Palacký University Olomouc
Faculty of Science
Joint Laboratory of Optics

# BACHELOR THESIS

# Calibration and monitoring of astroparticle telescopes

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**DECLARATION**

I hereby declare that I elaborated this bachelor thesis independently under the supervision of Ing. Ladislav Chytka, Ph.D., using only information sources referred in the Literature chapter.

In Olomouc August 31, 2021

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# Bibliographical identification

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# Contents

# Introduction

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`http://exfyz.upol.cz/didaktika/`

# Chapter 1

# Astroparticle detection

More than 100 years have passed since Victor Franz Hess first encontered cosmic radiation. Since those times the techniques and methods of detection have been strongly improved. We have moved up from elevating electroscopes by ballons to observe growing electric charge to specialized techniques, which allows us to measure particles' energies, trajectories, etc.

## 1.1 Cosmic rays and particles

## 1.2 Ultra-high energy cosmic rays (UHECRs)

## 1.3 Detection principles

# Chapter 2

# FAST telescope

The Fluorescence detector Array of Single-pixel Telescopes (FAST) is an international project of fluorescence telescope sensitive to UHERCs.

Until today there are four prototypes in active service. Three of them are situated in Black Rock Mesa site of the Telescope Array experiment in central Utah and one in Argentina near Pierre Auger Observatory.

## 2.1 Principle of operation

Main detection part of telescope consists of superreflective UV mirrors and photomultipliers.

The entire telescope along with monitoring systems and other instruments is situated in a hut with remote shutter, where it is protected from negative metrological phenomena, such as rain or fast wind, but also from dust and aerosols. Exposure of mirrors to any of this phenomena could lead to reduction of theirs reflectivity. It is also neccessary to monitor and protect PMTs from unwanted light sources. Even a low-intensity sources could decrease PMT's service life.

## 2.2 Remote control and monitoring

## 2.3

# Chapter 3

# Instrumentalization and measurement preparation

To perform all of neccesary measurements we need to use various types of optical and electronical equipment.

## 3.1 Integration sphere

The Integration sphere (IS) is a special optical equipment, which can be used either as extended uniform light source (EULS) or with spectrometer in determining the material reflectance. In our experiments we use general purpose Labsphere (Fig. 3.1).

Figure 3.1: General purpose Labsphere.

The IS inner surface consist of white optical diffusive material ($BaSO_4$ and Polytetrafluoroethylene). The IS also contains several circular apertures, which are called input/output ports. They can be used to mount detectors or optical sources or left free to let light flux enter or exit IS.

The inner surface is part where light intergration happens. The effect which takes place here is known as Lambertian scattering. After one spot of inner surface is hit by a ray, the energy should be uniformly radialy distributed. In output port this produces a homogenous light source. The homogenity decreases with increasing number and sizes of input/output ports.

Using optical source with IS requires baffle to prevent source's light flux or its part to exit IS without integration.

More deeper explanation of IS working principles and characterization of optical properties of identical IS, which we use, can be found in [1].

For our pusrposes, in case of FAST calibration, we use IS as EULS in UV spectre. In case of testing optical calibration source, we don't even care about homegenity. The reason why we use IS in this case is that it focuses the entire optical power of the source into output ports, where our detectors are mounted, and blocks any other external light source, which could affect our detectors.

## 3.2 Photomultiplier tube

Photomultiplier tube (PMT) is considered to be a high voltage optoelectronical part. It allows us to measure very low intesity optical signals. PMT is also characterized by high amplification, low noise and stability.

### 3.2.1 Operating principle

PMT consists of 6 main elements, which can be seen on scheme 3.2.

Figure 3.2: Photomultiplier tube scheme.

The input photon with sufficient energy, which strikes the PMT's photocathode, excites photocathode's electron. This electron then follows electrostatitc field to the first dynode of the electron multiplier, where it induces secondary emission of more electrons. These electrons are then attracted by the next dynode, where the emission process repeats. After few times of multiplying electron number over dynodes, the electrons are then collected by the anode, which is situated on the end of the electron multiplier. The anode output current is then converted to voltage signal by appropriate load resistor or by operational amplifier current-to-voltage circuit.

As all other laboratory instruments, which are based on accelerating electrons, such as electron microscopes, the photomultiplier's main parts must be kept in vacuum. To maintain vacuum, the photomultiplier is surrounded by special glass envelope. To avoid mechanical damage of the glass envelope, the entire photomultiplier is situated in a plastic tube.

One of the basic adjustable characteristic of PMT is its gain. The gain is defined as:

$$G = \frac{I_{\mathrm{a}}}{I_{\mathrm{p}}}, \tag{3.1}$$

where $I_{\mathrm{a}}$ is the anode current and $I_{\mathrm{p}}$ is the input photocurrent from the photocathode.

In case of ideal, noiseless PMT, we can adjust gain by variing the supply voltage. By variing supply voltage we can adjust gain according to an euqation:

$$\frac{G_2}{G_1} = (\frac{V_2}{V_1})^{\alpha N}, \tag{3.2}$$

where $G_2$ and $G_1$ are gains at supply voltages $V_2$ and $V_1$. $\alpha$ is coefficient given by dynode material and $N$ is the number of dynodes.

Other effects, such as temperature, may also vary PMT's gain, and it is neccesary to keep them on constant value or monitor.

### Window

The photocathode is superimposed by glass window, whose main purpose is to admit light of certain wavelengths. Glass materials are characterized by the spectral sensitivity to wavelengths. For transparency in UV spectre, it is advised to use borosilicate or fused silica glasses.

### Photocathode

The photocathode is the only light-sensitive part of PMT. It transfers the light flux into electric current.

One of its main parameters is quantum efficenty. It is refered as ratio of emitted photoelectrons to the number of incident photons expressed as a percentage. It is generally less than 35 %. For measurement, the more practical parameter is cathode radiant sensitivity. It is the ratio of photocathode current to an incident light power, which is expressed in mA/W.

Photocathode material must be sensitive to certain wavelengths, which we want to detect with the PMT, and must have sufficent quantum efficenty. Prefered materials are usually alkali antimodes.

### Electron multiplier

The electron multiplier consists of dynodes and one anode. Dynodes are electrodes, which produce more electrons through secondary emission. To maintain elecrostatic field between dynodes, each of dynodes is held on different potential. This is achieved by using the voltage divider. Every resistor in the divider sets the potential of one diode according to its resistivity.

All of the photoelectrons emitted by photocathode should be ideally collected by the first dynode. However, many of them could be diverted from their path to dynode due to various effects. The parameter, which characterizes this, is the collection efficiency. The Collection efficiency is a probability that photoelectron will strike area of the first dynode.

There are few types of dynodes arrangements. On the fig. 3.2 is the classic linear-focusing multiplier.

### Voltage divider and voltage adjustement

Voltage divider could be a simple resistor serial network, which divide high input voltage between the dynodes.

It is neccessary to consider, that the multiplier current density increases in direction to the anode, so it tends to lessen the voltage between last dynode and anode. This phenomena can shake the potential levels across the entire multiplier. One way to reduce the impact on PMT's behaviour is to choose the proper resistor values of the divider.

The resistor values could same for all the dynodes, but for some applications it is better to have progresive voltage distribution, which increases from cathode to anode, or intermediate distribution with highest values on the beginning of the multiplier.

In some aplications, where high anode current peaks are expected, the divider can be filled with reservoir capacitors, which prevent the temporaly charge exhaustion of the dynodes. In pulse mode, the unwanted oscillacions on dynodes may occur, in that case, it is desirable to connect additional damping resistor to the divider.

### 3.2.2 Gain and sensitivity

### 3.2.3 Noises and Dark current

### 3.2.4 Operating life and degradation

The operating life of PMT is defined as the time required for anode sensitivity to be halved.

### 3.2.5 FAST's PMTs

### 3.2.6 Calibration

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## 3.4 Hardware for experiment control

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# Chapter 4

# Calibration UV optical source

Blah blah we need it.

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## 4.2 Testing and measurement of UV source

## 4.3 Adding optical feedback

## 4.4 Modified UV source for drone mounting

# Chapter 5

# FAST Calibration data analysis

## 5.1 Photomultiplier relative calibration

## 5.2

## 5.3

# Conclusion

We are completely f****d.

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Preferované jsou citace podle norem ČSN ISO 690 a ISO 690-2, popř. styly APS (American Physical Society – u prací zaměřených fyzikálně) nebo APA (American Psychological Association – u prací zaměřených více didakticky a pedagogicky).