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Silicon PhotoMultiplier based detection structures for nuclear spectroscopy

Doctoral Thesis

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Contents

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Introduction

The silicon photo multipliers (SiPMs) are the solid state alternative and replacement for the classical light sensors, the photo-multiplier tubes (PMT), when used to collect the scintillation photons in ionizing radiation detectors. SiPMs feature low operating voltage, mechanical strength, immunity to magnetic fields and small size which opens the possibility to develop detectors of virtually any size and shape.

In order for a SiPM detector to be considered for replacing a PMT one, it should have similar or better energy and time performance. The goal of this PhD work is to study and develop silicon photo multiplier (SiPM) based detectors either as a replacement of existing PMT detectors either tailor-made solutions where a PMT is not applicable. The work I made during my PhD studies was possible as a result of the collaboration with the Nuclear Physics Department of IFIN-HH and by the use of their laboratories.

The paper work is structured in 5 chapters, covering the entire area of radiation detection and measurement, from detection mechanisms to data analysis.

Chapter 1 covers typical detector structure, types and detection mechanism with a focus on scintillator detectors, scintillator mechanism and light sensors.

Chapter 2 is a study of the front end electronics stage of a detector, covering signal amplifier typologies, filter structures needed to improve the signal to noise ratio, the Signal Driven Multiplexer readout architecture used in SiPM array detectors and noise.

Chapter 3 is an in depth analysis of the signal driven multiplexer, with the purpose to understand the influence of each design parameter over the time performance of the detector. The approach uses the analytical method of operational calculus based on Laplace transform to calculate y(t), the response of a system based on its response function, H(s).

Chapter 4 covers the most important theoretical aspects of radiation detector measurements like pulse parameters, noise, detector operation modes, sensitivity, response time, dead time, energy/time resolution and practical measurement setups.

Chapter 5 presents the results obtained during the PhD work, which are also published in scientific articles. The articles refer to scintillator's optical path contribution to signal rise time, $LaBr_3$(Ce) detectors performance, detector commissioning and characterization and detectors developed during work collaboration between IFIN-HH and ISOLDE CERN.

At the end of the paper, a list of personal contributions to the field is presented, followed by the appendices containing: i) the Mathematical framework needed for the S-Space analysis; ii) Python software source codes; iii) the SPICE model of the BAT15-04W Schottky diode, the key electronic component in the signal driven multiplexer architecture.

Radiation Detectors. Detection mechanism

The ionizing radiation (further called radiation) is detected based on its interaction with matter, therefore the architecture of a detector is tied to the radiation of interest and its interaction mechanisms. The structure of a detector also depends on parameters like size, shape, price, weight, application, minimum count rate, energy and time resolution, cost etc. There are two classes of detectors: i) ionization detectors and ii) scintillator detectors.

Ionization detectors directly collect the electric charge produced by radiation passing through the sensitive body of the detector. If the material of the body is a gas, the charge is represented by ions and electrons and collected by applying a bias voltage whose value also determines the operation mode: ionization chamber, proportional counter or Geiger-Muller counter. If the material is a semiconductor, the charge is represented by electrons and holes and also collected by applying a bias voltage. Common detectors are build with either Si or Ge and their architecture is of a reversed biased *pn* junction featuring very low leakage current.

Scintillation detectors are based on the property of certain materials to emit light upon the interaction with radiation. The light from the scintillator is collected and transformed into an electric signal with the aid of an optical sensor.

Commonly, a scintillator based detector is made out of 3 main components: i) the scintillator, ideally emits a number of optical photons proportional to the energy of incident radiation; ii) the light sensor converts the optical photons into an electric signal and iii) the front end electronics FEE, namely a preamplifier, placed in the proximity of the sensor, which amplifies the electric signal. The FEE is needed so that signals can be transmitted through cables over long distances with minimum signal to noise ratio degradation.

Scintillator materials can be organic or inorganic and present themselves in solid, liquid or gaseous state and have properties like photon yield, linearity, transparency, decay time, optical quality of the scintillating material, refraction index, wavelength of emission.

Scintillation mechanism is material dependant. In *organic scintillators* the light emission originates at molecule level, namely transitions of free valence electrons in the molecule's energy level structure in π*-molecular orbitals* while the scintillation of *inorganic crystals* resides in the energy band structure of the crystal. Sometimes activators are added to the inorganic melt during manufacturing to aid the scintillation mechanism, e.g. Ce in $LaBr_3$(Ce).

The most important **parameters of scintillators** are: light output, peak wavelength, decay constant, refractive index, density, softening point, bulk attenuation length and H:C ratio. Scintillators also present a few **unwanted phenomena** that affect their performance: photon loss, self absorption, internal reflection which affects energy and time performance of a scintillator detector.

The **Light Sensor** is an electronic device capable output an electric pulse when an optical pulse is provided. Common devices in nuclear applications are the photo-multiplier tube (PMT), the photo-diode also called PIN diode, the avalanche photo-diode (APD) and the a Silicon Photo Multiplier (SiPM).

The **Photo Multiplier Tube** is the most used light sensor in scintillator detectors, having excellent performance for both time and energy measurements. Regardless of the several configurations available commercially, a PMT is made out of two main components, the photocathode and the dynodes, responsible for photon conversion into electrons through photoelectric effect respectively electron multiplication through secondary emission.

The **Photo Diode** (frequently called PIN) is the simplest solid state alternative to a PMT for scintillator light collection. Scintillator photons ($3 \div 4$ eV) easily create electron-hole pairs in a semiconductor ($E_g = 1 \div 2$ eV). The charge collection is made inside the crystal leading to high quantum efficiencies. The number of electron-hole pairs is limited to the number of incident photons as no internal charge multiplication is present.

The **Avalanche Photo-Diode** (APD) operates at high reverse bias voltages, which triggers an process of avalanche that multiplies the original charge. The avalanche multiplication also generates significant noise, which should always be considered in applications using APDs. Their gain depends on the biasing voltage and temperature.

The **Silicon Photo Multiplier** exploits the breakdown phenomena in semiconductors and consists of an array of APDs (micro cells), each operating in Geiger mode. They are commercially available as integrated circuits with sizes ranging from 1x1mm to 10x10mm. While each micro-cell can only signal the presence or absence of a photon, the summed signal of the array is analog and carries information about the number of detected photons.

$LaBr_3(Ce)$ is selected for scintillator material as it performs well in both time end energy measurements. J-Series SiPMs are selected for the light sensor based on their previous evaluation by the IFIN-HH team as they also present good performance for both time and energy applications.

The Front-End Structure of a Detector

In any measurement system, the signal from a sensor needs to be amplified and carried out to a reading system, be it a display or an electronic acquisition system. When the output signal of a sensor is weak, the first stage in the electronic chain is a preamplifier. Additional electronic blocks can be integrated at the sensor end before the signal is passed to a reading system like signal conditioning, filtering, summation, pulse shaping and compensation. In a radiation detector, the electronics close to the sensor is called front end electronics, FEE. The structure of the FEE depends on the sensor type, its output signal and detector architecture.

With resistive sources, an amplifier can operate in two modes. The **voltage mode** amplifier is used with voltage sources, i.e. sensors (or previous stages) characterized by a low output resistance. The amplifier operating in voltage must have a high input resistance. Opposite to the voltage mode, the **current mode** amplifier has a very low input resistance R_i and is used with sensors with very high output resistance R_s (current sources). In both configurations, the voltage at the input of the amplifier is the result of the voltage respectively current distribution across the resistor network and can easily be calculated using Kirchhoff's circuit laws.

Some radiation detector sensors can act like a **capacitor source**. In this case the voltage present at the output of the sensor depends on the the charge produced by radiation and on the detector capacitance C, $V_o = Q/C$. The capacitor will discharge through the input resistance of the preamplifier R with a time constant $\tau = RC$. In this case the amplifier operates in voltage mode.

The voltage mode amplifier operating with capacitive sources presents a problem in the sense that the output voltage depends on detector capacity and this is not a parameter that can easily be controlled during manufacturing process and also depends on bias voltage. The configuration that cancels the influence of detector capacity is the **charge sensitive amplifier**. In this configuration the output signal of the amplifier only depends on the detector charge and an external component (the value of the feedback capacitor).

The **transimpedance amplifier** outputs a voltage when the input signal is a (often a continuous or slowly variable) current. This configuration is used to measure low currents and require large feedback resistors, often $R_f > 100M\Omega$.

In terms of implementation of the first stage, this can be made with discrete components or with integrated circuits (IC), mainly Operational Amplifiers (OpAmp). OpAmps can be used in **inverting and non-inverting configurations**. The voltage amplification A is mainly controlled by 2 resistors, named feedback and gain resistors. The inverting configuration has an input impedance equal to the gain resistor and virtually zero output impedance and outputs an inverted version of the input signal while the non inverting configuration has virtually infinite input impedance and zero output impedance. An important parameter of the OpAmps is their bandwidth often linked to the gain.

The **adder circuit** is useful when the signal from two or more sensors needs to be added together in a single output signal; it can only operate in the inverting configuration.

Another useful function in a FEE is **the filter**, which can be Low Pass, High Pass, Band Pass and Band reject. In radiation detectors, the purpose of the filters is to improve the signal to noise ratio by a process called pulse shaping. A common filter implementation is the Sallen-Key topology, a well documented architecture which offers good control over signal bandwidth and system response in general.

There are cases when the adder circuit can't be used, either because its impedance or speed are not suitable for the application either due to noise considerations. In this case, a multiplexer is desired, which selects and passes to the output only the signals of interest from the input, while masking the rest of the signals. For a large SiPM array, the **Signal Driven Multiplexer** configuration is used, which involves a pair of Schottky diodes for each channel, being an analog circuit. It preserves the time performance of the individual SiPMs in the array while keeping the size of the FEE to a minimum.

The main information of interest in nuclear electronic is energy, time and position. Energy information is carried by the so called *slow pulses* and in this case the precision in amplitude measurement is more important than speed. In such a circuit low noise and charge integrity are critical. On the other hand, time information is carried by the *fast pulses* and the precision of reading their amplitude is no longer critical but the slope to noise ratio becomes critical.

These 2 different circuits require specialized electronics, which are not compatible with each other, therefore the OpAmps used in each of the two channels have specialized architecture. The OpAmps used for the energy channel are the **voltage feedback amplifiers** while the OpAmps used for the time channel are of **current feedback amplifiers**, each having its own parameters, specific design requirements and limitations.

In some applications like silicon detectors used for low energy charged particles detection, operating in charge sensitive configuration, a **JFET amplifier** front end featuring low noise and very high input impedance is needed. FET input OpAmps (which are differential, thus have two input pins) are not recommended as the unused input pin of the device also contributes to the overall noise. Cooling of the JFET amplifier is often recommended to decrease the resistive thermal noise of the device.

The pulse filtering, shaping and clipping mentioned above can change the pulse shape. In applications where the pulse shape must be preserved, a **Pulse Shaping and P/Z compensation network** should be included.

There is a large amount of technical information related to **noise contribution** and its sources. The noise theory proves to be a very useful tool to the engineer when signal to noise ratio is critical. Theory deals with source noise matching, filtering, voltage and current sources and the contribution of each one to the overall system performance.

Analytical Analysis of a Signal Driven Multiplexed SiPM Array

In nuclear physics, there is a high interest in precisely marking the moment particle enters the body of a detector. There are several methods for time pick off: Leading Edge Triggering LE, Crossover timing, Constant Fraction Timing (CFT), Amplitude and Rise Time Compensated Timing (ARC). All of them depend on the slope of the signal and the amount of noise present in the signal. The slope of the signal is directly connected to the rise time of the leading edge of the signal. This chapter is an analytical analysis of the signal driven multiplexer, with the goal to determine the design parameters with highest impact over the rise time of the response.

Signal Driven Multiplexer - System analysis. The analysis is based on Laplace Transform formalism and a simplified model of the signal driven multiplexer circuit. In order to derive the simplified circuit, the Schottky diode (the main component in signal driven multiplexer) is replaced by its small signal equivalent circuit, based on passive components, namely dynamic resistance and capacitance. Parasitic elements like resistance, inductance and capacitance are also considered in the model definition, their values being taken from the SPICE model provided by the manufacturer of the diode.

Using the simplified model, the S-space **transfer function** of the system is calculated. The poles and zeros of the system are also calculated for a series of parameter values and y(t), the response to an input step function (Heaviside) is calculated. All the output data is analyzed, the rise time for each set of values is calculated and a conclusion is presented for each parameter.

Due to the complexity of the transfer function, a Python software based on Numpy and Sympy libraries was created. The software was also used to handle all the data processing, parameter sweep and file handling.

The **Dynamic Capacitance of the Schottky diode**, C_d, depends on the operating point of the diode, when forward biased. For a small variation around 0.3pF, which corresponds to a small forward current through the diode, the step response varies significantly from an almost smooth response to a strong ringing and overshoot while the falling edge is not affected by this parameter. Overall, the conclusion is that C_d is a critical and sensitive parameter for timing performance of the system.

The **dynamic resistance of the diode**, R_d, depends on the operating point as well. It affects the leading edge of the response function, the falling edge and the maximum amplitude of the output signal. R_d along with C_d indicate that the best timing performance should be searched close to $V_f = 0V$.

The **parasitic inductance of the Schottky diode** has no significant impact over the output signal for a wide range of plausible values, $L \in [0.5; 2]nH$.

The **parasitic resistance of the Schottky diode** has no significant impact over the output signal for a wide range of plausible values, $R_s \in [2; 10]\Omega$.

The analysis show a clear influence of **PCB traces parasitic inductance**. In order to keep both parasitic inductance and stray capacitance of the PCB traces as small as possible, the OpAmp of the first stage should be placed on the same PCB with the SiPM cells, which results in short traces and at the same time eliminates the board to board connector inductance.

The results show a strong influence of **OpAmp input capacitance** over the step response of the system. Extra care should be taken when designing the PCB layout, since the stray capacitance of the PCB traces will parallel the input capacitance of the OpAmp. Although OpAmps like AD8012 have an input capacitance of 2.3pF, stray capacitance around a few pF is also a common value for PCB traces. The traces connecting the SiPM fast output and the OpAmp input should be kept as short as possible.

Results show that the **Input Resistance of Operational Amplifier**, R_i, has no significant impact over the output signal for a wide range of plausible values, $R_i \in [3; 9]M\Omega$

N, **the number of SiPM cells in a group** has a strong influence on the output of the system, affecting the leading edge slope, rise time, maximum amplitude while the trailing edge has the same decay time thus N is a critical parameter to consider in array design.

Although **SiPM output equivalent resistance**, R_p, is not a parameter a designer can control and is not even specified in the data-sheet of the product, it is considered however for the completeness of the analysis. Results show a clear dependence between R_p and the step response, a higher value rendering a slower rise time and a lower amplitude of the signal. The trailing edge time constant is also affected by R_p, a higher value leading to a longer decay time.

The impact of C_p, the **output capacitance of the SiPM** cell has no significant impact over the leading edge of the output signal but has an impact over the trailing edge. While the direct impact of this parameter over the timing performance of the system is insignificant, it can however improve the counting rate of the system. Smaller values of C_p lead to shorter pulses, which correspond to small sized packages like 1x1mm and 3x3mm while the larger values are available for 6x6mm (ON Semiconductors J series).

Analysis show that Schottky diode bias resistor, R_{sch}, has no significant impact over the output signal for a wide range of plausible values, $R_{sch} \in [5;20]k\Omega$. However, its value controls the bias point of the diodes, impacting R_d and C_d. Thermal dissipation should be considered however in some cases.

The S-Space approach was preferred instead of SPICE simulation because S-Space provides information about fast transient signals which are not always visible in the output signal of a SPICE simulation. The pole/zero locus charts are providing an understanding of why the system behaves in a certain way while a SPICE simulation can only show how the system behaves while not providing a way to predict what will happen when a parameter will change. Several critical parameters were identified along with their impact (absolute and relative) over the system's response.

Parameters and measurements specific to radiation detectors systems

The output signals of a ionizing radiation detector, carry information about the energy of the particle generating the signal, about the time of arrival of the particle in the active volume of the detector and in some cases the position of the interaction point too. The energy measurement is useful in spectroscopy applications like isotope identification based on its disintegration spectra, high energy particle spectra in astrophysics or fission fragment identification.

In order to understand the results of the measurements, it is important to first understand the basic factors influencing the measurement itself, like statistical fluctuations and electronic noise as well as the detector parameters and limitations which can have a serious impact upon the final results and should be analyzed during a characterization process, following the initial bring-up phase of the detector.

Any measurement of a physical quantity is affected by some variability and error which eventually will reflect in result uncertainty. There are several statistical models available which are modelling this hazard nature of things but the binomial distribution, the Poisson distribution and the Gaussian distribution are the most important and common ones and they play an important role in the nuclear physics and its specific measurements. Regardless of their complexity, each statistical model has a simple probability function, a mean value μ and a variance σ^2.

The binomial distribution applies to many experiments in which there are two possible outcomes, such as heads–tails in the tossing of a coin or decay–no decay in radioactive decay of a nucleus. **The Poisson distribution** is a particular case of the binomial distribution. In nuclear physics it is used to describe particle reactions and nuclear decay. **The normal (Gaussian) distribution** is a continuous symmetric distribution derived from the binomial distribution. In nuclear electronics the normal distribution is found in measurements of electrical quantities like voltages and currents in the form of noise.

Electronic systems always present a certain level of noise which limit their performance. Noise has various sources and can have certain behaviour from a power distribution over frequency.

Thermal noise is caused by the vibration of the charge carriers, usually produced by resistors. **Low-frequency noise 1/f** or *Flicker noise* is present in all active and many passive devices. **Shot noise** is the result of charge carriers moving across a voltage barrier as in the case of a *pn* junction. **Burst Noise**, ”also called popcorn noise, is related to imperfections in semiconductor materials and heavy ion implants and is characterized by discrete high-frequency pulses with a rate that may vary while the amplitude, several times the thermal noise, remains constant. **Avalanche noise** is generated by *pn* junctions operating in breakdown mode, which is the case for Zener diodes, silicon photo multipliers (SiPM) or transistors purposely biased to operate in this regime.

The terminology of electronic pulses and the detector properties are studied and documented as they present a base for detector characterization and comparison against existing detectors. The work presents the following important parameters: baseline level, pulse height, baseline noise, leading edge and its rise time, trailing edge and its fall/decay time, pulse width and pulse types. The detector properties considered relevant for the work are: detector operation mode, response function, sensitivity, detector response to a radiation type, energy resolution, Fano factor, FWHM, response time and dead time.

The most common form for presenting the end result of a spectroscopy measurement is the differential **pulse height spectra**. In order to obtain an energy spectra, a setup of several electronic modules is required, along with SW analysis of the data. A typical setup, used for the characterization of SiPM Array + $LaBr_3$(Ce) based detectors developed at IFIN-HH, consists of a detector whose energy signal is passed to a spectroscopy amplifier followed by a Multi Channel Amplifier (MCA). It is convenient to use the Oscilloscope HDO4104 MS for data acquisition and data processing.

In nuclear measurements, time is relevant only when reporting the moment of an event to the moment of another event. There are several techniques to pick-off the time of an event, based on the analogue pulse provided by the detector, the most common methods being i) leading edge triggering ii) Zero crossing iii) constant fraction timing (CFT) and iv) amplitude and rise-time compensated timing (ARC). Special electronics and software techniques are further used to read and convert the pulses from 2 or more detectors in order to determine if they are coincident or not. All time measurements are affected by *time jitter*, caused by the noise present in the signal.

Data analysis

During this work, several measurements were made. The first set of measurements has the purpose to understand the contribution of each component of the system to the fast output signal rise time. The second set of measurements is focused on noise influence over detector performance of the detector, i.e. the energy and time resolution. The third set of measurements represent the data from an in-beam experiment at Tandem accelerator in IFIN-HH and consists of data taken for calibration and the data from the actual experiment.

Laboratory measurements

It is known that the size of the crystal leads to a strong variation in Coincidence Resolving Time (CRT) performance of a detector. Information exists based on both measurements and simulation data, for various crystals and configurations but a direct measurement of the crystal optical path contribution to the rise time when coupled to a SiPM array is not available. Thus an experiment was conducted to determine the **optical path contribution to the rise time**.

In this experiment, pulses of light are injected into a scintillator crystal through a small opening created by slightly offsetting the SiPM array, in order to maintain a good overlapping of the array and the crystal. The light was injected at different angles in order to study its influence over the rise time. The results indicate that the optical path contribution of the crystals used in the study is in the range of 6÷8 ns and the collection time of the optical photons sets a lower bound for the rise time parameter of a complete detector.

In order to characterize the components of the detector, the first measurement of **the rise time** parameter for fast pulses was made by illuminating the SiPM array with short laser pulses (100 ps) generated with an ALPHALAS LD-510-50 Laser system. The recorded rise time is $t_r \approx 1.75$ ns. The measurements were made with full array uniform illumination, with mask openings for 1, 2, 4 and 8 cells, covering 1 and 2 groups of signal driven multiplexed SiPMs but also with narrow beam and reduced number of cells being illuminated. The results didn't show significant variability.

In the initial work conducted by C. Mihai and G. Pascovici, rise time values for fast pulses ranges in $15 \div 23$ ns. The impact of the Schottky diodes parasitic capacitance C_d over the rise time in the Signal driven Multiplexed configuration was identified and its value optimized. The analysis in Chapter 3 proves that the dynamic resistance also plays and important role defining the rise time and the best rise time performance should consider both C_d and R_d. G. Pascovici identified BAT15-04W diodes to be the best option from a C_d point of view, thus further rise time reduction should be achieved by R_d adjustment. As a result of the present work, the rise time was decreased to $t_r = 8.5$ ns for the 1.5" sized array while for the 2.5" array the rise time dropped to 10 ns.

The conclusion of the rise time measurements is that the SiPM array and the front end have a large bandwidth (1.75 ns rise time equivalent) of the fast channel, larger than the bandwidth of the scintillator signals (6÷8 ns rise time equivalent) and thus it is not a limiting factor in time performance, but the limitation comes from the collection of the optical photons at multiplexer level. However, it must be noted that a bandwidth of the amplifier much larger than the bandwidth of the signal can lead to increased noise which in turn causes time jitter, but at this stage of the work, this is not a concern.

Baseline noise is important for a detector as it has an impact on both energy and time measurements resolution. Both channels show an offset in the mV range, which does not pose any problem to modern signal processing units used nowadays.

For the fast channel, the measurements are made on a scale $0 \div 2.5$ V with 50 Ω termination. The baseline offset is given by the average of a normal distribution, $\mu = 3.67$ mV. The noise amplitude follows a normal distribution characterized by a computed value of $\sigma = 2.37$ mV, corresponding to a peak to peak value of $V_{p-p} = 15.64$ mV and FWHM=5.57 mV. For a rise time of 8.5 ns, this results in a jitter with a FWHM = 99 ps.

For the slow signal output, the measurements are made on a scale $0 \div 2.5$ V with 50 Ω termination. The baseline offset is given by the average of a normal distribution, $\mu = -2.97$ mV. The noise amplitude follows a normal distribution characterized by a computed value of $\sigma = 1.88$ mV, equivalent to peak to peak value of $V_{p-p} = 12.41$ mV and FWHM=4.42 mV. For a signal amplitude of ≈ 0.33 V (γ with energy of 661keV from ^{137}Cs), the impact of the noise on energy resolution is $4.42mV \div 0.33V = 1.33\%$. Since the best reported resolution of the $LaBr_3$(Ce) crystals is 2.6% and the statistical effects add in quadrature, the baseline noise of the slow signal has little to no impact on overall energy resolution of the detector.

The **energy resolution** of a γ-ray detector is typically reported for the energy of 661 keV corresponding to a β^- decay of the ^{137}Cs isotope. The measurements at the reference energy of 661 keV show that the resolution of the SiPM assembly is the same as the resolution of the PMT assembly, namely 26.18(15) keV respectively 26.31(9) keV or, if reported to 661 keV, 3.96(2)% respectively 3.98(1)%.

The **time resolution** was determined using a ^{60}Co source which undergoes a β^- decay during which it emits 2 γ-rays with energies of 1 173 keV and 1 332 keV, which can be considered coincident for the measurement. First, 2 identical PMT detectors were used in order to determine their individual time resolution (Coincidence Resolving Time (CRT)). Energy signals were used to filter only the photons whose energy was completely absorbed by the scintillator. The PMT-PMT pair CRT measured a FWHM = 189.8(10) ps while the PMT-SiPM pair CRT measured a FWHM = 187.5(10) ps. In the PMT-SiPM pair, one of the PMTs was replaced by the SiPM array, while maintaining the scintillator crystal in place.

Following in lab characterization, **in beam measurements** were made. Four detector types based on $LaBr_3$(Ce) were developed during this work, with scintillator sizes of 3x3 Inch, 2x2 inch, 1.5x1.5 Inch and 1.5 Inch truncated cone. These detectors are used on a daily basis during experiments that take place at the Tandem accelerator at IFIN-HH, ISOLDE CERN in Geneva and GSI Helmholtz Centre in Darmstadt. Calibration spectra are also presented, part of the experiment setup.

Three more β tailor-made detectors were developed for ISOLDE-CERN, for Tape Station, IDS and WISArD respectively. Calibration and in experiment spectra are presented in the work.

The objective of the work was reached. As a result and personal contribution to the field, I designed, executed and commissioned seven (beta and gamma) radiation detectors. I developed for the first time an analytical model of the signal driven multiplexer and ran an analytical analysis of its behaviour. My work is documented throughout six scientific articles, four of them already published.

The general conclusion of the work is that SiPMs are a versatile solid state alternate to the PMTs while featuring robustness, small size, low operating voltage and magnetic fields immunity along with good energy and time resolution. Being relatively new for mass production and commercial purchase, their behaviour in large array circuits is not completely understood and thus further development and evolution can be expected.