LPT 22 - Liquid scintillators with SiPMs

Simon Weingarten, Lars Steffen Weinstock

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1 The Detector

The topic of this lab course is the commissioning and characterization of a scintillation detector read out by SiPMs. Figure 1 shows the basic construction of the detector.

The main component of the detector is the liquid scintillator contained in the inner barrel. The inner barrel is coated with a reflective colour in order to improve its light yield. Additionally, it is covered in a light absorbing black foil shielding the inside from outside light sources. A single SiPM mounted behind a protective window looks into the inner barrel and is hit by the emitted and reflected scintillation light. The

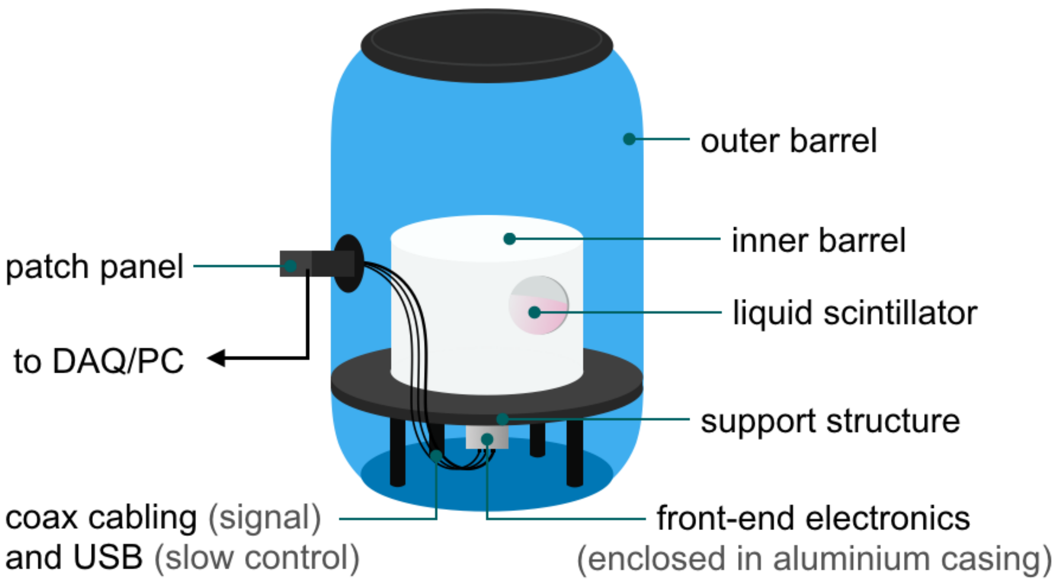

Figure 1: Basic construction of the detector used in LPT 22.

SiPM is connected to its front-end electronics, which is contained in an aluminium casing providing a good shielding from radio frequency electromagnetic radiation. The casing is thoroughly mounted to the top of the inner barrel. The inner barrel with the electronics attached rests in a support structure securing the detector inside the outer barrel. The outer barrel protects all components from environmental influences.

2 Front-End Electronics

The first part of the lab course is to ensure proper function of the front-end electronics and software access to the slow control. The front-end is made up of the amplifier and the power supply.

The amplifier consists of two amplification stages. The first stage is a transimpedance amplifier which takes the high impedance current signal emitted by the SiPM and uses a feedback resistance of $R = 1\,\mathrm{k\Omega}$ to convert it into a low impedance voltage signal. The second stage is an inverting amplifier with a gain of $G = -1$. The output signal of both stages is fed through to the two LEMO connectors at the back of the casing.

The power supply for the SiPM is provided by the C11204-02 integrated circuit (IC) by Hamamatsu. The C11204-02 measures the temperature of the SiPM using an externally connected temperature sensor and adjusts the voltage accordingly. The bias voltage at $25\,^{\circ}C$ V_{op} and the temperature coefficient $\Delta T V_{op}$ for the attached SiPM can be written to and current, temperature, and voltage measurements read from the IC using a serial interface. A FT232 converts this serial interface into USB and thus provides an easy way to communicate with the slow control. You will be provided with a working software skeleton and complete toolchain in order to debug and communicate with the C11204-02.

3 Tasks

In order to commission the detector properly the front-end has to be tested. Therefore you should complete the following tasks:

- Produce a Bode plot of the two amplification stages using a Vector Network Analyzer (VNA).
- Measure the bandwidth of both output stages.
- Write methods to read the output voltage and current of the C11204-02 and the temperature of the SiPM.
- Measure temperature, current and voltage of the SiPM during all long term measurements of the lab course.

After the functionality of the front-end is tested the detector can be characterized. Since the detector will be used as trigger the timing resolution and detection efficiency are of great interest:

- Set up the trigger logic using both PMTs and the detector module.
- Take long term measurements of cosmic muons (preferable over night).
- Produce pulse height spectrum.
- Calculate the timing resolution.
- Calculate the efficiency as a function of pulse height.

4 Discussion

Before the actual experiment there will be a discussion centering around the following points:

- What is cosmic radiation? What is a cosmic shower?
- Which reactions happen in a cosmic shower? What are its components?
- How are the energy losses (Bethe-Bloch)? What is the average energy of cosmics on earths surface?
- What are scintillators? What kinds of scintillators exist? What are their up- and downsides?
- How does a scintillator work (energy band model)?
- What is a PMT? How does it work (construction)? What are typical supply voltages?
- What are semiconductors (structure/zones, bands, doping, different types)?
- What is an APD and how does it work (modes of operation)?
- What is an SiPM (equivalent circuit diagram, quenching, signal/pulse spectrum)?
- Comparison of PMTs to SiPMs (size, sensitivity, supply voltage, ...)?
- How would you build a cosmic trigger using two PMTs and the detector described above?
- What is efficiency and timing resolution? How do you calculate them (and their errors)?
- What is a digitizer? What is the sample rate, memory depth, and bandwidth of a digitizer?
- Why do you need front-end electronics (power supply/slow control, amplifier)?
- What is a transfer function? What is a bode plot?
- How do you measure the bandwidth of an amplifier?

5 Preparation

The following links might help you with your preparation:

- Introduction to SiPMs:
  Physics and operation of the MPPC silicon photomultiplier (*Slawomir Piatek, Hamamatsu Corporation, New Jersey Institute of Technology, February 2014*)

- Transfer functions and Bode-Plots:
  Transfer Functions and Transfer Characteristics (*Randy Geiger, Iowa State University, Jan 2010*)

- Calculating errors on efficiency:
  Calculating Efficiencies and Their Uncertainties (*Marc Paterno, FNAL/CD/CEPA/SLD, May 2003*)
  Error analysis for efficiency (*Glen Cowam, RHUL Physics, July 2008*)

- Master thesis Simon Weingarten:
  Prototypdetektoren fur das geplante Upgradeprojekt Muon Track Fast Tag am CMS-Experiment (*Simon Weingarten, RWTH Aachen, September 2013*)