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SENSE - Ultimate Low Light-Level Sensor Development

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SENSE - Ultimate Low Light-Level Sensor Development

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Abstract. SENSE, a roadmap for the ideal low light-level sensor development is a project funded by the European Commission under Future and Emerging Technologies (FET) Open Coordination and Support Action (CSA). It aims at coordinating, monitoring, and evaluating the R&D efforts of research groups and industry in advancing low light-level (LLL) sensors and liaise with strategically important European initiatives and research groups and companies worldwide.

The projects objectives are: (1) to conduct the development of a European R&D roadmap towards the ultimate LLL sensors, and to monitor and evaluate the progress of the development with respect to the roadmap, (2) to coordinate the R&D efforts of research groups and industry in advancing LLL sensors and liaise with strategically important European initiatives and research groups and companies worldwide, (3) to transfer knowledge by initiating information and training events and material, (4) to disseminate information by suitable outreach activities.

The consortium has four partners: the Deutsches Elektronen Synchrotron (Coordinator), Germany; the Université de Genève, Switzerland; the Max-Planck Institute for Physics, Germany and Karlsruhe Institute of Technology, Germany. Several international experts for all areas of LLL development are involved in SENSE, some advise the project n the Experts Group and the others in the working group of the project which is regulated by a Cooperation Agreement.

1. Introduction

The SENSE project started its activities in September 2016 and received funding for three years. The goal of the project is the coordination and evaluation of the R&D developments in the field of low light-level sensoring.

To achieve these objectives, the SENSE project working plan is structured in five work packages (WPs), which are lead by different partners of the consortium: **WP1** (lead by Max-Planck Institute for Physics) deals with the creation of the roadmap for LLL sensor R&D and the monitoring and evaluation of the subsequent R&D work.

WP2 (lead by Université de Genève) focuses on working on an agreement on R&D cooperation between Research Institutes in Europe, linking to other European initiatives as well as fostering the exchange between academia and industry. A laboratory set up has been created and validated at Ideasquare at CERN for measuring properties of silicon photosensors.

WP3 (Karlsruhe Institute of Technology) takes care of outreach of the project and developing the Technology Exchange Platform (TEP/ SENSE Forum), as major part to exchange between developers.

Three tasks are planned for **WP 4** (Deutsches Elektronen Synchrotron) all around training and learning: the organisation of technology training sessions during existing summer schools, establishing a training section on the TEP and to organise LLL technology training events. All groups participated to outreach through public events.

WP5 (Deutsches Elektronen Synchrotron) describes the management duties of the overall project.
All work is carried out in close cooperation and with mutual assistance.

2. Roadmap

For preparation of the first draft of the roadmap the different developments concerning LLL were discussed and evaluated within the consortium and the experts. A first document was drafted based on this. It is focused on developments that are crucial for two photo-sensing technologies: silicon photomultipliers (SiPMs) and photomultipliers (PMTs).

Three major sectors of development were identified for each technology:

- the performance of the sensors (which usually depends on the application);
- the readout and control electronics;
- the integration of such electronics into the sensor.

For each sector, the specifications required to individual fields of application and which challenges must be overcome are pointed out. In addition, the results of ongoing specific R&D activities taking place in line with the roadmap idea within SENSE are shortly presented. Until the end of the project a final document with clear recommendations and also some concrete examples will be published.

3. Cooperation Agreement

A cooperation agreement for providing a framework for the testing and performance studies of photosensors was developed. Various institutions and industrial partners, have expressed their interest in carrying out together a long-term detector R&D for future ultimate LLL photosensor, which also includes an educational and technology training component. This agreement should lead to open access publications which will be approved by the SENSE consortium.

At the moment the document is signed by the following institutions:
University of Geneva (UNIGE), Max-Planck-Institute for Physics (MPI), Karlsruhe Institute of Technology (KIT), Deutsches Elektron Synchrotron (DESY), Nagoya University (Nagoya), INAF-Osservatorio Astrofisico di Catania (INAF-CT), University of Heidelberg, Institute for High Energy Physics of Barcelona (IFAE), University of Barcelona ICCUB.

An example of measurements that were produced between cooperating institutes is shown in figure 1, which shows the optical cross talk as a function of the over-voltage for some silicon photomultipliers which were compared. These measurements were carried out under the direction of the University of Geneva and are published in [1].

4. SiPM Characterisation

Initiated by SENSE a collaboration between several labs, experienced in measuring photosensors, was developed. The aim is to characterize LLL sensors and standardize measurements and analysis procedures. Each lab has slightly different test facilities for the measurement of

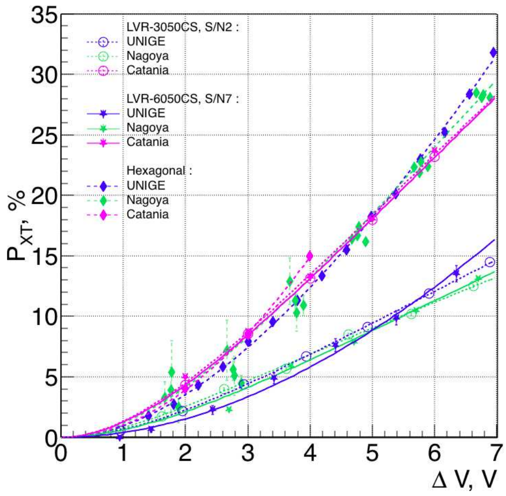

Figure 1. Cross talk probability of three compared silicon photomultipliers by three institutions in the cooperation agreement as a function of the overvoltage, from [1].

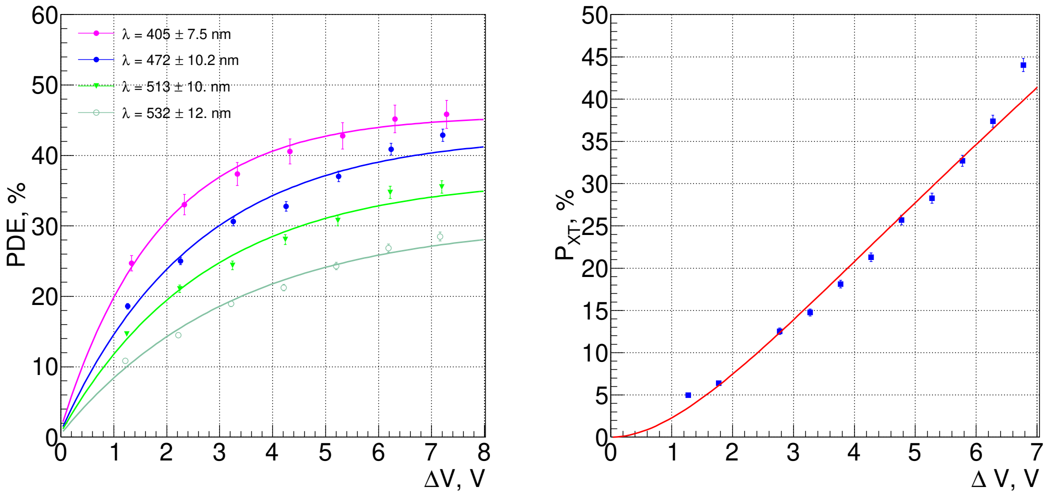

Figure 2. Photon detection efficiency and cross talk probability of SensL MicroFJ-SMTPA-30035 as a function of the overvoltage.

photosensors, so in a first step each platform is characterized and systematic errors relevant for various measurements are compared. This minimizes the double effort for the characterization of sensors and common precision on measured quantities are established. First results are published jointly under open access in [1]. An example of the current measurement is shown in Fig. 2.

5. Public Relations

In terms of outreach activities the project aims to inform, to disseminate results and to allow for open communication between all involved partners, for the people concerned and also for the general public. Therefore it is important to offer information material at different levels and to

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Figure 3. SENSE booth at the spring meeting of the German Physical Society

use various channels.

A broad audience with different interest and knowledge can be reached online, e.g. via a website or using social media, while the participation at conferences is dedicated to a specific audience. In order to address as many people as possible we at SENSE therefore use both online and offline outreach opportunities.

5.1. Website, Newsletter & TEP

The SENSE website `www.sense-pro.org` provides information about the project itself and the people behind as well as general informations on different photosensors and their usage. Under the menu item *Portraits*, test stands and experiments working with photosensors are presented. This category is regularly extended by further articles, which are also sent out in a newsletter.

Reports about current actions of SENSE, references to conferences and published articles as well as other events of interest to the community are also sent in the newsletter and can be found on the website as *News* and *Events*. Information on conferences are also available in the calendar.

For the future a sophisticated section for training and learning shall be developed and made available on the website.

Furthermore, the results obtained in the activities on SiPM characterisation will be collected in a database and published on the website.

5.2. Presentation at Conferences

For the presentation of SENSE at conferences various information materials are produced: A general brochure on SENSE containing information about the project and general on low light-level sensors, a flyer dedicated to the roadmap and posters or talks, which are adapted to the respective needs and the respective audience. As an example, figure 3 shows the SENSE booth at the spring meeting of the German Physical Society.

In addition to making SENSE generally known, the scientific results from lab measurements are also presented at conferences. However, personal contact and exchange and the opportunity to establish new contacts with various community working on photosensors are one of the main reasons for attending conferences.

6. Training Activities

In order to continue advancing the development of photosensors in the future, interested young scientists are needed. That is why we want to introduce young people to the topic and inspire them with enthusiasm.

A series of lectures on different topics like detector principles, light interactions with matter or signal processing, are developed and will be made available on the website. These lectures should be held additionally at a summer school dedicated to photosensor development.

We already held lectures and practical sessions at the MAGIC hardware school and the TESHEP summer school, see Fig. 4- on the left. But also already high school students got in touch with SENSE during the TecDay in Geneva, see Fig. 4- on the right, or the IceCube Masterclass.

Figure 4. Lecture during TESHEP summer school (left) and TecDay (right)

In this context, two show case experiments were developed, one by UNIGE and the other one still in the design phase at KIT.

6.1. Show Case Experiments

Both experiments aim at the measurement of cosmic muons once with a thermos flusk used as water Cherenkov detector and once using a scintillator bar as detector. Both setups use a SiPM as light detector, operated without high voltage, which is of special importance for a student hands-on experiment.

Figure 5 shows the experimental setup of the experiment currently developed at KIT. The idea of using thermos flusk is already realized in many student experiments but so far the light pulses are read out using a PMT. The biggest advantage of this improved setup is the elimination of high voltage due to the use of SiPMs for light detection. For the analysis of the measured signal the free and open source software picoCosmo [2], also developed at KIT, is used. This software also includes the possibility to define different trigger conditions and to search for double pulses which allows the measurement of the lifetime of muons.

The setup developed at UNIGE is shown in figure 6. Muons are measured using a 1m plastic scintillator bar that is coupled on both ends to SiPM detectors. The measured signal is visualized using an oscilloscope. To separate the signal of cosmic ray muons from detector noise signals the detectors are read out in coincidence mode. Then the rate of cosmic ray muons can be measured, and also the muon rate as a function of the inclination can be studied.

7. Summary

SENSE was proposed to European Commission by experts who spent a long time understanding photosensors - SENSE should create a common voice towards industry. Therefor, many institutes working in the LLL development area have to be convinced to work together with SENSE. A

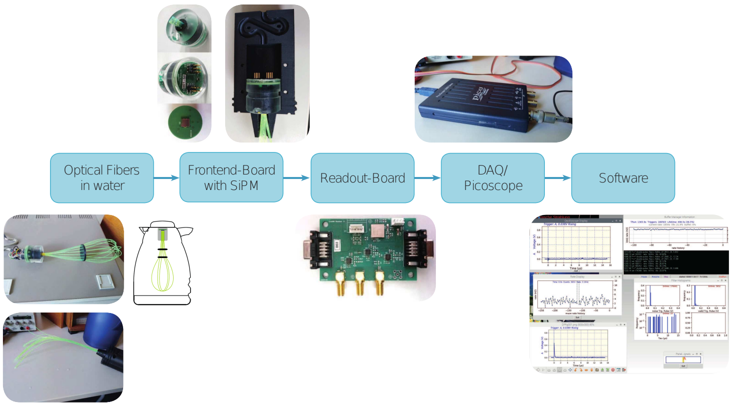

Figure 5. Setup of the show case experiment developed at KIT

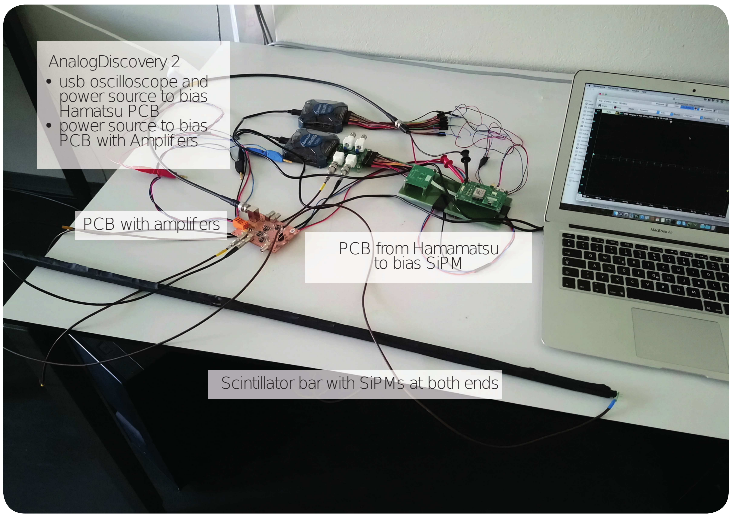

Figure 6. Setup of the show case experiment developed at UNIGE

first step in this direction was done with the agreement of common testing in the cooperation agreement. During many conferences and trainings SENSE was made public. The publicity which is reached now in different application disciplines of LLL sensors should be now be used for the last year of SENSE to develop a strong final roadmap introducing directions in which development of LLL sensors should go in future.

Acknowledgments
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[2] Software picoCosmo, available at *https://github.com/GuenterQuast/picoCosmo*