 2020 . . . .

Citation of this thesis

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Abstrakt

Tato práce se zaměřuje na implementaci vzdělávací webové aplikace pro středoškolské studenty. Obsahuje základní popis procesu hledání tzv. Axion-Like částice a také dokumentaci implementovaného prototypu.

Klíčová slova AFP, ALP, ATLAS, CERN, vzdělávací webová aplikace

Abstract

This thesis focuses on implementing of educative web application for high school students. The basic description of Axion-Like Particle finding process is provided as well as documentation of implemented prototype.

Keywords AFP, ALP, ATLAS, CERN, educative web application

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Introduction

The main goal of this project is to provide an interactive educative web application for high school students, which are interested in advanced physics. For this purpouse we will use the current experiment finding Axion-Like Particle.

The first chapter of this thesis contains basic description of Axion-Like Particle finding process. In the second chapter the details of an assignment are provided and the last chapter contains documentation for implemented prototype.

Chapter 1

CERN and ATLAS

This chapter provides a very basic historical background and technical details which are important for our task. Once finished this chapter, the reader should have better understanding of what our project is about.

1.1 Brief history of CERN

CERN, the European Organization for Nuclear Research, is the world's leading laboratory for particle physics. It provides a unique range of particle accelerator facilities enabling research at the forefront of human knowledge. Its business is fundamental physics, finding out what the universe is made of and how it works.[1]

It was founded in 1954 on the French–Swiss border, nearby the city of Geneva and the main ideas behind this project were both to stop the brain drain to America that had begun during the Second World War, and to provide a force for unity in post-war Europe.[2]

The CERN's first particle accelerator - Synchrocyclotron - was built in 1957.

Figure 1.1: CERN logo

One of the most important turning points (especially from the point of view of our topic) in the history of CERN happend on 27 January 1971. That day the world's first interactions from colliding protons was announced.

1.2 Large Hadron Collider

The event we will focus in this task takes place in the Large Hadron[1] Collider (LHC), which is the world's largest and most powerful particle accelerator. It first started up on 10 September 2008, and remains the latest addition to CERN's accelerator complex. The LHC consists of a 27-kilometre ring of superconducting magnets with a number of accelerating structures to boost the energy of the particles along the way.

Inside the accelerator, two high-energy particle beams travel at close to the speed of light before they are made to collide. Just prior to collision, another type of magnet is used to "squeeze" the particles closer together to increase the chances of collisions.[4]

LHC hosts several experiments, e.g. ALICE[2], CMS[3] or the one which is important for our task - ATLAS[4].

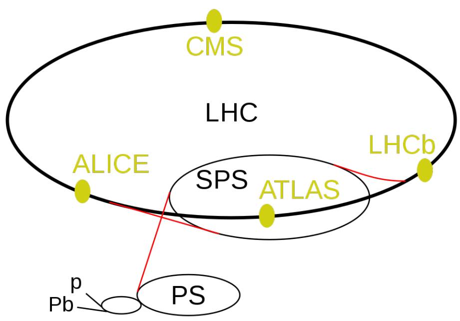

Figure 1.2: The LHC experiments and the preaccelerators

1.3 ATLAS experiment

A Toroidal LHC Apparatus (ATLAS) investigates a wide range of physics, from the search for the Higgs boson to extra dimensions and particles that could make up dark matter. Beams of particles from the LHC collide at the

[1] Hadron is a subatomic composite particle made of two or more quarks held together by the strong force in a similar way as molecules are held together by the electromagnetic force.[3]

[2] https://home.cern/science/experiments/alice

[3] https://home.cern/science/experiments/cms

[4] https://home.cern/science/experiments/atlas

centre of the ATLAS detector making collision debris in the form of new particles, which fly out from the collision point in all directions. Six different detecting subsystems arranged in layers around the collision point record the paths, momentum, and energy of the particles, allowing them to be individually identified. A huge magnet system bends the paths of charged particles so that their momenta can be measured.[5]

The two ends of ATLAS are called the A-side and the C-side (B is the central barrel).[6] This notation is used in this paper as well.

ATLAS central detector will be the most significant source of input data for our application.

1.3.1 ATLAS Forward Proton Detector

The ATLAS Forward Proton (AFP) detector will identify events in which one or two protons emerge intact from the proton-proton collisions at the LHC. Tracking and timing detectors will be placed 2-3 mm from the beam, 210 m away from the ATLAS interaction point.[7]

Data from these detectors will be used as an additional information, which will help us to extract only the data important for finding the Axion-Like Particle (ALP).

1.3.2 Axion-Like Particle

Axion-Like Particle is, as believed, a particle which is created during the near miss of two protons. It quickly disappers while producing a photon pair. ALP was originally proposed by Peccei and Quinn.[8]

Chapter **2**

Analysis

In the sections of this chapter, the analysis of the assignment can be found. Making such analysis is a cornerstone for designing the required software.

2.1 Analysis of assignment

Based on the assignment instructions and discussions with supervisor, the goal is to create an educative web application which will show how the additional data can help and improve existing data. This should be shown on a current process of finding Axion-Like Particle (ALP). The technical details of this process are provided in chapter CERN and ATLAS.

2.1.1 Event

Event (for the purpose of our application) is a near miss of two protons which are moving agains each other. The user will be able to *fire* these protons. During this near miss of given protons number of particles is created, two of them being photons. The information about these particles are provided by ATLAS Central detector (ACD). Based on information provided by ACD, we can calculate the energy loss of the photon pair ($\xi_{ATLAS_{A,C}}$). The protons are, due to the near miss, diverted from their original direction and eventually can hit the AFP detector. This detector can tell us the energy losses of protons ($\xi_{AFP_{A,C}}$). It turns out that when the difference of $\xi_{ATLAS_{A,C}}$ and $\xi_{AFP_{A,C}}$ is less than 10 %, the energy mass of the photon pair $m_{\gamma\gamma}$ is approximately 1 TeV.

2.1.2 Autofire

In order to have descriptive results at least hundreds of events needs to be fired and we cannot expect user to do it manually. Therefore the autofire action needs to be implemented. It will become available once at least ten

Table 2.1: Matching cases

ξ_{ATLAS_A} and ξ_{AFP_A}	ξ_{ATLAS_C} and ξ_{AFP_C}	Case name
Match	Match	Double tag
Match	Not match	Single tag
Not match	Match	Single tag
Not match	Not match	No tag

events will be fired manually, one of them having Single tag or Double tag (see section 2.1.3).

2.1.3 Matching

Once the photons passed the AFP detectors, the user will decide whether the $\xi_{ATLAS_{A,C}}$ and $\xi_{AFP_{A,C}}$ are similar enough (match) or not. Depending on the user's decision, one of the three cases happens as described by table 2.1.

2.1.4 Result

We keep two pieces of information for each event triggered by user: the invariant mass ($m_{\gamma\gamma}$) and the result of matching (Single tag, Double tag or No tag). These information will be store in two histograms with the invariant mass values on the x-axis. One histogram will store all the events, the other will store only events having the matching result either Single tag or Double tag.

2.1.5 Aproximation of physics processes for illustration purpouse

Because of our goal and the target audience (13 - 17 years old students; for more details see Introduction), we need to aproximate and simplify the high statistics physics analysis in order to keep the message we are trying to give them, both understandable and interesting. The esential of this process is to keep basic physics principles and not showing something, that is not true.

Chapter **3**

Documentation

The information in this section are supposed to help users with the usage of created software.

3.1 User interface

User interface (shown in picture 3.1) consist of six parts:

- **Control panel** - Panel with buttons and instructions. The user will perform almost all the operations using this part. Detail in figure 3.2
- **Events counter** - Gives user information about number of total events registred in histogram since the last reset, and in case of *Auto fire* function was performed, it's progress is listed as well
- **ATLAS Central detector** - Display the particles created during the near miss of protons. Photons, unlike the other particles, do not have any track (because they have zero mass). Track is drawn in light green. The thick dark green columns represent energy of the particle.
- **ATLAS Central detector - side view cutaway** - The point of this part of GUI is to show the near miss of protons, the AFP detectors and the detection of protons by AFP detectors
- **Energy loss matching charts** - In this diagram user is supposed to decide whether the ξ_{AFP} and ξ_{ATLAS} are matching or not for both, A side and C side. See figure 3.4.
- **Histograms** - Two histograms are shown. The left one - *Central detector only* - contains all the fired events (no matter what action user makes in the *Energy loss matching charts*). On the other hand, the event is added to the *With AFP matches* histogram only if the user finds at least one match in the *Energy loss matching charts*.

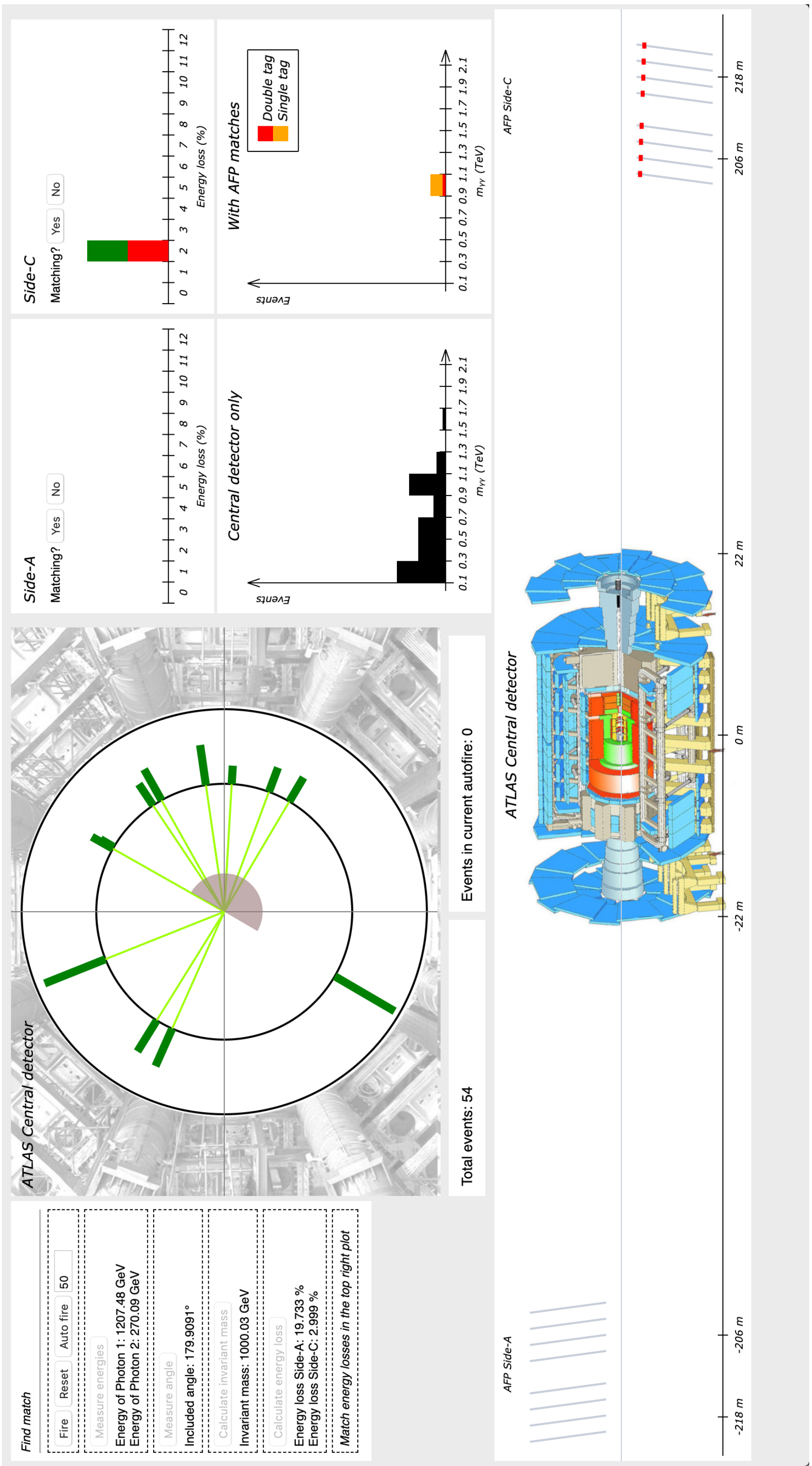

Figure 3.1: The user interface - full view

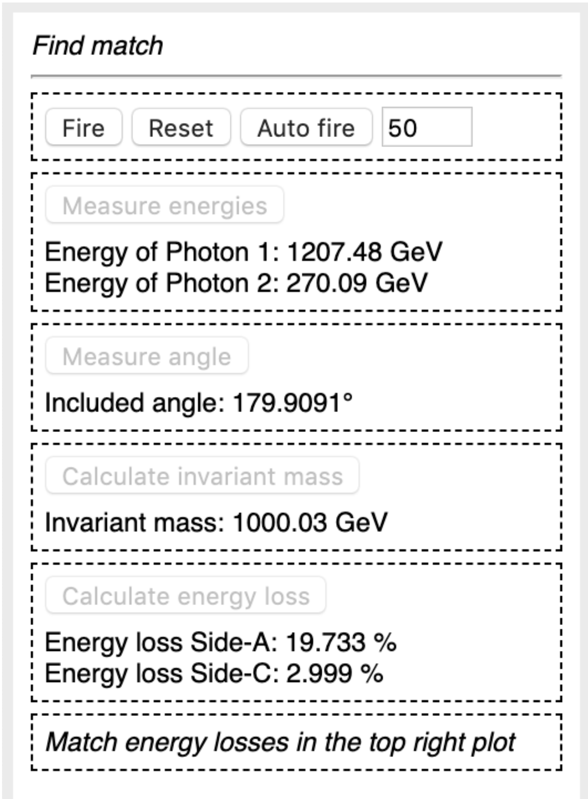

Figure 3.2: The user interface - Control panel

3.2 User manual

1. When the application is started, the only action which can be made is to trigger the event. This will be achieved by pressing the *Fire* button. in the *Control panel* (figure 3.2). The visualisation of proton's near miss and created particles are started. If a proton was detected by an AFP detector, a red column is shown in corresponding bin. Example in the figure 3.3.

2. Click the button *Measure energies* and then click on the energy columns of photons in the *ATLAS Central detector* plot. (Photons are the ones without the track.) Once the photons are successfully selected, their energies are written in the *Control panel* and button for the next step is anabled.

3. *Measure angle* between vectors of previously selected photons by clicking the button with corresponding label. The angle is shown in the *ATLAS Central detector* plot and it's value is displayed in the *Control panel*.

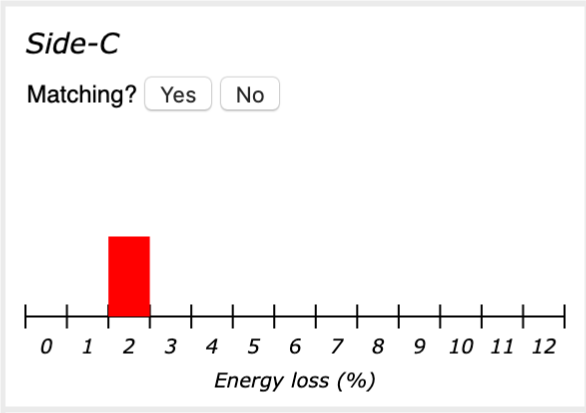

Figure 3.3: The user interface - Energy loss

4. *Calculate invariant mass.* Once clicked, the invariant mass value is shown in the *Control panel*.

5. By clicking the *Calculate energy loss* button, the energy loss of the photon pair is calculated and displayed in the *Control panel* and the green columns, representing the energy loss are displayed in the *Energy loss matching charts*.

6. In this step, the user has to decide whether the energy losses from ATLAS and AFP are matching or not. In figure 3.4, the match is at C-side, but not at A-side.

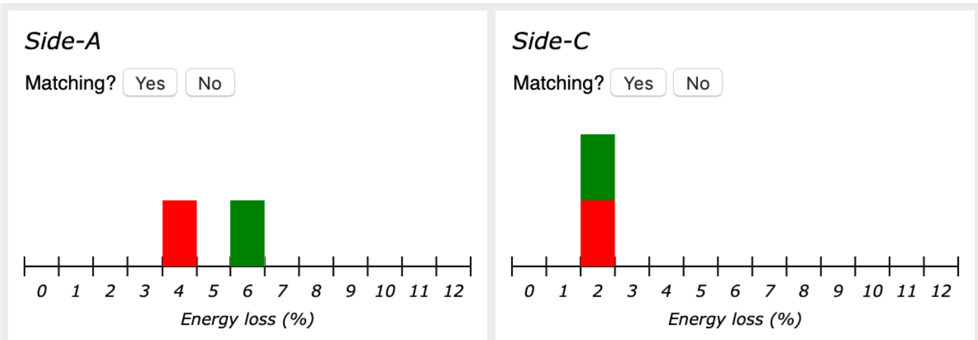

Figure 3.4: The user interface - Energy loss, Single tag

7. Based on the users decision in the previous step, the event is added either to left, or to both histograms.

8. Steps 1-7 should be repeated manually several times in order to understand the presented principles, then the *Autofire* function should be started by clicking the corresponding button in the control panel.

9. Once several hundreds of events is recorded, the distributions in the histograms should look similar as the ones in the figure 3.5.

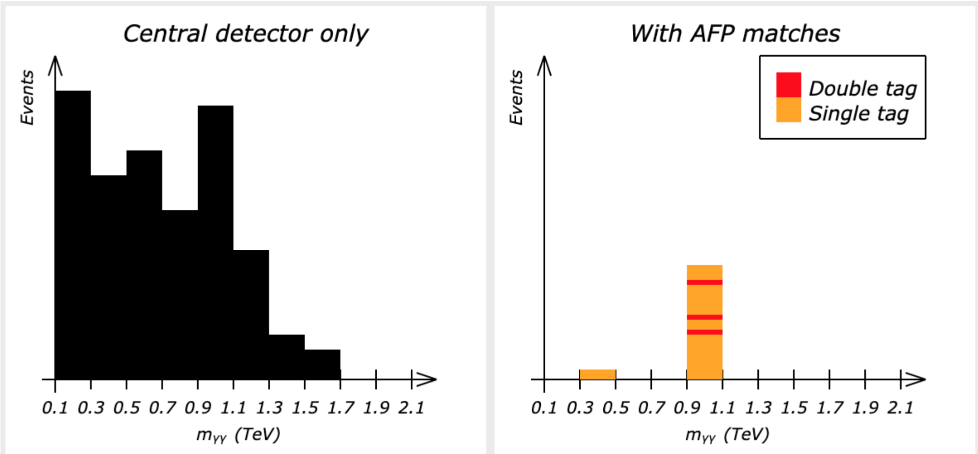

Figure 3.5: The user interface - Histograms

Conclusion

Despite only minor part of required work was finished and described in this thesis, the basic analysis of complex physics process was done and working prototype was implemented. These provide solid foundation for further work on this project.

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Appendix A

Acronyms

ALP Axion-Like particle

CERN Conseil Européen pour la Recherche Nucléaire; the European Organization for Nuclear Research

LHC Large Hadron Collider

Appendix B

Contents of enclosed CD

```
readme.txt ........................ the file with CD contents description
ATLAS ....................................... the directory of application
  index.html ................................ the application entry point
thesis .................. the directory of LaTeX source codes of the thesis
text ........................................... the thesis text directory
  thesis.pdf ............................. the thesis text in PDF format
  thesis.ps ................................ the thesis text in PS format
```