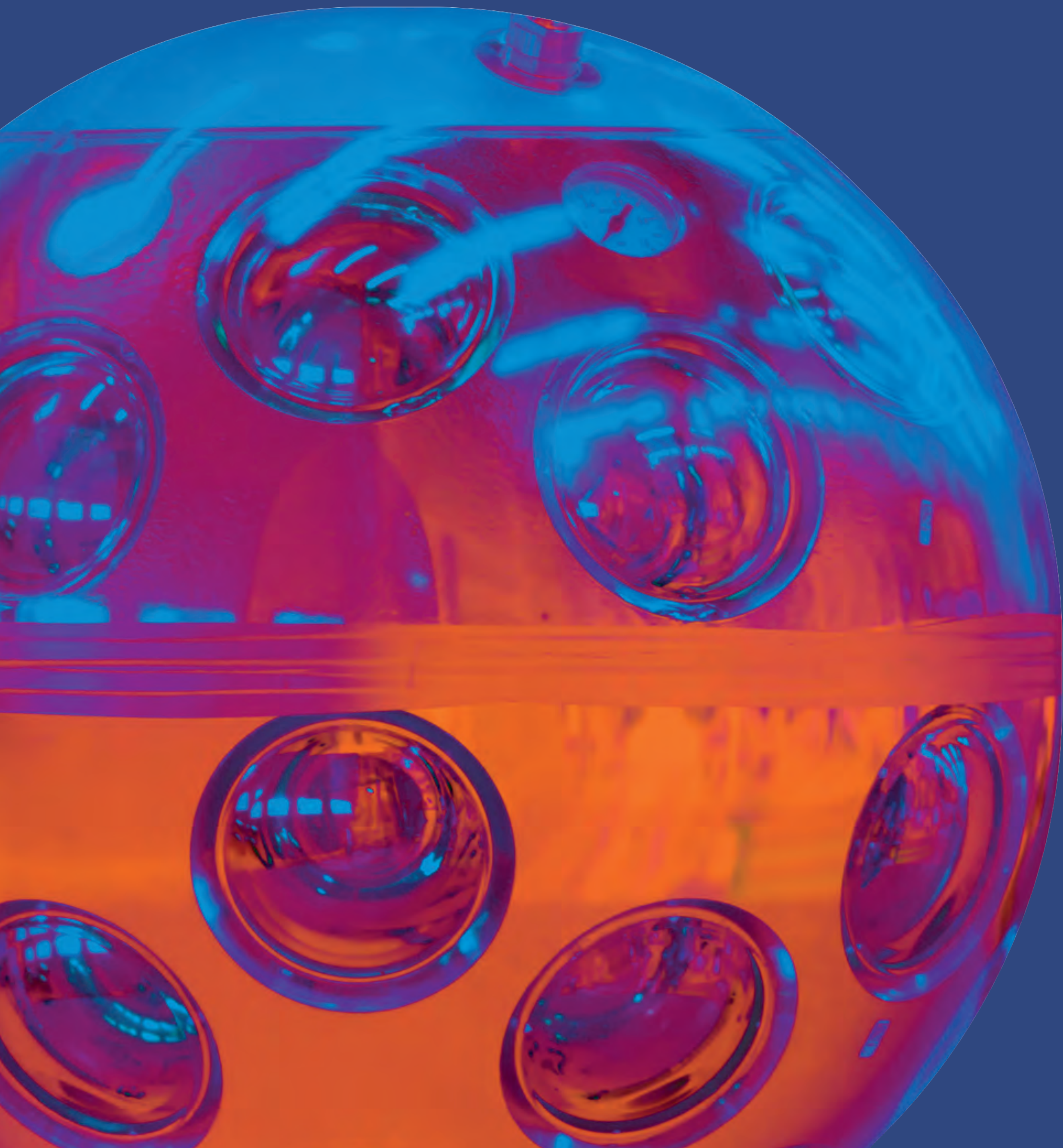
APPEC Technology Forum 2015

APPEC

LOW LIGHT-LEVEL DETECTION

In Astroparticle Physics and in Medical Application



22–23 April 2015

Munich Nymphenburg Castle

APPEC | Astroparticle Physics European Consortium | www.appec.org

Low light-level detection:

Key technologies developed in astro-particle physics

Detection of light is one of the major, basic principles of measurements and diagnostics in science and many applications. Medical diagnostic applications (e.g., X-raying) provide an example with an enormous societal impact and any improvement in detection efficiency of light sensors will turn into a straightforward gain for health and life quality.

Nowadays most of the light detectors employ the photoelectric effect, which occurs when matter releases/emits electrons upon exposure to light; for the discovery/explanation of the photo effect Albert Einstein received the Nobel Prize of the year 1921. Many applications require single photon detection in various energy domains. The low light-level detection in the coming years has the promise of a technology revolution. Comparable to the change from the electron valve to the semiconductor transistor technology and its subsequent tremendous innovation boost and applications both in science and in everyday life, significant improvements of currently existing products can be expected when the Photo Multiplier Tubes (PMTs) will be largely replaced by the emerging technology of Silicon Photo Multipliers (SiPMs).

SiPMs are robust and feature numerous advantages compared to PMTs, such as compactness, lightweight, automated mass production, insensitivity to magnetic fields, low bias, high photo detection efficiency. Nonetheless, they are still so compact that instrumenting large surface area requires complicated readout electronics. A breakthrough in the technology also addressing the SiPM noise issue and the relatively long dead time is going to take place in the next years. In addition to these two technologies a complete proof-of-the-concept exists for a novel design of low light-level detectors, called Abalone, which has to be evaluated for its commercialization. Other novel ideas like the superconducting transition edge sensors (TES), the Neganov-Luke light devices, or new generation organic image sensors require further R&D before becoming a commercial product.

Currently, with about 600000 PMTs/year medical diagnostic instrumentation is the largest consumer of PMTs; PMTs are used in Positron Emission Tomography (PET) scanners, Gamma cameras, and many applications in Life Sciences. Besides specific applications of PMTs, e.g., in oil drilling industry, large scale experiments in basic research are consumers of up to several 100000 low light-level sensors. The demand of reaching lower and lower levels in light detection efficiency with highest precision in astroparticle, particle, and nuclear physics experiments is one of the main R&D drivers in the domain of low light-level detection.

Any improvement in the PMT technology evolving from science projects has allowed medical diagnostics industry to immediately come up with advanced products. Together with this immediate market effect there is a clear positive societal impact: a doubling of a light sensor's efficiency in a medical diagnostic instrument will allow to half the radiation doses for patients and thus reduces the possible negative consequences of irradiation. PET scanners allow one studying the functional activity in vivo, which is important for cancer research, Alzheimer studies as well as drug tests. When replacing PMTs with SiPM devices it might be possible, for instance, to combine PET with the very strong magnetic field of MRI coils. Also, one will profit from ultra-fast time resolution of SiPM, for the so-called Time-of-Flight reduction of the background.

The APPEC Technology Forum 2015

The APPEC Technology Forum 2015 (ATF2015) on low light-level Detection in astroparticle physics and in medical applications was organized five years after a similar Technology Forum organized in the frame of the EU funded ASPERA project. About 80 technology developers from academia and industry attended the ATF2015, which was again organized at the premises of the Carl-Friedrich von Siemens Foundation at the Nymphenburg Castle in Munich. Compared to the earlier event in 2010 the presence of many young scientists at ATF2015, male and female, clearly demonstrated that the topic of this Technology Forum addresses a rather challenging and timely R&D field.

The clear intention of APPEC was to take a detailed look at the developments during these 5 years and reveal alternative detector technologies that may find application in astro-particle physics experiments. Generally speaking, "traditional" photomultiplier technology has constantly and substantially been advanced during the last decade. Figure 1 demonstrates these advancements by plotting the signal-to-noise ratio for a single impinging photon as a function of the quantum efficiency (QE); the signal-to noise ratio (SNR) of a given photocathode with QE = P can be calculated as $SNR = \sqrt{[N \times P/(1 - P)]}$.

Figure 1 demonstrates that the long existing PMT technology has not yet reached any limit and can substantially be further advanced. Photocathode material cleanness and its depositing technology may improve the quantum efficiency even further that future PMTs will be capable to detect each single impinging photon.

PMTs are produced by companies in all sizes, from very small (~1cm in size) to very large (50cm). Test samples of Hamamatsu PMTs for CTA are confirming the currently available high quality, substantially better than the requirements on QE, after-pulse rates and Peak/Valley ratio of single photon counting set by the CTA collaboration.

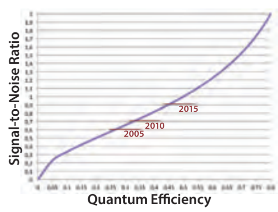


Figure 1: Development of the quantum efficiency and resulting signal-to-noise ratio of PMTs. Note that in the time between the 1960s until 2005 it was believed that this technology cannot be further advanced.

SiPM technology finds first application in astroparticle physics experiments (e.g., in gamma cameras and dark matter experiments). Examples are the FACT camera and a SiPM-based sensor cluster for MAGIC, which is under tests and evaluation.

Currently, a large variety of SiPM matrixes are available in the sensor market, also alternative readout solutions are there. SiPM matrixes with improved filling factor are currently being developed to overcome the low geometrical efficiency of these devices. However, for fast timing applications the size of SiPMs is limited to several mm, because of the charge collection time; also, increasing the cell size to higher values will unfortunately increase its gain and the much unwanted crosstalk.

SiPM-based matrixes with complete readout, like in a CMOS (or in a CCD) camera would allow a simple assemby in arbitrary shape, arriving at large coordinate-sensitive imaging camera. However, stray heat might cause a problem in fast on-chip digital readout solutions.

Inter-calibration of PMT and SiPM solutions still indicate higher photon detection efficiencies for PMT, however, more measurements are needed. Table 1 provides a comparison of basic parameters for PMTs and SiPMs available in 2010 and 2015. The improvements of both technologies are clearly demonstrated.

Cryogenic PMTs are currently the standard light sensors applied in dark matter searches using LAr and LXe. In addition to standard requirements such as high QE, low dark count rate (DCR) and stable performance these PMTs need to be optimized concerning a very low radioactive contamination, especially a low U and Th content is necessary to suppress any neutron background.

Gaseous PMTs (GPM) are explored as alternative in low light-level detection in cryogenic applications. This technology may provide a high filling factor and may allow to fully surround an experiment and to detect light in all directions. First measurements with 4″ GPMs demonstrate a large dynamic range, good stability, energy and time resolution as well as a low DCR.

	2010	**2015**
PMT		
Peak QE	28–34%	36–43%
Photo Electron Collection Efficiency on the 1st Dynode	60–80%	94–98%
Afterpulse rate (for a set threshold ≥ 4 ph.e.)	0.5%	< 0.01%
SiPM		
Peak Photon Detection Efficiency	20–30	50–60%
DCR	1–3 MHz/mm^2	50–100 kHz/mm^2
Light crosstalk	> 40–60%	5–10%

Table 1: Comparison of basic parameters characterizing PMTs and SiPMs available in 2010 and 2015

The GERDA experiment uses a combination of conventional and novel light detectors and is thus the first experiment with a large SiPM array operated at cryogenic temperature.

The successful application of a tungsten transition-edge sensor (TES) operated below 100 mK in the ALPS-II experiment to detect single photons in the near-infrared demonstrates that this technology is entering astro-particle physics. One can speculate that further R&D may help this promising low background single photon detection technology to find wider application in research.

Several developments of optical modules for high-energy neutrino experiments have been presented, single and multi-PMT designs. Prototyping for a completely new design, a wavelength-shifting optical module (WOM), has been presented. Further R6D is required to demonstrate the performance of the WOMs design.

APPEC makes SENSE: low light level sensoring selected in Horizon 2020 call

In March the results of last year's Horizon 2020 call in the domain of Future Emerging Technologies (FET-Open) were announced by the the European Commission. In this highly competitive call the SENSE proposal, submitted by a team of four APPEC related partners (University of Geneva, MPI for Physics in Munich, Karlsruhe Institut of Technology, and DESY as coordinator), was among the 13 selected projects.

The SENSE project will be funded as a Coordination and Support Action with the aim of coordinating the research and development efforts in academia and industry in low light level sensoring. This initiative has emerged from the series of Technology Forums organized within the frame of ASPERA and APPEC. SENSE is a three-year project. Starting in September 2016, R&D experts will be invited to prepare an R&D roadmap towards the ultimate low light level sensors. SENSE will then coordinate, monitor, and evaluate the R&D efforts of research groups and industry in advancing low light level sensors and liaise with strategically important European initiatives and research groups and companies worldwide.

To foster cooperation and knowledge transfer SENSE will build up an internet-based Technology Exchange Platform. Training events and material shall be prepared to especially engage young researchers.

A kick-off event is planned for 27th September 2016 in Munich, Germany.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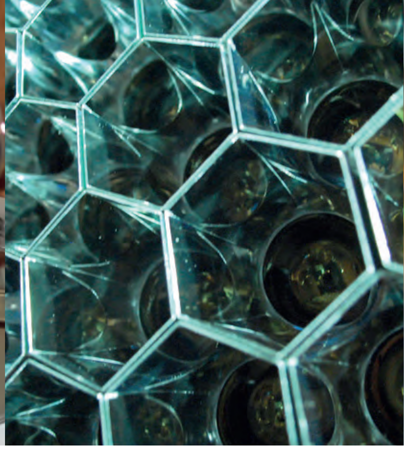
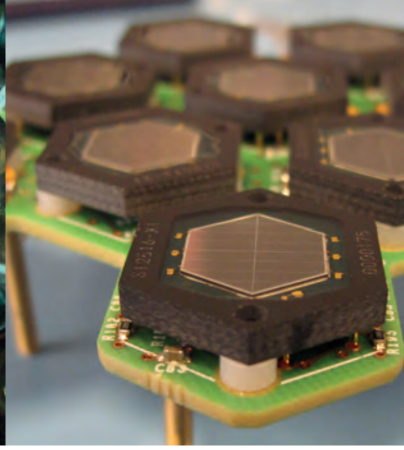


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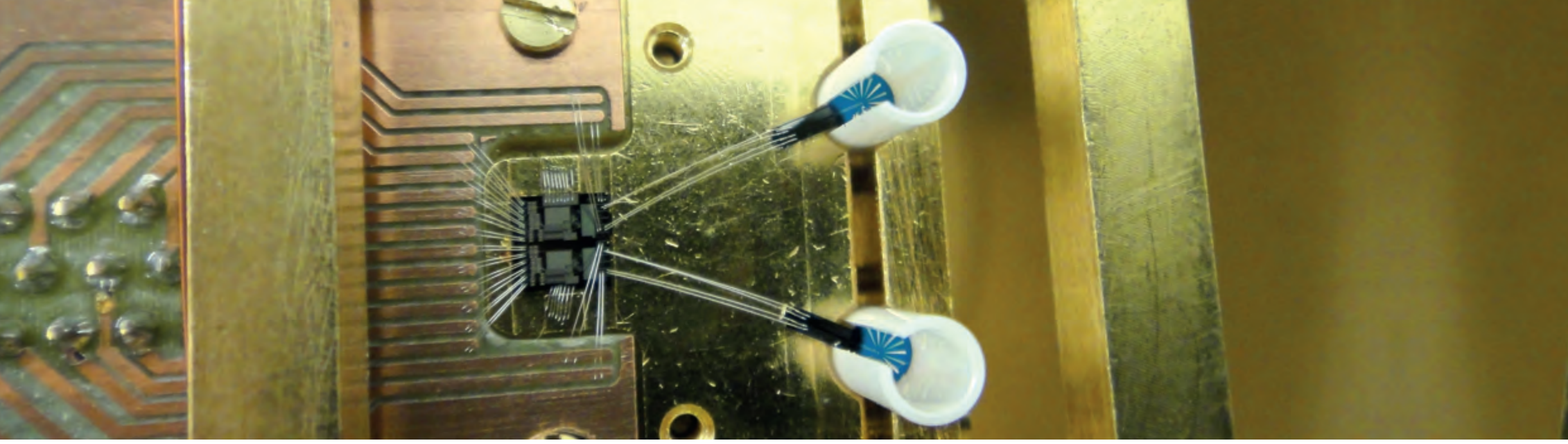
Companies



ALPS

Any Light Particle Search

General

A light-shining-through-a-wall experiment searching for photon oscillations into weakly interacting sub-eV particles.

Specification

Photosensors

Two microcalorimetric W TESs (Tungsten Transition-Edge Sensors) chips developed by NIST (U.S. National Institute of Standards and Technology). The sensitive area for each chip is of $25 \times 25\ \mu m^2$. The detection efficiency for such TES is > 95 % and the background $< 10^{-2}\ s^{-1}$ for 1064 nm photons. At this wavelength, the intrinsic dark count rate is of $1.0 \cdot 10^{-4}\ sec^{-1}$. The relative energy resolution for 1064 nm signals is < 8 %. In order to bias accurately the device and for reading purposes, TESs are inductively coupled to a SQUID (Superconducting Quantum Interference Device).

Requirements

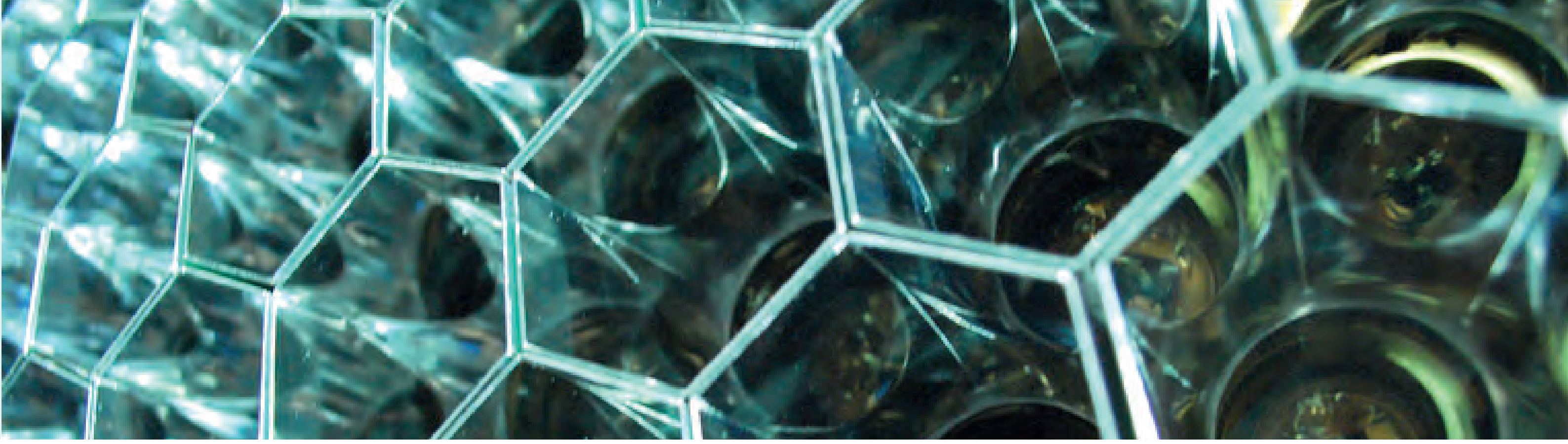
Photosensors

The main requirements for the ALPS II experiment are:

- low dark count and background rates,
- high efficiency for infrared photons,
- long-term stability,
- good relative energy resolution,
- good time resolution.

Schedule

2015	2016	2017	2018
Characterization of the detector as well as background reduction			
	ALPS II a (search for hidden photons)		ALPS II c (search for axion-like particles)



Pierre Auger Observatory

Ultra high energy cosmic ray observations

Specifications

1700 Photosensors 22–38 mm diameter for scintillator readout and 1700 Photosensors 22 mm diameter to increase dynamic range of WCD in addition to the three 9 inch PMTs per detector.

Auxillary electronics
Re-design of readout-electronics and replacement of 1700 times 3 HV modules for operation of the existing PMTs in WCDs as well as 3400 HV modules for the afore mentioned smaller PMTs.

Requirements

Design phase
Immediate selection of optimal photo-detector
- for scintillator optimized for green light,
- for Cerenkov low priority on sensitivity since overlap with large PMTs.

Priority on high linearity.

Prototyping phase
- reliable and well tested products for prompt product readiness,
- interaction with companies for available prototypes or possible developments on short timescale.

Construction phase
Quality control in test setups of each single PMT.

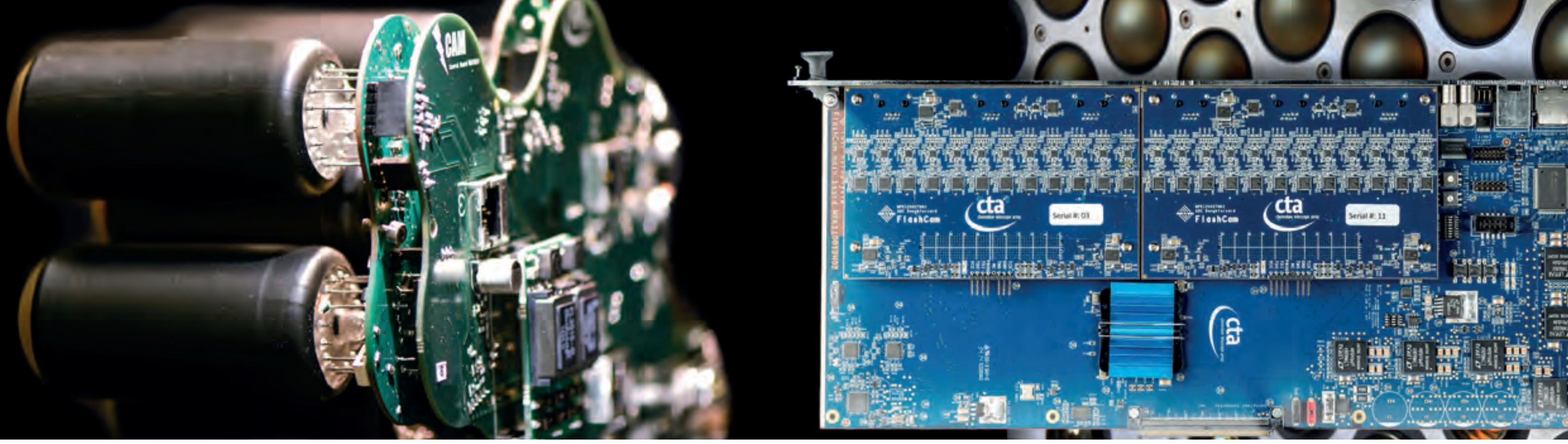
Comments

In parallel, R&D for a next generation observatory for ultra high energetic cosmic rays: Global COSmic ray Observatory.

Schedule

2015	2016	2023	> 2025
Auger upgrade PDR '2 →			
	Begin upgrade →		
		End of operation →	
			GCOS →

http://www.auger.org



FlashCam for CTA

A fully digital camera for the Cherenkov Telescope Array

General

FlashCam is a Cherenkov camera for CTA medium-sized telescopes. The cameras consist of ~1800 photomultiplier tubes (PMTs) each, which are served by a fully digital readout and triggering electronics system.

Specifications

Photosensors
~40,000 PMTs (~100,000 for entire CTA) according to common CTA specifications: 1.5 inch sensors, enhanced QE, fast response, low afterpulsing rate.

Auxiliary Electronics
Low-power HV system; 250 MS/s ADC system to digitize PMT signals; FPGA-based, fully digital signal and trigger processing; Ethernet-based front-end readout.

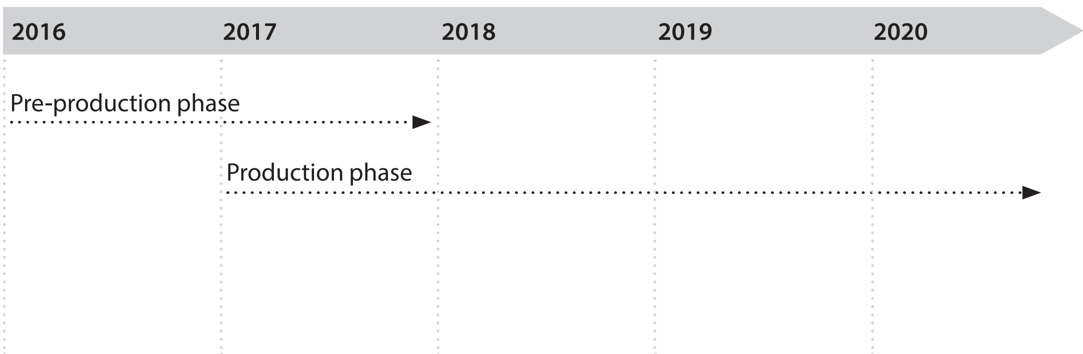
(see e.g. http://adsabs.harvard.edu/abs/2013arXiv1307.3677P)

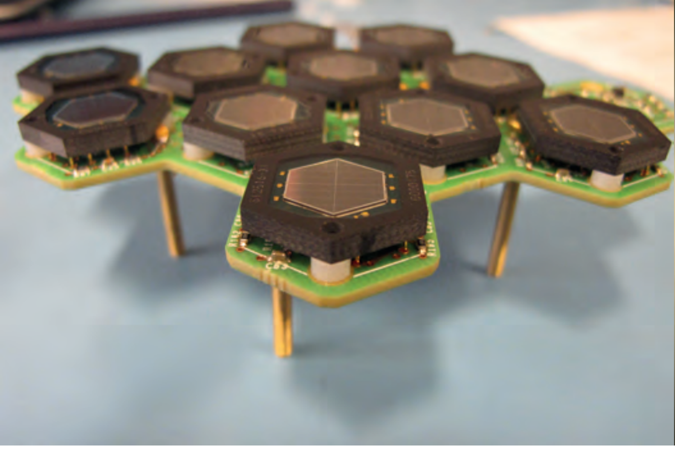
Requirements

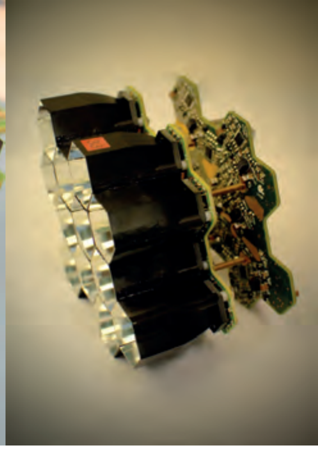
Pre-production phase
Production of PMTs for 2 pre-production cameras (~3600 PMTs).

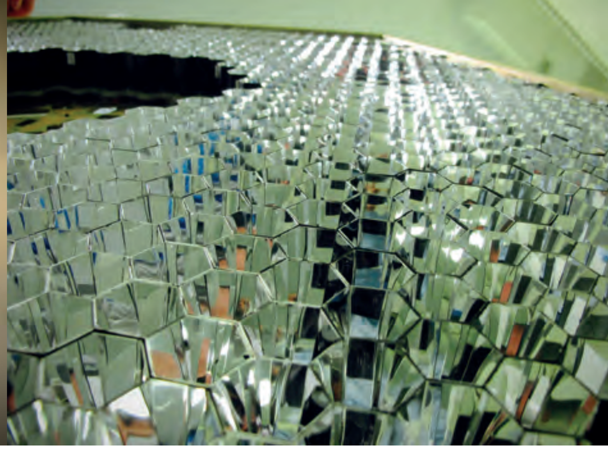
Production phase
Production of PMTs for camera series production.

Schedule









SST-1M Camera for CTA

An innovative SiPM camera for Gamma-ray Astronomy

General

SiPMs have been introduced in the gamma-ray astronomy community as they provide considerable improvement compared to photomultipliers thanks to their low voltage and stable operation, their low cost and high photodetection efficiency but mostly their robustness against light allowing observation of the sky with high moon thus increasing the observation time.

The SST-1M camera uses 1296 pixels composed by a hollow light concentrator coupled to a custom monolithic hexagonal SiPM of 1 cm^2 area designed in collaboration with Hamamatsu in their low crosstalk technology (~50% PDE, low dark count rate 50kHz/mm^2). Each pixel can cover almost the same area of 1" PMT.

The camera readout is a fully digital readout with a programmable trigger logic, based on lastest generation FPGA. Its compact digital readout/ trigger (65x30x30 cm^3) can sustain high trigger rates with no deadtime up to tenths of kHz.

Specifications

- Robust against light
- Power consumption of < 2 kW
- lightweight : about 200 kg
- compact. ~ 1 m diameter and 75 m thickness
- high throughput
- almost dead time free
- stable performance thanks to a self calibrating system that tunes the bias depending on the measured temperature.

Requirements

The first prototype is almost complete and is being tested in laboratory. This will be followed by a preproduction of three telescopes, which can be hosted at the CTA site, to prove the capability to produce 20 telescopes for the CTA Southern Array.

Schedule

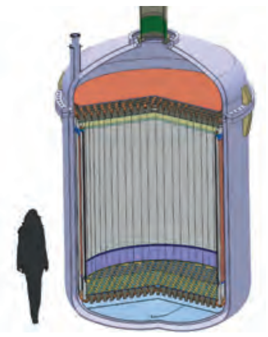
2016 | 2017 | 2018 | 2019 | 2020

Pre-production phase: 2 full cameras by 2018
2600 cones/ 2600 SiPMs / 60 Readout boards

Production phase: 20 full cameras by 2020
26'000 cones/ 26'000 SiPMs / 600 Readout boards

DARWIN DARk matter WImp search with Noble liquids

The ultimate ~50 ton Xe dual-phase dark matter detector



Photosensors

No decision on the photosensors for DARWIN has been taken yet. Currently, the consortium is following a rich and diverse R&D program. Possible options are:

- **PMT (baseline option):** 3" or 4" diameter; QE > 30% at 178 nm; radio-purity < 1 mBq/sensor (emphasis on low neutron emission); coverage 50–60%. Total number: ~1000
- **SiPM:** could be a viable option if the dark count rate is < 0.01 Hz/mm2 at liquid xenon temperature. Additional requirements: photon detection efficiency >15% at 178 nm with >80% coverage in modular flat-panel configuration; cross talk must be minimised to the few % level.
- **SiGHT (R&D):** 3–5" diameter hybrid vacuum photosensors, composed of a SiPM and a photocathode on a hemispherical radio-pure synthetic silica body; QE > 30% at 178 nm; coverage 50-60%; radio-purity <1 mBq/sensor. Total number: ~1000
- **GPM (R&D):** Large-area imaging gaseous photomultipliers composed of cascaded electron multipliers with CsI photocathodes.

Expected photon detection efficiency ~15–20% at 178 nm, with ~90%% coverage. Radio-purity per unit area must be similar to PMTs.

Requirements

Design phase

Increasing PMT size to 4" to reduce number of sensors, with possible increase in coverage. Extensive R&D on laboratory-prototypes of alternative sensors, with emphasis on performance, radio-purity and industrialisation. TPC design will depend on the R&D results of alternative sensors and their associated electronics.

Prototyping phase

Long-term laboratory tests of industrial prototypes of selected sensors, under cryogenic conditions. Development of dedicated front-end electronics, upon requirement; parallel effort on DAQ design, HV components, intelligent trigger schemes, data treatment & storage.

Construction phase

Methods and strategy of mass production, particularly for alternative sensors; test facilities and quality-control protocols; sensor-optimised installation, powering and readout schemes.

Schedule

2010/2013	2014/2019	2019/2021	2022/2032
First R&D phase, Aspera funded	R&D and design study	Engineering studies	Construction, commissioning, science run

GERDA

Germanium Detector Array – Search for neutrino-less double beta decay

General

The GERDA experiment has been proposed in 2004 as a new 76Ge double-beta decay experiment at LNGS. The GERDA installation is a facility with germanium detectors made out of isotopically enriched material. The detectors are operated inside a liquid argon shield.

Specifications

Photosensors

- PMTs operated in water for Cherenkov light detection (muon veto system); 8 inch, 66 PMTs
- ultra-low background PMTs operated in liquid argon for scintillation light detection; 3 inch, 16 PMTs
- ultra-low background SiPMs coupled to wavelength shifting fibres operated in liquid argon for scintillation light read out; 3 x 3 mm, 90 in total

Requirements

Improve QE of light sensors; low-background front-end electronics. R&D needed to improve stable operation of PMTs at low temperatures. Also higher radiopurity is favorable. Both can only be (and have been) accomplished in close cooperation with manufacturer, as development of large area SiPM arrays operated at low temeperature can be done only with the help of companies.

Quality control could be ensured via acceptance test of photo sensors in liquid argon;
ICPMS for determination of uranium, thorium and potassium trace elements; low-background gamma spectroscopy.

R&D towards a tone scale experiment requires prototype devices both PMTs and SiPMs. The final setup will be probably ten times larger then the current experiment.

Schedule

2015

Phase II
commissioning then ~5 year data taking

In parallel R&D on photo sensors for standard and liquid argon scintillation detection is pursued on laboratory scale in GERDA.

A follow-up one ton germanium experiment is conceived in world wide collaboration. Precondition is a successful performance of the GERDA Phase I/II and the Majorana demonstrator experiments. Technology decisions will be based on the performance of those experiments.

http://www.mpi-hd.mpg.de/gerda/

IceCube-Gen2

A GeV-PeV neutrino telescope in the Antarctic ice

Project

A multi-cubic kilometer neutrino telescope in the deep ice at the South Pole for the observation of high-energy cosmic neutrinos incorporating a densely instrumented core (PINGU) for the determination of the neutrino mass hierarchy.

Specifications

The detector will consist of around 10,000 optical sensors. In the baseline design, the optical sensors comprise a single 10″ PMT (peak optical efficiency above 30 %). Alternative sensors with enhanced photon detection properties for some portion of the detector are under investigation:

- 2 x 8″ PMTs per sensor (peak optical efficiency above 27 %); 8″ HPD possible alternative
- 24 x 3″ PMTs per sensor (peak optical efficiency above 25 %)
- 0.3 m^2 of wavelength shifters read out with 2 x 1.5″ PMTs per sensor (peak optical efficiency 35 %, dark count rate < 10 Hz @ -40 C)

Most important PMT specifications are: small TTS, short single pe / pulse rise time, high gain, low dark count rate, low pre- and after-pulse rate.

Auxiliary electronics
Low-power PMT base and readout electronics required. Signal processing anticipated to use 14 bit ADC plus FPGA. Communication with surface performed via copper cables. Electronics rating for -55 C.

Requirements regarding PMTs

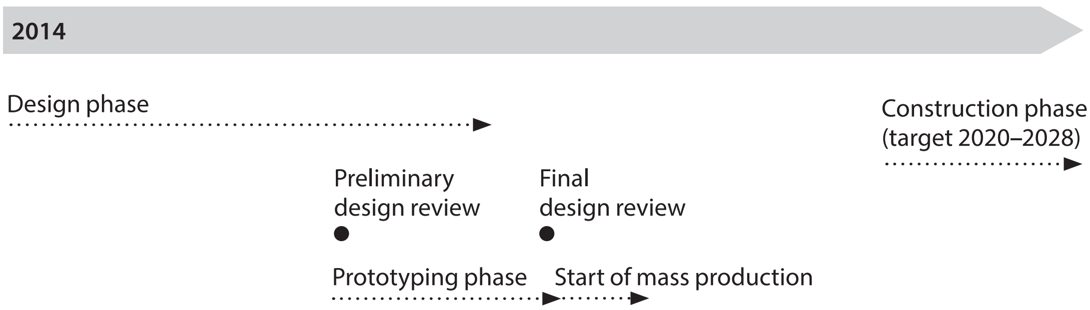
Baseline design with 10″ PMTs: PMT development essentially finished

Alternative sensors – Design phase
Use of existing commercial models which fulfill minimum requirements. Interaction with companies established.

Alternative sensors – Prototyping phase
Sufficient number of close-to-final PMTs for construction and test of prototype optical modules. Verification of properties of each PMT and specification of acceptance criteria.

Alternative sensors – Construction phase
Provision of full quantity of PMTs over a period of 5–6 years. Implementation of efficient quality control in cooperation with manufacturers.

Schedule



JEM-EUSO

Extreme Universe Space Observatory

Project

The JEM-EUSO mission aims to explore the origin of the extreme energy cosmic rays (EECRs) through the observation of air-shower fluorescence light from space. Such a space detector offers the opportunity to observe a huge volume of atmosphere at once and will achieve an unprecedented statistics within a few years of operation. Several test experiments are currently in operation or will be in operation in coming years.

Specifications

- More than 300.000 pixels of MAPMT (or SiPM) on a focal surface area of approx. 4 m^2 in the JEM-EUSO baseline design.
- Each of the various test experiments need photosensors of c. 10 % of the baseline design.

Auxiliary electronics

- Small-size, space qualified readout electronics based on ASICs and FPGAs.
- For MAPMT, the HV is integrated in Cockroft-Walton type suppliers.

Design phase, R&D

- Single photoelectron detection, photoelectron collection efficiency, dark current, after pulsing, linearity, lifetime, etc. for the MAPMT (with Hamamatsu).
- Alternatives to classical PMTs, e.g. SiPM, in particular in respect to after pulses, dark currents, temperature stability, large area coverage, UV sensitivity, digital and fast readout as well as space qualification.

At this phase there is strong interaction with the companies.

Schedule

2015 **2016** **2017** **2018**

Test experiments on ground and at balloons started 2014 and will be continued.

Launch to the ISS originally foreseen in 2017 will not be possible.

Mini-EUSO (inside ISS, monitoring the Atmosphere through UV window) launch in 2017.

http://jemeuso.riken.jp

KM3NeT 2.0

Astroparticle and Oscillations Research with Cosmics in the Abyss (ARCA and ORCA)

Specifications

Photosensors
KM3NeT 2.0 is a deep-sea infrastructure. It will comprise 345 strings with 6210 digital optical modules (DOMs), carrying 31 3-inch PMTs each. The main specifications are QE > 23 % at 404 nm, TTS < 5 ns (FWHM), small dark count, pre-pulse and after-pulse rates, long lifetime (continuous operation > 15 years).

Light collection rings
Each PMT face is surrounded by a reflective conical ring increasing the light collection efficiency by ~ 30 %.

Auxiliary electronics
Custom-designed low-power PMT base; signal processing by FPGA. Digitised start time and time over adjustable threshold read out for each PMT signal. Transition to optical signal transmission in DOM.

Requirements

Design and prototyping phase
Different companies have developed suitable 3-inch PMTs for KM3NeT, in close cooperation with the KM3NeT Collaboration
Critical points were a short form factor combined with large photocathode area and small TTS, production capacity and cost effectiveness.

First construction phase
Almost 18,000 PMTs for 31 strings will be delivered and tested until 2016. The return of experience may imply requests for design modifications.

Construction of KM3NeT 2.0
Further 175,000 PMTs will be needed until 2020 to complete the construction of ARCA (230 strings altogether) and ORCA (115 strings). Cost effectiveness, operation stability and light detection efficiency are the most important requirements.

Future plans
In a future phase on KM3NeT construction after 2020, further 260,000 PMTs will be needed for additional 460 strings.

Schedule

2016	2018	2020
First construction phase concluded Formal start of KM3NeT 2.0	Start of continuous operation of KM3NeT 2.0	Construction of KM3NeT 2.0 ready

XENON1T / XENONnT

Direct detection of dark matter using liquid xenon detectors

General

XENON1T & XENONnT: liquid xenon (LXe) time projection chambers with total LXe masses of 3.3 t and ~7 t, respectively. The LXe scintillation light is read out by two arrays of photomultiplier tubes (PMTs), on top and bottom of the detector.

Specifications

Photosensors
3-inch R11410-21 PMTs from Hamamatsu (about 250 units) have been purchased by the XENON collaboration. This sensor fulfills the radioactivity requirements of XENON1T, has a high QE with an average at around 35 % at 178 nm (LXe scintillation wavelength) and has a performance optimized for operation in LXe.
For XENONnT additional sensors will be required. Depending on the size of the PMT (4 or 3 inch), the number of sensors required would be around 100 to 200. Hybrid options with different PMTs on top and bottom arrays are also being considered.

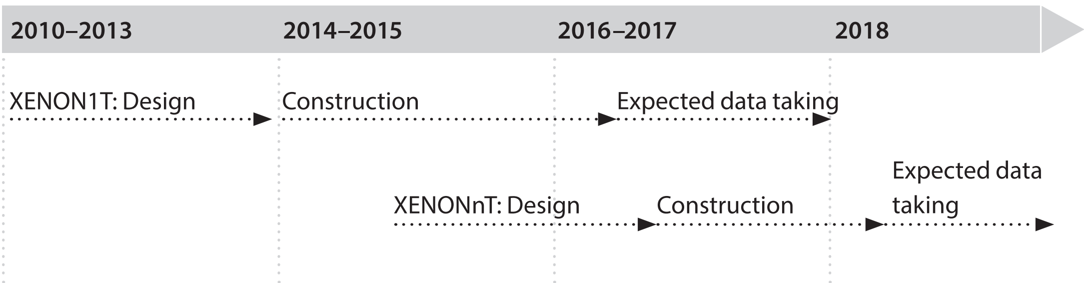
Requirements

Design phase
Completed for XENON1T. For XENONnT, new low-temperature and high-QE tubes under development are being considered. The goal is to reduce internal radioactivity to meet XENONnT background requirements. Collaborative activities between XENON and Hamamatsu are on-going to achieve this goal.

Prototyping phase
PMT prototypes for XENONnT by Hamamatsu will be tested by different groups of the XENON collaboration. Both the internal radioactivity and the performance in LXe need to be verified.

Construction phase
XENON1T construction is on-going and first data is expected in 2016. Most components necessary for XENONnT are already in place. The new design of the inner detector including photosensors will start once XENON1T is operational.

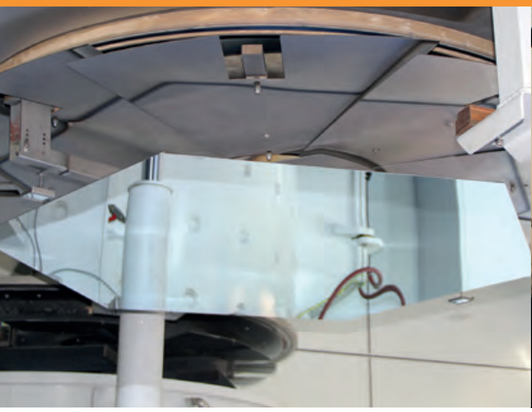
Schedule



http://xenon1t.org

Bte

Bte GmbH is a leading company in vacuum thin film coating of optical components. A specialty is the coating of mirrors and other components for telescopes like in the HESS or CTA projects.



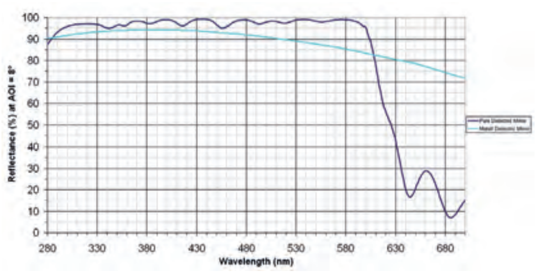
We have 70 employees, 25 coating machines with diameters up to 1,900 mm and are experienced in many markets from natural sciences over medicine, industrial sensorics to automotive components. We are ISO 9001 and ISO 14001 certified and supply our products to customers world wide. Successful coating work for the HESS 1 telescopes and the various CTA prototypes is proofing our skills in the telescope mirror field.

Products

The coatings of Bte are very well suited for applications in the astronomy in the spectral range between 200 nm and 2500 nm.

The coating of Cherenkov telescope mirrors in particular requires high reflection between 300 nm and 600 nm.

Metal/Dielectric and Pure Dielectric Mirror



With our dielectrically enhanced aluminium mirrors we achieve a reflectance of > 90 % from 300 nm to 600 nm (> 94 % in the maximum). The enhancement layers work also as a protection against impact from the environment.

Our pure dielectric coatings result in reflectance values of even > 95 % from 300 nm to 600 nm; suppressing reflection outside the spectral region of interest. In addition the dielectric coatings are unique in environmental durability.

Our coating machines are capable for the coating of SST, MST, LST and SCT mirrors, i.e. pentagons and hexagons with diagonals of > 1700 mm. All mirror types for CTA have been coated at Bte for prototyping tests.
Both the coating of light weight panels as well as of pure glass sheets with the following slumping process done by our partners have been performed successfully; altogether ca. 70 mirrors so far (March 2015).

Our cost structure and the time frames take advantage from the existence of 6 machines with the necessary size as well as a skilled personnel staff and a process line suited for the coating of a high number of big sized mirrors.

Other work successfully done for CTA components were mirror coating of light guide components and the coating of end windows with layer systems for anti-reflection (AR) or for dichroic optical filters.

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Entropy

Entropy GmbH is a cryostat manufacturer specialized in closed-cycle technology for the Kelvin and milliKelvin temperature range.

The company was founded in 2010 and is based in Munich, Germany. With five employees we design and manufacture several types of state of the art cryostats such as:

- GM cooler based cryostats for temperatures < 10 K,
- Pulse-tube cooler based cryostats for temperatures < 3 K,
- Closed-cycle Joule-Thomson cryostats for temperatures < 1 K,
- Adiabatic Demagnetization Refrigerators (ADR)
- and Dilution Refrigerators (DR).

The modular design of our cryostats allows easy customization and optimization for applications in material science, astronomy, detector physics and quantum physics. All cryostats are available with a full package of software for control and data logging.

ENTROPY

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ET Enterprises electron tubes

ET Enterprises Limited is a new UK company which manufactures and supplies the long established Electron Tubes brand of photomultipliers and associated signal processing hardware and electronics to meet the needs of low light level detector users in industry and research around the world.

ET Enterprises electron tubes

We have an associate company in Sweetwater, Texas, and distributors in most other parts of the world.

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Although a new company, its history can be traced back to the 1930s when, as part of EMI, it first became involved with light detection technologies. Specialisation in the development and manufacture of photomultipliers started in the late 1940s, and the company continued to grow to become a major international supplier of low-level light detection devices and systems. Now a subsidiary of Ludlum Measurements Inc, ET Enterprises Limited has the benefit of the combined resources of the production facilities of ADIT, a US based producer of photomultipliers, and ET Enterprises' UK based development facilities and experience in a wide range of different photomultiplier applications worldwide.

We offer a wide choice of high quality products, both standard and customised, together with comprehensive technical and application support, and competitive prices. All of our UK facilities, which include design, development, production and distribution, are located on one site in Uxbridge, west London. We have been operating under ISO9001 certification since the early 1990s.

Outside the US, ET Enterprises distributes and supports ADIT brand photomultipliers, which are manufactured by our sister company in Texas and are used primarily in nuclear radiation measurement systems. The ADIT manufacturing facility is also ISO9001 accredited.

Design and Manufacturing facilities in
Uxbridge, UK; Sweetwater, USA

Products

Photon counting modules

Our photomultiplier range includes
- Active diameters from 2.5 to 280 mm
- Spectral range options from 110 to 900 nm
- Operation from -196 to +175 deg. C
- High quantum efficiency with low dark noise
- Ultra-low background glass and all-quartz options
- Wide dynamic range from a few photons/s to >50 M/s
- New compact variants

Photomultiplier manufacturing for 60 years
- As ET Enterprises – from 2007
- Electron Tubes – 1990's
- Thorn EMI Electron Tubes – 1970's
- EMI Electron Tubes – 1950's

Photomultipliers for HEP
- Babar – 28 mm water resistant glass
- Borexino – 200 mm water resistant glass – ultra low background glass
- CTA – high QE pmts
- ICARUS – 200 mm – 186 deg. C – ultra low background glass
- KM3Net – 3" pmt
- MACE – 38 mm 6 stage fast hemispherical
- MAGIC – 25 mm 6 stage fast hemispherical
- WARP – 50 and 75 mm – 186 deg. C – ultra low background glass
- ZEPLIN – 50 mm all-quartz - 110 deg C

Hamamatsu Photonics

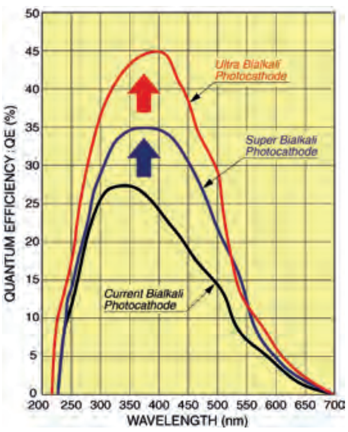
Hamamatsu Photonics is a worldwide leading manufacturer of opto-electronic components and systems. Among others we offer sensors and systems for spectroscopy (including ultra fast), scientific-grade cameras, beam monitoring solutions, photon counting detectors and systems, photomultipliers, photodiodes, IR detectors.

PMT Series

Features

- Fast time response
- Low after pulse noise
- Large active area: Active area from ½" to 20"
- High sensitivity: SBA cathode technology QE 36 %, UBA 43 %
- Multi anode technology
- Low cost for large area
- PMT for cryogenic experiments

Ultra/Super Bialkali Spectral response

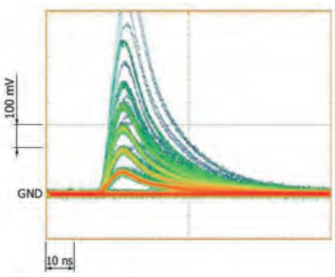


MPPC Arrays and Modules

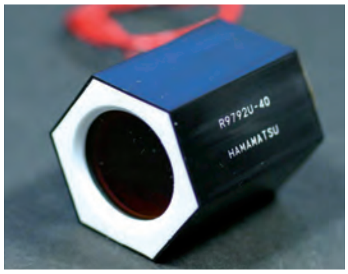
Features

- Geiger-mode APD
- Suitable for mass production
- Insensitive towards to magnetic field
- High sensitivity
- Single Photon Counting
- High time resolution
- Low crosstalk
- Low afterpulsing

Measurement example: Analog output (C11208)



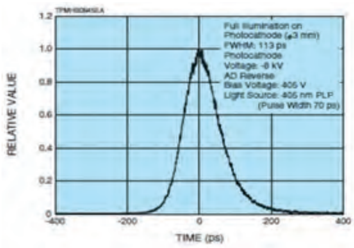
Hybrid Photo Detector



Features

- High gain
- Ultra fast time response
- No after pulse noise

T.T.S.: Transsit Time Spread (R10467U) (single-photoelectron state)



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LASER COMPONENTS

LASER COMPONENTS offers components for the laser and optoelectronic industry – often developed according to customer specifications and usually manufactured in house. In addition to the products made by us, we also offer components from selected premium suppliers. More than 180 employees worldwide work in sales, administration, and production.

In-house production comprises laser optics, avalanche photodiodes, pulsed laser diodes, IR detectors and emitters, pyroelectric detectors, laser modules, photon counters, and the assembly of optical fibers.

Avalanche Photodiodes

Similar to photomultipliers, avalanche photodiodes are used to detect extremely weak light intensities. Si APDs are used in the wavelength range from 250 to 1100 nm and InGaAs is used as semiconductor material in APDs for the wavelength range from 1100 to 1700 nm. Our silicon APDs are available with diameters of the active area ranging from of 230 µm to 3.0 mm. Specifically selected APDs can also be used for photon counting in Geiger mode, where a single photon triggers an avalanche impulse. Our IAG series of InGaAs APDs exhibits a high damage threshold of > 200 kW/cm². The responsivity of the detector peaks at 1550 nm and the active area is available in diameters of 80 µm, 200 µm, and 350 µm.

Photon Counters

In order to detect single photons at wavelength ranges from 350 nm to 1600 nm we offer plug-and-play modules which operate with a 12 VDC power supply. Incoming photons generate corresponding electrical pulses which may be conveniently read out at the TTL output. With dark count rates lower than 10 cps and detection efficiencies larger than 70% in the red and larger than 50% in the blue wavelength range the silicon-based COUNT®-series offers everything needed for low light applications such as spectroscopy, fluorescence measurements, medical technology and LIDAR. The integrated gating function allows the modules to be disabled between measurements. The COUNT® modules are available with an optional FC connector with a pre-aligned Grin lens inside.

Pyroelectric Detectors

IR detectors have been a part of our standard product range at LASER COMPONENTS for almost three decades. A distinction is made between sensors for the near infrared range (NIR) from 1.0 µm to 2.5 µm and those for the mid-infrared range (MIR) above 2.5 µm. IR detectors of all types of operation are a part of our product portfolio and leave nothing to be desired. In addition to InGaAs and extended InGaAs PIN detectors, we also offer lead sulfide and lead selenide detectors as well as other MIR detectors. Our pyroelectric detector portfolio is based on both common $LiTaO_3$ material and high-performance DLaTGS which provides the largest pyroelectric effect known.

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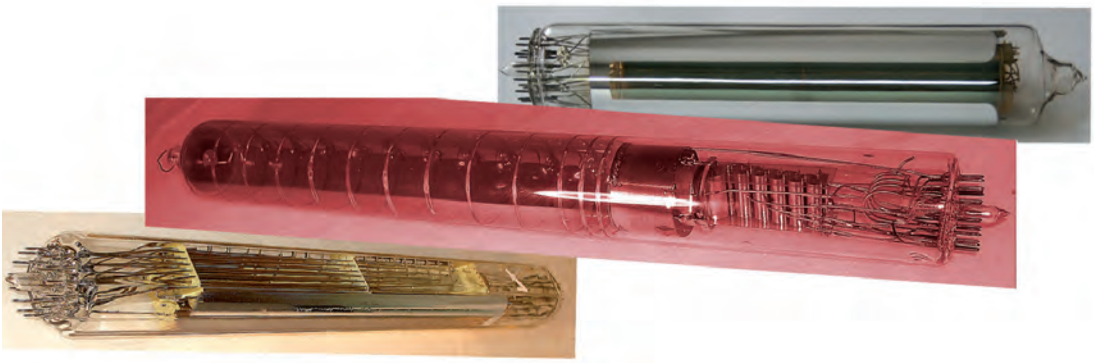
MELZ FEU

Strong traditions and innovations in photomultiplier tubes production.
MELZ FEU is global supplier of Photomultiplier Tubes (PMT) and Accessories.



Profile

MELZ FEU work with it's clients, identifies and understands client needs and requirements for special task solutions.
We have more than 50 years experience in design and production of PMT.
Our plant combines R&D department and factory.
Quality MELZ FEU devices is tested for a long-time.

PMT R&D and Manufactures

PMT – for different applications

- Photo-, radio-, spectrometry
- Nuclear research, simulations
- For high temperature media
- Scientific Large scale spectrum
- For photon counting
- etc

Accessories – for PMT

- Adaptors, connectors, sockets
- Power suppliers, amplifiers
- Magnetic shields

New & non-standard PMT

- Multichannel PMT for special applications
- Ultra-short PMT (4 dynodes)
- The small-scale series PMT for individual projects.

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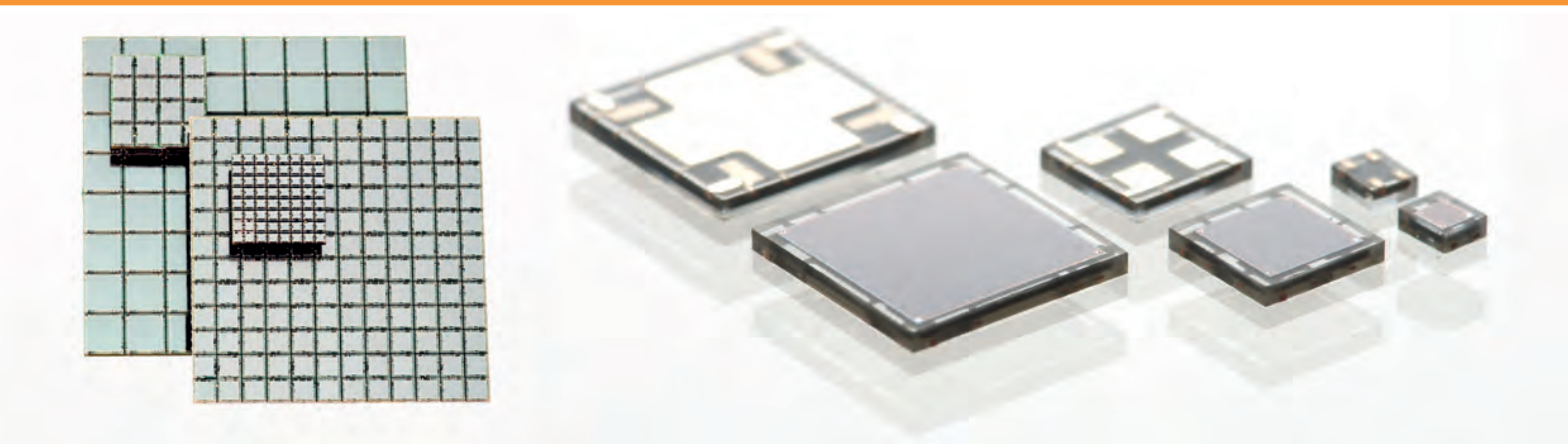
SensL

Our SiPM technology offers industry-leading uniformity in operating voltage and optical response, enabling world-class system performance and compelling cost advantage.



SensL was formed in 2004 and has been driving the development of SiPM technology ever since. Our SiPM technology offers industry-leading uniformity in operating voltage and optical response, enabling world-class system performance and compelling cost advantage.

At the heart of the product line are the 'Micro' families of SiPM sensors in a range of sizes and packages. The most recent addition to the range, the J-Series, have PDE (photon detection efficiency) of > 50% and incorporate major improvements in the transit time spread which results in a significant improvement in the timing performance of the sensor.

Compared to other photosensor technologies, such as PiN diodes, APDs and PMTs, SiPMs offer a winning combination of properties. These include high gain, excellent PDE and fast timing along with the practical advantages associated with solid-state technology, such as compactness, ruggedness, low bias voltage and insensitivity to magnetic fields.

The J-Series sensors use an 8" process in a CMOS foundry, with the entire supply chain, from wafers to packaging geared to high-volume, high-reliability manufacturing. A custom chip scale package using a TSV (through silicon via) process has been developed to house the sensors and create custom arrays. Until recently, no standard reliability assessment program existed for SiPM, and so SensL have followed industry standard test flows designed for integrated circuits.

J-Series

The J-Series sensor range is leading the way for high performance detection and timing applications. A few highlights:

- >50% PDE at 420nm and extended sensitivity to 200nm for improved UV sensitivity
- <100kHz/mm2 typical dark count
- ±250mV breakdown voltage uniformity
- <150ps coincidence resolving time (FWHM) for 3x3x20mm2 LYSO crystal
- Ultra-fast rise times of between 100ps - 300ps
- Temperature stability of 21.5mV/°C negating the need for active voltage control
- Available in a high fill-factor, reflow solderable TSV package
- 3mm and 6mm active sensor areas

sensL
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APPEC, the AstroParticle Physics European Consortium has been founded in 2012 by major funding agencies active in Astroparticle Physics. Ministries, funding agencies or their designated institutions from Belgium, Croatia, France, Germany, Ireland, Italy, Netherlands, Poland, Romania, Russia, Spain, Sweden, Switzerland, and UK joined until beginning of 2015. Based on the achievements of the EU-funded ERA-NET ASPERA the partners of APPEC agreed to coordinate their funding activities and undertake common actions to support Astroparticle Physics in Europe.

The development of a common European strategy for Astroparticle Physics and the update of the roadmap for this research field are important achievements of APPEC. Related to this, APPEC is continuing to release common calls for funding of common R&D projects and establish a common public outreach. Furthermore, APPEC aims at supporting synergies between Astroparticle Physics and other scientific domains as well as R&D cooperation with industry in Europe.

Astroparticle Physics itself is a young and very active science discipline comprising a lot of R&D activities in advancing detection methods and technologies to the maximum. Programmatically it is both, performing particle physics with cosmic accelerators and performing astronomy at highest (particle) energies.

Astroparticle physicists search for the tiniest amount of energy released by a dark matter particle in their experiments, fine tune their antennas to discover the infinitesimal small squeezing of the earth when passed by a gravitational wave, and – to the other extreme – build detector arrays of the size of 3000 km^2 to measure the footprint of the most energetic cosmic particles hitting the earth atmosphere.

Altogether, Astroparticle Physics in Europe covers:

- Astronomy at Gamma-ray energies
- Direct dark matter search
- Dark energy surveys
- Gravitational wave astronomy
- Determination of neutrino properties
- Neutrino astronomy
- Determination of the nature and origin of cosmic rays

Interested to know more about APPEC? Please contact: appec@desy.de