Modern detectors for study Standard Model and Beyond

Thesis Subtitle

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Doctor of Physics

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Abstract

The increased necessity of experimental proof of physics beyond Standard Model (SM) and Dark Matter theories leads us to develop new detectors for high energy experiments, like ATLAS with his upgrade (New Small Wheel project in particular) for the luminosity increase at LHC and a new experiment on SPS facilities at CERN called NA64; to search for Dark Matter on invisible(visible) decays of dark photons.
For this two experiments, detectors from our institute have been made to be part on such enterprise. Characterizations and tests have been done with the use of particles beam (electrons, pions, muons and gamma rays) from the Experimental Area at CERN.

Dedication

Acknowledgments

Contents

1. Introduction **11**

2. Characterization of sTGC **13**

2.1. ATLAS Detector Upgrade 13

2.1.1. High Luminosity Large Hadron Collider - HL-LHC 13

2.1.2. ATLAS Detector 14

2.1.3. New Small Wheel 14

2.2. Small-strip Thing Gap Chamber 14

2.3. Construction process 16

2.3.1. Quality Control of cathode boards 16

2.3.2. Cathode preparation 17

2.3.3. Graphite spraying 17

2.3.4. Polishing 18

2.3.5. Glue internal parts 18

2.3.6. Winding wires 18

2.3.7. Detector Assembly 18

2.3.8. Planarity and thickness measurements 19

2.4. Gain uniformity measurements 19

2.4.1. Setup 20

2.4.2. Results 20

2.5. Test under high rate 21

2.6. Spatial resolution strips 21

2.7. Charge sharing between pads 22

2.8. summary 24

3. Brillance380 under high rate **25**

3.1. Scintilators counters 25

3.2. high count rates 25

3.3. Internal radiation 25

3.4. Experimental setup 25

3.5. Spectrum and rates under different attenuation filters 25

3.6. Data Analisys 25

3.6.1. Wavelets 25

3.6.2. Peak identification 25

3.7. Results 25

4. LYSO crystals array as SRD **27**
4.1. NA64 experiment 27
4.1.1. Physics Motivation 28
4.1.2. Dark Photon signal 28
4.1.3. Setup 28
4.2. Synchroton Radiation Detector 28
4.2.1. BGO 28
4.2.2. Pb+Sc 28
4.2.3. LYSO 28
4.3. Calibration 28
4.4. Position and time resolution 28
4.5. Hadron rejection 28
4.6. Purity 100 GeV electron identification 28
4.7. Summary 28

5. Conclusion **29**

A. Appendix **31**
A.1. Mechanical Measurements sTGC Module 0 31
A.2. PMT RT7525 Data Sheet 31
A.3. Data Structure NA64 Experiment 31
A.4. DAQ system 31

1. Introduction

Let's see if this thing apppear as a introductio

2. Characterization of sTGC

2.1. ATLAS Detector Upgrade

2.1.1. High Luminosity Large Hadron Collider - HL-LHC

The Large Hadron Collider (LHC), run by CERN at the Franco-Swiss border near Geneva, is a circular accelerator with 27 km of acceleration pipes, is the largest scientific instrument ever designed and built for scientific research. Successfully commissioned in March 2010 for proton-proton collision with a 7 GeV centre-of-mass energy.
The LHC is pusshing the limits of human knowledge, enabling physicist to go beyond Standar Model (SM): the enigmatic Higgs boson, mysterious Dark Matter and the world of supersymetry are just three of the long-awaited mysterous that the LHC will unveil. The announcement given by CERN on 4 July 2012 about the discovery of new boson at 125-126 GeV, almost certainly the long awaited Higgs particle, is the first fundamental discovery, hopefully the first of a series, that the LHC can deliver.
Such discovery was thanks to the different detectors located on the four interaction points; ALICE, LHCb, CMS and ATLAS. This last one is the detector where our university is taking part.

	Period	Energy $\sqrt{s}$	Upgrade on LS	L	Integrate L
Run I	2010-2012	7-8 TeV	-	$6x10^{33}cm^{-2}s^{-1}$	25 fb^{-1}
LS1	2013-2014	Go to design energy, nominal luminosity, bunch spacing 25ns			
Phase 0	2015-2018	14 TeV	-	$1x10^{34}cm^{-2}s^{-1}$	75-100 fb^{-1}
LS2	2019-2020	Upgrade muon spectrometer;NSW, LAr Calorimeter & FTK			
Phase I	2021-2023	14 TeV	-	$2x10^{34}cm^{-2}s^{-1}$	~350 fb^{-1}
LS3	2024-2025	New Inner Tracker and trigger architecture			
Phase II	2026-2030	14 TeV	-	$5x10^{34}cm^{-2}s^{-1}$	~3000 fb^{-1}

Figure 2.1: LCH Schedule

CONTINUE WITH LHC UPGRADE and GOALS

2.1.2. ATLAS Detector

The ATLAS detector it is a general-purpose detector, designed to explore proton-proton colissions at center of mass up to $\sqrt{s}$ =14 GeV. Looking for....

Such energy has been achived from 2015 and successfuly working with a luminosity of 1x10^{34}cm$^{-2}s^{-1}$ from 2016.

Describe ATLAS detector and its part, together with the problem faced by now. ENDING WITH THE FAKE TRIGGERS AND PROBLEMS FOR LOW PT.

2.1.3. New Small Wheel

In manner to fullfill the LHC program (in fig.2.1), and in order to benefit from the expected high luminosity performance that will be provided by the Phase-I upgraded LHC, the first station of ATLAS muon end-cap system (Small Wheel, SW) will need to be replaced. The New Small Wheel (NSW) will have to operate in a high background radiation region (upto 15kHz/cm^2) while reconstructing muon tracks with high precision as well as furnishing information for the Level-1 trigger. These performance criteria are demanding. In particular, the precision reconstruction of tracks for offline analysis requires a spatial resolution about 100 μm, and the Level-1 trigger track segments have to be reconstructed online with an angular resolution of symroximately 1mrad. The NSW will have to chamber technologies, one primarily devoted to the Level-1 trigger function (small-strip Thin Gap Chambers, sTGC) and one dedicated to precision tracking (Micromegas detectors, MM). The sTGC are primarily deployed for triggering given their single bunch corssing identification capability. The MM detectors have exceptional precision tracking capabilities due to their small gap (5mm) and strip pitch (symroximately 0.5mm). Such a precision is crucial to maintain the current ATLAS muon momentum resolution in the high background environment of the upgraded LHC. The MM chambers can, at the same time, confirm the existence of a track segments found by the muon end-cap middle station (Big Wheels) online. The sTGC also has the ability to measure offline muon tracks with good precision, so the sTGC-MM chamber technology combination forms a fully redundant detector system for triggering and tracking both for online and offline functions. This detector combination has been designed to be ablo to also provide excellente performance for the eventual High Luminosity LHC upgrade.

2.2. Small-strip Thing Gap Chamber

The Small strip Thin Gap Chamber (a.k.a sTGC) detector it is a multi-wire proportional chamber (MWPC) working in a high gain mode with a cathode-anode pitch smaller than the anode-anode pitch, mostly based on the design of the Thin Gap Chamber[1], with thinner strips as the main improvement from the previous version. The TGC tecnology has been used since 1988 in OPAL experiment and currently are part of the the muon spectrometer in ATLAS.

This new chamber has the advantage of having a 3.2mm strip width compare to the 5-6 mm from the previous TGC, that is why it is called small strip Thin Gap Chamber.
The size of the strips has been choosen to cope up with the precision resolution require for the NSW (explained before), where it has to be better than 100 μm and provide a reponse with a few nanoseconds. For this purpose, chambers with different strips sizes has been build and test under pion beams, chosed the 3.2mm has the best option[3].

The sTGC is made of two resistive cathods planes, one with csymer strips and the other with pads, each cathode plane is made of FR4 with 1.6mm of thickness, where 100 μm of csymer is etched for strips (pads) and then pressed with a 100 μm of FR4 over it and then sprayed with graphite to provide 100-200 k$\Omega/\square$ (1 M$\Omega/\square$ for TGC) so it can be treatead as a resistive cathode plane.
The anodes are golden tungsten wires of 50 μm diameter, distributed at 1.8 mm between each other. The gas gap (2.8mm) is filled with a mixture of carbon dioxide (CO_2) and n-pentane(C_5H_12) in proportion 55:45 respectively both strongly quenching gases that provide a high amplification factor and relatively low sensitivity to mechanical variations.[ref Mechanical variations]

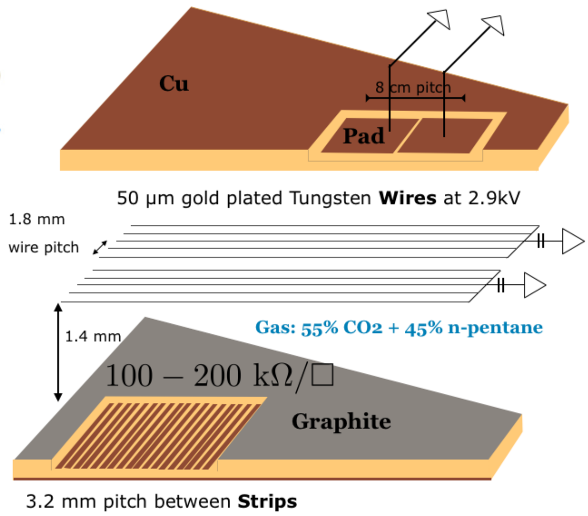


Figure 2.2: Single plane sTGC

A MWPC detector type is a relativetely old technology, its succesfuly introduction to detector system in 1968 gave the Nobel prize to George Charpak in 1992. This device has been a major ingrediente in detector systems since it can achieve spatial resolutions of 500 μm or less, and has typical time resolution of about 30 ns.
The TGC has been built as a MWPC with a thinner gas gap, its means, the distance from the anode-cathode is smaller than the anode-anode (wire to wire) to provide a fast time response, and at the same time giving a higher amplification, to achieve this smaller distance, precautions must be taken into account when the internal pieces are construct, for that a precision of 50 μm must be achieve.
To work with such geometry several test were made to find the proper gas mixture[2].

Find the most suitiable mixture of 55% well known carbon dioxide as a quenching gas, and a 45% of n-pentane, which for his nature can absorb energy in many ways of molecules degree of freedom, vibrational, rotational, etc.

- voltaje de operacion.
- resitividad del graphito y para que usamos grafito.
- Que es lo moderno de este detector...

2.3. Construction process

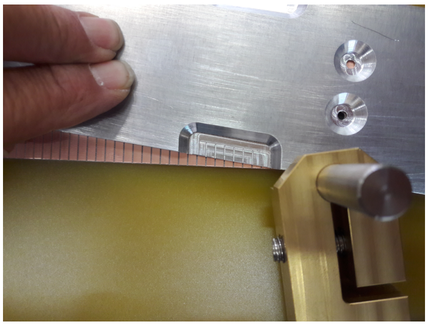
Since the main novelty on this detector is the high resolution obteined on xy plane due to the strip boards and the alignment between each chamber to get precission about 50μm and 30μm respectively, its important to discuss how we achieve those numbers. Everything relies on how well are those chamber built and also how the cathodes boards (strips and pads) are fabricated. The size of each chamber are around 1m^2 to 2m^2 and for the current fabricant it is complicated to achieve 50 μm resolution etching a pcb board accross 1.5 m without taking into consideration that the standard size for pcb boards are 70 cm long. The attempt of this sections is to give an idea how the sTGC Quadruplets are built, mostly on the first module 0 produce by UTFSM, which is the QS1 (Quadruplet Small sector, part 1). Being the smallest detector to be produce for the NSW, has some pro and cons. The main cons is related to the posistion of the QS1 inside the NSW, it is the closest one to the interaction point and for that it get the highest rate of particles. For the same reason the position resolution is a key point and the response against high rate particles it is a must. Some pros are related to the size of it, with approximetely 1m long and 55 cm the small side and 75 cm the large side of the trapezoidal shape, the sTGC QS1 can be handly without any problems, its 45 kg at the final step is easy to manage between two people, and with almost 1m long, the etching of strips boards (2.7 mm strip width and 0.5 mm etch) can be achieve with 50 μm.

2.3.1. Quality Control of cathode boards

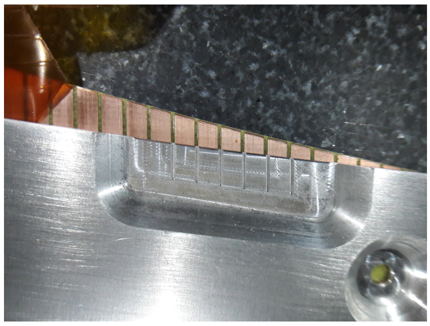
The cathodes for the module0 were maid by an Italian company MDT, and since it was the first production, the review was done at their place.
The thickness of the board is measured in 19 points around the perimeter with a micrometer. The values of theses measurments must be whithin 1.6 mm $\pm 25\mu$m,exceding this numbers lead to the partial rejection of the cathode boards, however if there is a single point deviation of less than $\pm$ 35μm about the average, it could be used in combination with another cathode board that does not have the same local deviation. The raw data is found in appendix X.

An electrical test is donde with a multimiter, to check if there is any short between strips or pads depending on the cathode board.

The last step and the most important is the dimensional control: this must be perform on a flat surface (done on a granite table at the construction site), with 2 pins that match the brass inserts on the cathode and using a special caliper above the cathode board the misalignment is measured. The caliper is an aluminuim ruler machining with a precision of 30 μm at 20 Celsius degrees has the same strip pitch for the first and last five strips and to avoid any paralax the thickness is the edge for those strips is 1mm. Looking with a lens glass around this point it posible to detect some misaligment between this two strips (caliper and cathode board). A photography is taken and analize to calculate this misaligment. For such distance (about 1 m long) some precaution must be take, considering the expansion coeficient for both material. machining with a precision of 30μm measure at 20 Celsius degrees.



(a) Al ruler used to check shift over the last strips.



(b) Zoom-in Comparing strip position

2.3.2. Cathode preparation

Once the cathodes pass all the dimensional control are cleaned with Acetone and Isopropyl acohol and placedplaced on a granite table with a flatness of better than 30μm, and a vacuum system underneath and fixed on the edges with metal jigs which also has marks for the internal wire support or chamber section. The places which does not be sprayed with graphite, like the wire support and the edges are covered with a 3.5mm black tape to the designated wire support locations across the board, and a blue tape the edges preventing spray graphite on the places where they will be glue.

2.3.3. Graphite spraying

A key point for this process is to prepare the 'painting' a mixture of Graphite-33 with Plastik-70 bonding agent. The graphite must be agitated for at least 2 hours before mixing with Plastik-70. A proper ratio of 1500g Graphite and 540g Plastik is mixed for 20min before spraying.

A spraying machine is in charge to get this process done, meanwhile a temperature and humidity must be controlled. After the cathode is painted the superficial resistance is measured on the edges and values above 100k$\Omega/\square$ must get otherwise the cathode needs to be sprayed again.

2.3.4. Polishing

In manner to ensure an uniform resistivity across the chamber, the cathode is visually divide in 5x6 squares. Inside each square t e resistivity is measure in 5 to 7 points with a probe and simultaneously brush it in the orientation that the wires will be wound. The brush must be done carefully without over-polish areas because onces resistance drops down nothing will bring it back up.

2.3.5. Glue internal parts

After removing all the blue and black tape, all the internal parts such buttons to provide mechanical support to the gas gap, the wire support which help them to not bend due to gravity and create catenary effect, and all the external frames to provide the 1.4mm height for the gas gap. All this part are cleaned with isopropyl alcohol, meanwhile the glue, a type of epoxy (2011-Araldite) is prepare. This glue will not only fix the part, also will fill the surfaces where those part are had less thickness than is requested.

2.3.6. Winding wires

A flat table which can spin around on one axis is used to winding the cathodes board. On each side of the table one cathode with all the internal parts previosly glued is mounted and tight it with metal clamps on the edges, meanwhile a vacuum is apply underneath to ensure the flatness of the cathode. A winding machine is in charge of this process, taking all the precautions to place every wire at 1.8mm between each other with 50μm precision?.
After the process is done, all the wires are solderd in group of 10 in the wire rulers with 10MΩ resistor to the high voltage line, later on the remaining wire can be cut and the metal clamps around the edges can be removed.

2.3.7. Detector Assembly

Once the Pad cathode board with all wires soldered is cleaned with clean water and dry with clean air. The board is place on the granite table, vacuum is applied underneath so it can be ready to connect it to high voltage. It is necessary to monitor the current from the cathode meanwhile the voltage is increased, starting with 100V and reach 3000V, every 100V step the current is monitoring and check that never goes higher than 1μA, if it is the case, the cathode needs to watch carefully on each corner to see some small sparks around dust or remaining glue from the previous process.
Reaching the nominal current, the strip cathode board is placed against the pad cathode board carefully, and an aluminuim frame with a sillicon rubber is placed on top to isolate the chamber from the environment, afterwards the vacuum is applied to this chamber and only CO2 is flushing inside the chamber. Now it is the time to turn on the power supply and watch if there is no sparks (monitoring the current), if it is not the case, the glue is prepared to close the chamber inmediataly to prevent any dust enter the chamber

when the sillicon ruber and the strip cathode board is remove. Finishing this process, a single chamber detector is considered done.
Closing two chambers is possible build a doublet, for that it is necessary to glue a honeycomb with a well known thickness (5±0.02mm)

2.3.8. Planarity and thickness measurements

Total thickness.

2.4. Gain uniformity measurements

After the chambers are built it is important to know the response of the detector, and a primitive way to do such thing without any electronic readout attach to strips or wires, is to measure the current draw from the power supply and see how it behaves to a radiation source.
There are two ingredients that can produce gain variations on wire detectors, the first one is the ńature" gain fluctuations from the charge production in proportional counters which follow Polya distribution, however is less pronounced in semi-proportional mode such as sTGC working region.
The second one is related to the mechanical tolerances, this part is very well known since 40 years as it is presented on Sauli's book about drift chambers and tell us that for a diameter variations of the wire about 1% (fabrication precision) will result on a 3% change in the gain, where as about 100μm difference in the gas gap thickness (2.7mm) results in about 15% change of the gain. The effect of a wire displacement of about 100μm of a wire plane results in 1% int the charge of the two adjacent wires which with a gain of $\sim 10^6$ will give a $\sim$ 10% change in the gain.
Taking all of this in consideration is expected to get a gain variation less than 20% as Quality Acceptance.
In this test the gain is considered as the current draw measured from the power supply and its need to test under two different working points (bias voltage), one when the chamber it is not in the limited proportional region, 2500 volts, a take it as a reference compare to the 2900 volts which is the operational voltage.

For such test the x-ray source is used due to the many advantages:

- Mostly mono-energetic photons.
- Variable current: which can provides different rates. [1μA - 200μA]
- Variable voltage: modifying breaking voltage of electrons inside the x-ray gun. [10keV - 50keV]
- Different spot size: with a set of collimator it is possible to irradiate only interesting area.
- Portable, it is possible to move across the sensitive area of the detector.

2.4.1. Setup

To perform such test a x-ray gun called Mini-x from Amptek is used, with silver (Ag) as transmission target with a beryllium (Be) end window is used. Working under 50kV with 45μA, the emission spectra Fig.2.4 show two main photo peaks with 22 and 25 keV. The aperture emissions is about 120 degrees, so a collimator of 5 degrees is placed to provide a spot size of 4mm.
The gun is mounted on a robot arm KUKA, to move it across the detector irradiating a long the wires. Since the high voltage power supply give us a current average per second, the vertical and horizontal step can be adjust to perform a spot size of $4mm^2$ however the Mini-x device had some overheat issues so a 5cm vertical step was chosen to perform a full irradiation test in less time. A more suitable step would be 1cm to detect internal structures of similar sizes. The horizontal step was 1.5cm, enough to change completely from group wires, although it will better to improve the granularity it is not possible since the issue explained before.

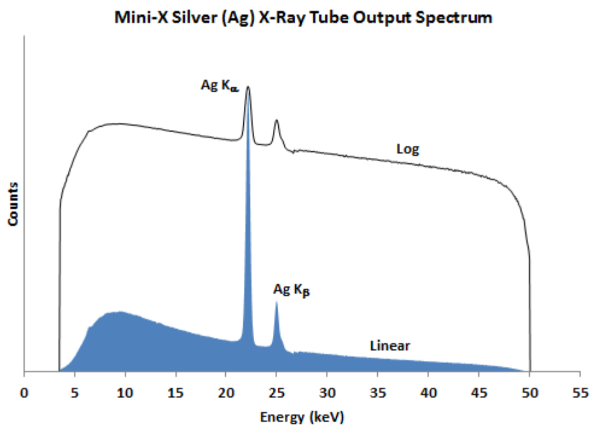


Figure 2.4: X-ray emission spectra from Mini-X gun

The irradiation test is taken in approximately one hour and the four chamber are done at the same time, meanwhile the division of each chamber are connected to the same HV channel.

2.4.2. Results

The next two set of histograms shows the distribution of the current draw at two different voltage, one at 2500V to take it as reference since the cahmber can be consider with no gain (no proportional mode), and the second one the voltage at what our chamber must be working 2900V.
On the Figure 2.5 an average of approximately 200nA can be observe on the four layers, considering 50nA when no source is present (leakage current). As previously discuss the important part is to get how uniform are the chambers across the whole sensitivity area, even the places where the internal parts are found, such a wire supports and buttons, which in that case a notoriously decrease of gain (less current draw) is expected due to

the lack of gas volume, and so no amplification.
On the Fig2.6 the current draw for each single chamber is shown with uniformity less than 17%. Definitely improve the uniformity if only the places without wire support are removed, having a XX%.

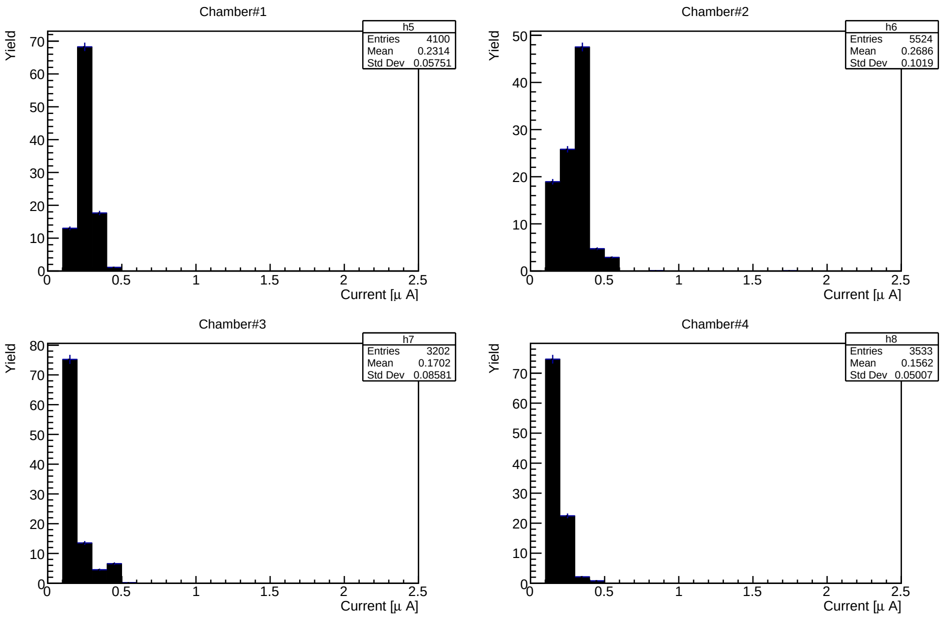


Figure 2.5: Current from power supply at 2500V

2.5. Test under high rate

One of the key feature of this detector is to be able to work under different particles rates, and if it is capable of handle rates higher than 15kHz/cm^2. For this Test of module0 inside of GIF++, together with rate measurement with small TGC monitor. Detector test under different atteuation filters.

2.6. Spatial resolution strips

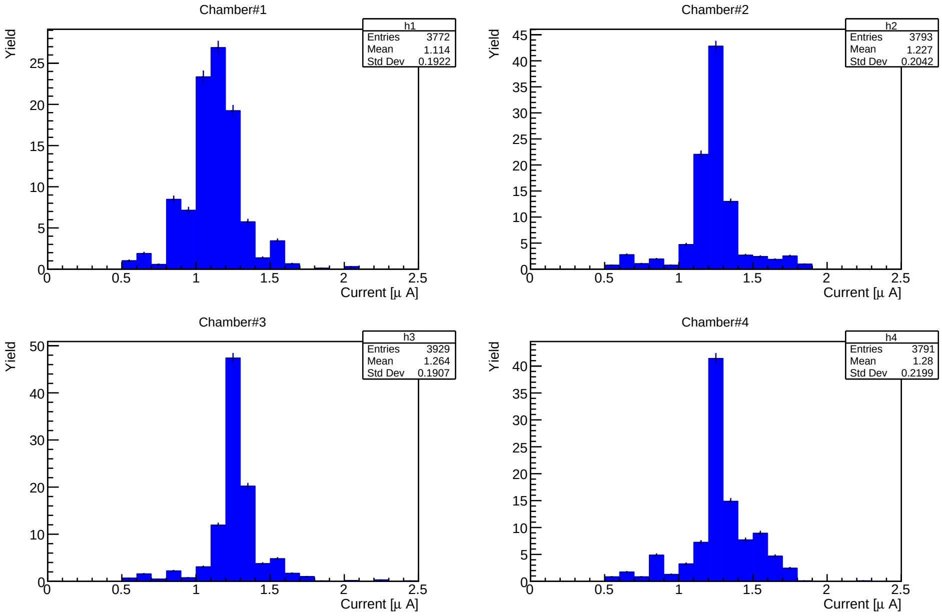


Figure 2.6: Current from power supply at 2900V

2.7. Charge sharing between pads

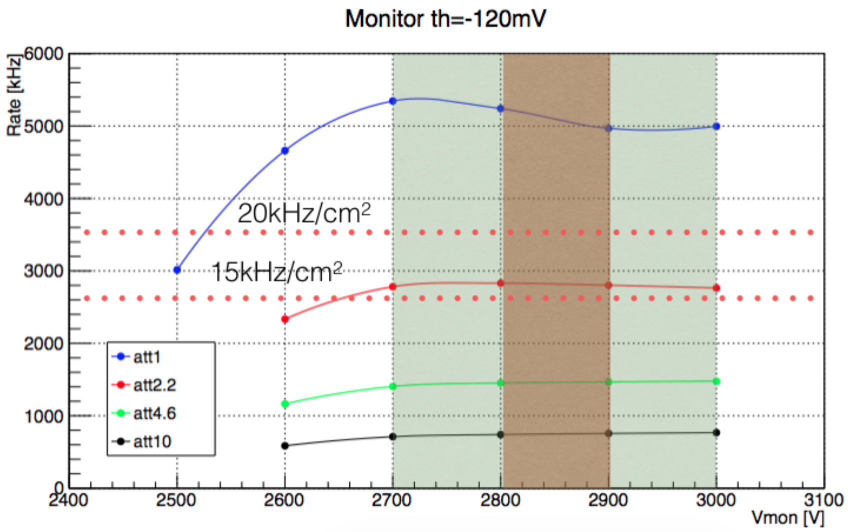


Figure 2.7: Monitor rate

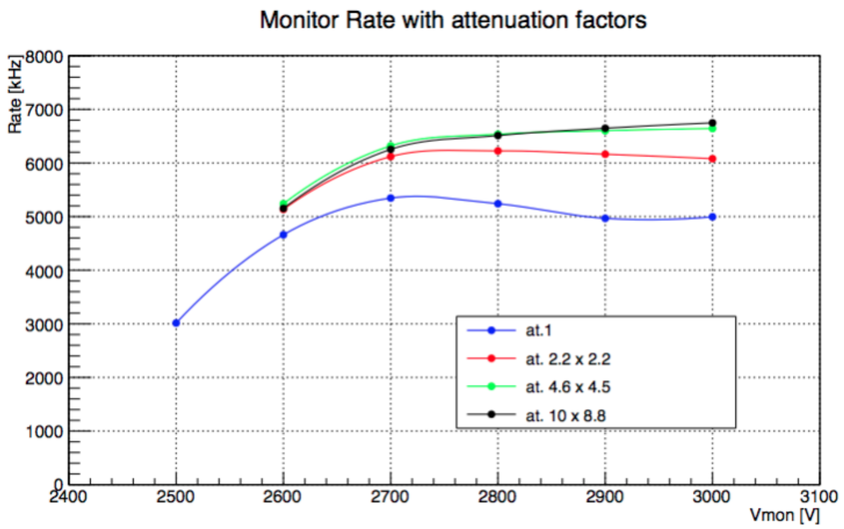


Figure 2.8: Filters applied

2.8. summary

3. Brillance380 under high rate

3.1. Scintilators counters

3.2. high count rates

3.3. Internal radiation

3.4. Experimental setup

3.5. Spectrum and rates under different attenuation filters

3.6. Data Analisys

3.6.1. Wavelets

3.6.2. Peak identification

3.7. Results

4. LYSO crystals array as SRD

4.1. NA64 experiment

The NA64 experiment is a fixed-target experiment at the CERN SPS combining the active beam dump and missing energy techniques to search for rare events.
A fully hermetic detector placed on the H4 beam line has been built with the primary goal to search for light dark bossons (Z') from dark sector that are coupled to photons, e.g. dark photons (A'), or sub-GeV Z' coupled only to quarks. In some cases the Z' is coupled only to μ or tau, so we call the Z' the dark leptonic gauge boson. The experiment is also capable to search for $K_L \rightarrow$invisible decay, which is complementary to $K+ \rightarrow \pi^+ + \nu\nu$, and invisible decays of π_0, η,η', K_S mesons.
The advantage of this approac is that the sensitivity (or number of signal events) of the experiment is roughly proportional to the Z' coupling squared ε^2, associated with the Z' production in the primary interaction in the target/ While in a classical beam dump experiment, it is proporiotional to ε^4, one ε^2 came from the Z' production, and another ε^2 is either from the probability of Z' decays or their interactions in a detector located at a large distance from the beam dump.
The sensitivities of these two methods depend on the region under study in the (ε^2,m_Z) parameter space, background level for a articular process, available beam intesity, etc.[Beam intensity] In some cases, much less running time and primary beam intensity are required to observe a signal event with our approach.

4.1.1. Physics Motivation

4.1.2. Dark Photon signal

4.1.3. Setup

4.2. Synchroton Radiation Detector

4.2.1. BGO

4.2.2. Pb+Sc

4.2.3. LYSO

4.3. Calibration

4.4. Position and time resolution

4.5. Hadron rejection

4.6. Purity 100 GeV electron identification

4.7. Summary

5. Conclusion

A. Appendix

A.1. Mechanical Measurements sTGC Module 0

A.2. PMT RT7525 Data Sheet

A.3. Data Structure NA64 Experiment

A.4. DAQ system

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