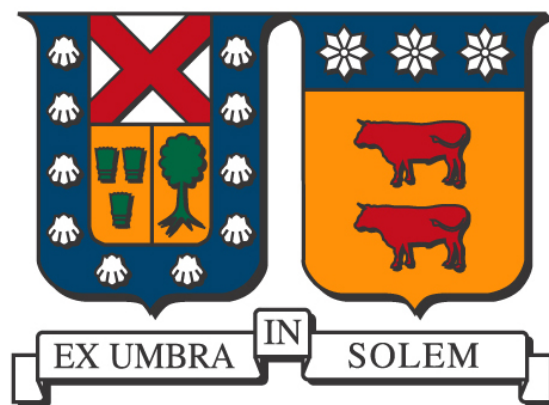


# Thesis Title

Thesis Subtitle

A thesis presented for the degree of  
Doctor of Physics



Department Name  
University Name



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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.



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# Dedication



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# Acknowledgments





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# 1. Introduction

Let's see if this thing appear as a introductio



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## 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 pushing 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 mysterious 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	-	$6 \times 10^{33} \text{cm}^{-2} \text{s}^{-1}$	25 fb $^{-1}$
LS1	2013-2014	Go to design energy, nominal luminosity, bunch spacing 25ns			
Phase 0	2015-2018	14 TeV	-	$1 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$	75-100 fb $^{-1}$
LS2	2019-2020	Upgrade muon spectrometer; NSW, LAr Calorimeter & FTK			
Phase I	2021-2023	14 TeV	-	$2 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$	$\sim 350 \text{ fb}^{-1}$
LS3	2024-2025	New Inner Tracker and trigger architecture			
Phase II	2026-2030	14 TeV	-	$5 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$	$\sim 3000 \text{ fb}^{-1}$

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 collisions at center of mass up to  $\sqrt{s}=14$  GeV. Looking for....

Such energy has been achieved from 2015 and successfully working with a luminosity of  $1 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$  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 fulfill 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  $15 \text{kHz/cm}^2$ ) 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  $100 \mu\text{m}$ , and the Level-1 trigger track segments have to be reconstructed online with an angular resolution of approximately  $1 \text{mrad}$ . 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 (Micro-megas detectors, MM). The sTGC are primarily deployed for triggering given their single bunch crossing identification capability. The MM detectors have exceptional precision tracking capabilities due to their small gap ( $5 \text{mm}$ ) and strip pitch (approximately  $0.5 \text{mm}$ ). 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 able to also provide excellent performance for the eventual High Luminosity LHC upgrade.

## 2.2. Small-strip Thin Gap Chamber

The sTGC detector it is a multiwire 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. The TGC technology 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  $3.2 \text{mm}$  strip width compare to the  $5-6 \text{mm}$  from the previous TGC, that is why it is called small strip Thin Gap Chamber (sTGC)

from now on).

The size of the strips has been chosen to cope up with the precision resolution require for the NSW (explained before), where it has to be better than  $100\text{ }\mu\text{m}$  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[2].

The sTGC is made of two cathods planes, one with copper strips and the other with pads, each cathode plane is made of FR4 with 1.6mm of thickness, where  $100\text{ }\mu\text{m}$  of copper is etched for strips (pads) and then pressed with a  $100\text{ }\mu\text{m}$  of FR4 over it to provide a homogenous surface so it can be sprayed with graphite to achieve  $100\text{--}200\text{ k}\Omega/\square$  ( $1\text{ M}\Omega/\square$  for TGC). The anodes are golden tungsten wires of  $50\text{ }\mu\text{m}$  diameter, distributed at 1.8 mm between each other. The gas gap (2.8mm) is filled with a mixture of  $\text{CO}_2$  and n-pentane in proportion 55:45 respectively both strongly quenching gases that provide a high amplification factor and relatively low sensitivity to mechanical variations.

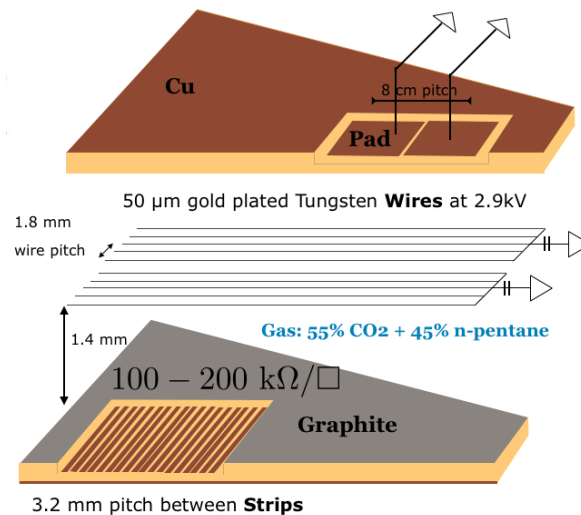


Figure 2.2: Single plane sTGC

A MWPC is a relatively old technology, its succesfuly introduction to detector system in 1968 gave the Nobel prize to George Charpak in 1922. This device has been a major ingrediente in detector systems since it can achieve spatial resolutions of  $500\text{ }\mu\text{m}$  or less, and has typical time resolution of about 30 ns.

- Explicar geometria del sTGC, gas gap y wire pitch.
- explicar eleccion de gas
- voltaje de operacion.
- resitividad del graphito y para que usamos grafito.
- Que es lo moderno de este detector...

## 2.3. Construction process

Cathode production and how we achieve the resolution requeride for this.

Clean cathode

Sprayed process

Achieve the proper superficial resistivity

glue internal parts

Winding wires, soldered and clean afterwards

test wires under hv

Close chamber and filled with CO<sub>2</sub>, no sparks must found

glue chamber

Thickness measurments

Repeat process till get 4 modules

Overall thickness measurements and pin position check

## 2.4. Gain uniformity measurements

One of the Quality Acceptance and Quality Control (QA/QC) is to test each single plane under x-rays to check the homogenity of the detector on different spots, looking for construction issues that may cause some high variation on the signal for a single hit. To provide such test we use a x-ray gun placed in a robotic arm (KUKA) and move it through different position of the chamber, going from active to non active areas covering the full size of the detector, recording at the same time the current draw from the High Voltage power supply.

What can affect the gain?

Why we use X-rays?

### 2.4.1. Setup

Provide explanation of setup and posterior details of instruments.

- X-ray source: Mini-X gun with photons of 50 keV and flux of 45  $\mu$ A
- Collimator: 5°.
- Distance from source:  $2.5 \pm 0.3$  cm. Spot size:  $2 \pm 0.26$  mm.
- KUKA arm; giving vertical steps: 1.5 cm, horizontal steps: 5 cm.
- HV power supply: 50 nA resolution. Sampling rate: 1 sample/s.



## 2.4.2. Results

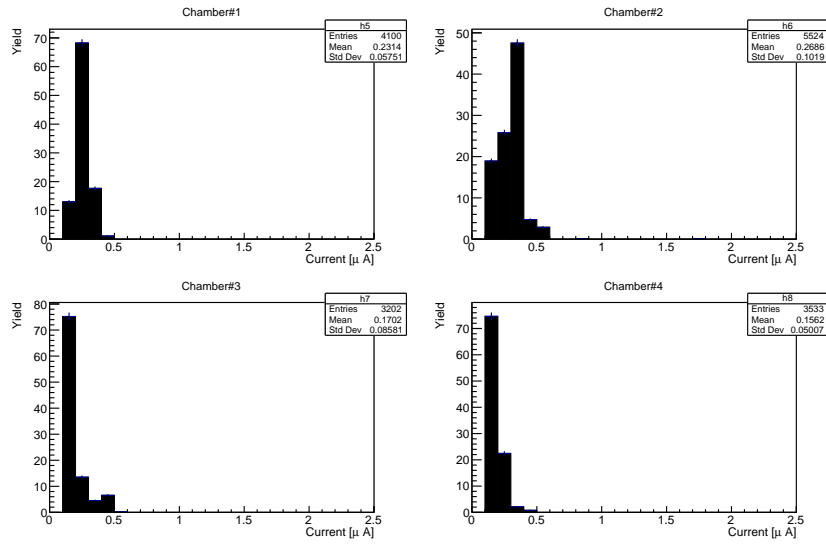


Figure 2.3: Current draw from PS at 2500V

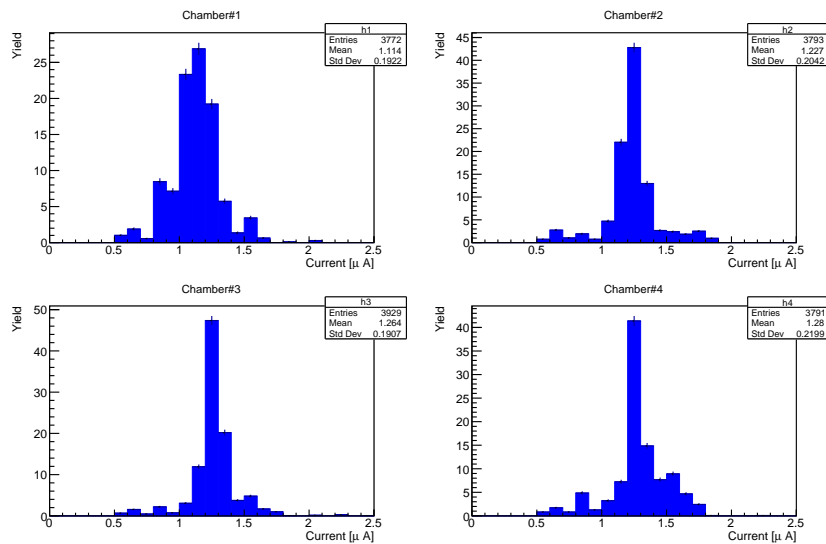


Figure 2.4: Current draw from PS at 2900V

- 2.5. Test under high rate
- 2.6. Spatial resolution strips
- 2.7. Charge sharing between pads
- 2.8. summary

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## 3. Brillance380 under high gamma 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 Analysys

#### 3.6.1. Wavelets

#### 3.6.2. Peak identification

### 3.7. Results



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## 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 bosons ( $Z'$ ) 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  $\mu$  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  $\pi_0$ ,  $\eta, \eta'$ ,  $K_S$  mesons.

The advantage of this approach is that the sensitivity (or number of signal events) of the experiment is roughly proportional to the  $Z'$  coupling squared  $\varepsilon^2$ , associated with the  $Z'$  production in the primary interaction in the target/ While in a classical beam dump experiment, it is proportional to  $\varepsilon^4$ , one  $\varepsilon^2$  came from the  $Z'$  production, and another  $\varepsilon^2$  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  $(\varepsilon^2, m_{Z'})$  parameter space, background level for a particular process, available beam intensity, 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. Synchrotron 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

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## 5. Conclusion





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## 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



# Bibliography

- [1] G. Mikenberg. Thin-gas gap chambers for hadronic calorimetry. *Nucl. Instr. and Meth. A*, 265:223–227, 1988.
- [2] et al V.Smakhtin. Thin gap chamber upgrade for slhc: Position resolution in a test beam. *Nucl. Instr. and Meth. A*, 598:196–200, 2009.