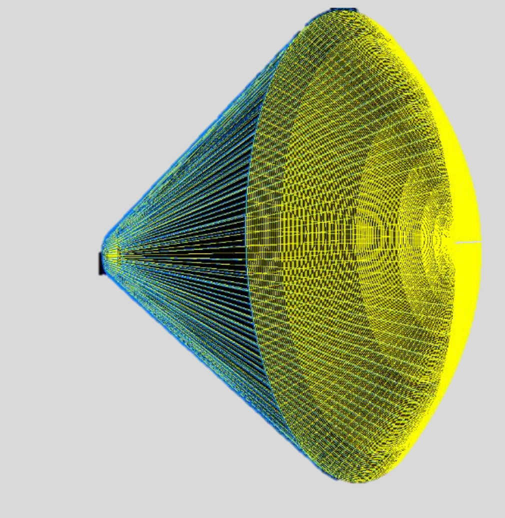
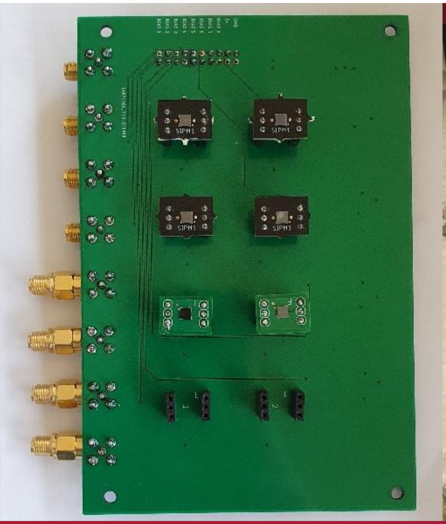
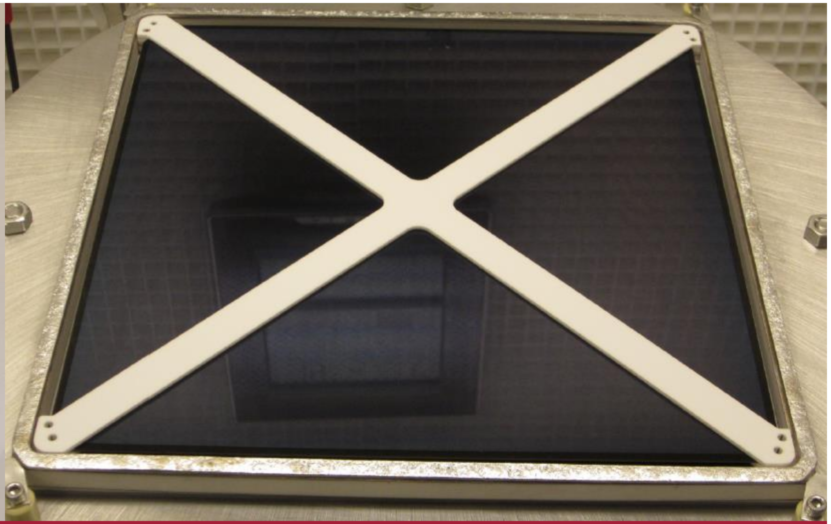
Mathematisch-Naturwissenschaftliche Fakultät

Kepler Center for Astro and Particle Physics







Photodetector Development with fast Light Sensors

Bundesministerium für Bildung und Forschung

07.06.2021, Marc Breisch, BMBF Scintillator R&D general meeting 2021

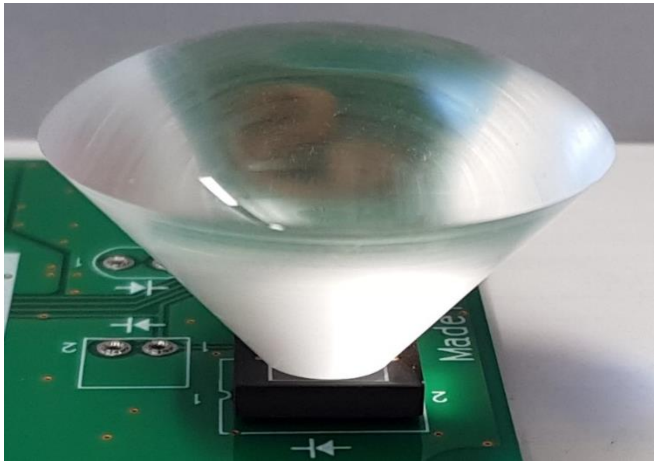
Motivation

- Most of the current neutrino experiments use large photomultiplier tubes (PMT) in their setups
- For the next generation fast and small detectors for a higher spatial and time resolution are an interesting alternative, but there are very few options
- For this reason an approach utilizing SiPMs and scintillators was investigated in Tübingen and will be further expanded on later
- A goal of such detectors could be to separate the scintillation and Cherenkov light, as it is produced in high energy events in water-based-liquid-scintillator (WbLS), which is only a few (<10 ns) apart

The SiPM with Active Light Guide design

- The SiPM with Active Light Guide (SiALG) design combines SiPM with scintillators to act as active light guides

- The general idea is to keep the number of SiPM as well as channel to be read out to a minimum and have the scintillators act as light guide to increase the effective photosensitive area



Prototype light guide on a SiPM

- The scintillators will be developed and produced in cooperation with the group of Michael Wurm of the JGU Mainz

- At the same time, the development of the electronics will be done in Tübingen alongside the simulation for the optimal shape of the scintillator

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Status of the scintillator development and production

- At the JGU Mainz a lab has been set up to produce said scintillators and it will focus on producing plastic scintillators with polystyrene (PS) as basis
- Additionally multiple wavelength-shifters (WLS) are available to be mixed with the PS (like PPO, bis-MSB or BPEA) depending on what is needed

Early prototypes form left to right: PS, PS+PPO, PS+bis-MSB, PS+BPEA

Status of the scintillator development and production

- A process in which the scintillators will be polymerized in a vacuum oven (to extract bubbles) and then purified by distillation to enhance the optical transparency is used

- Since a lot of progress has been made in optimising the production process a wider variety of producible sizes is now possible. While in the beginning only 1'' scintillators where possible, by now up to 2''+ are doable

- This versatility gives us a great starting point to design the light guides since we will need to shape the scintillators from a cylindrical shape to what we deem as useful

- In addition a setup to measure the spectral absorption and emission as well as the light yield is being set up in Tübingen and available in Mainz

Status of the scintillator development and production

Vacuum Oven

Aluminum Oxide Column

Rotary Evaporator for distillation

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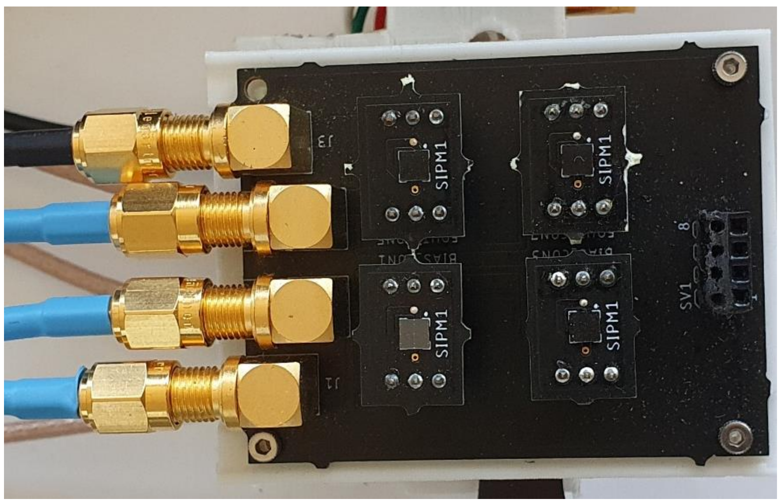
Status of the electronics development for SiPM arrays

- In March 2020 a new Bachelor student joined the project and took over the development for a set of custom electronics that will be used for a later 8x8 SiPM array



A 2x2 prototype SiPM array

- It started off with a simple 2x2 SiPM array consisting of a base and several shuttle boards with the SiPM mounted on them

- The intention was to separate electronics from SiPM and later SiPM + scintillator to have them be easily replaceable or removable

- This design proved to be a good first step. Although the signal to noise ratio was very small, dark pulses as well as single p.e. events induced by a light source could be seen.

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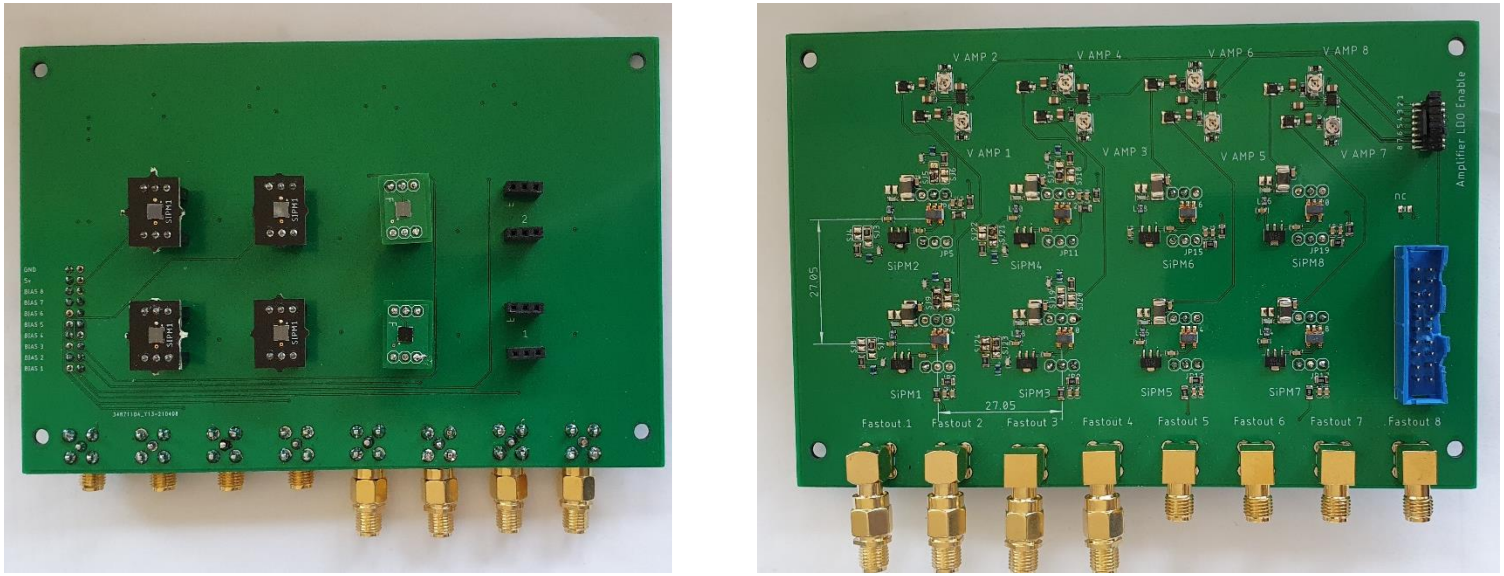
Status of the electronics development for SiPM arrays

- This first design did not offer any kind of control and solely relied on external devices

- To improve on this first design a follow-up design with 2x4 SiPMs was designed as a master thesis by the same student and should provide the direct schematic for the future 8x8 array

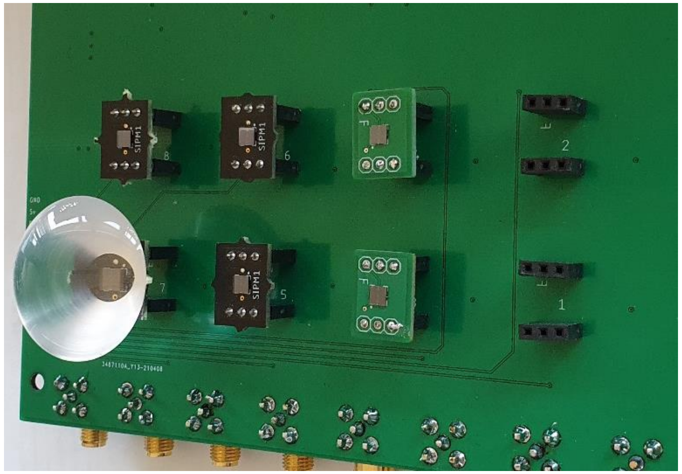


New 2x4 SiPM array main board with SiPMs mounted frontplane (left) and backplane (right)

Status of the electronics development for SiPM arrays

- The bias voltage is thereby supplied via a high density cable by a custom designed voltage board, which features an individual voltage control and a temperature regulated voltage correction for every SiPM

- This gives a high level of control over the individual SiPMs' gain as well as information about the current temperature which will coincide with the dark count rate



Example of the combination of SiPM and scintillator for the 4x2 array

- Since the important part is the coupling with a scintillator the spacing is chosen to match a high level of coverage (exemplary shown for one SiPM+scintillator)

Status of the electronics development for SiPM arrays

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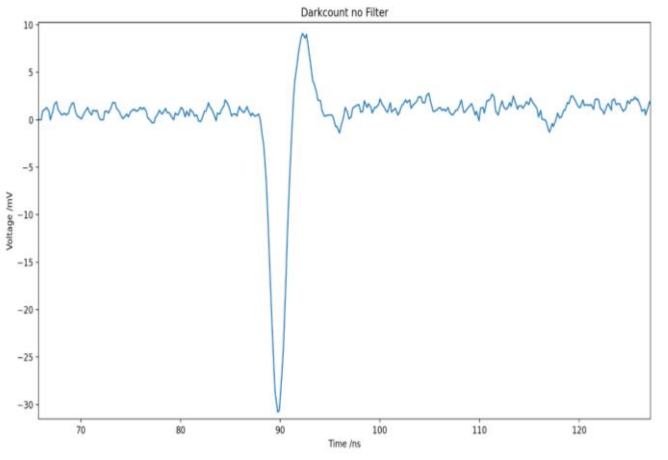


Example plot of a dark count of channel 1

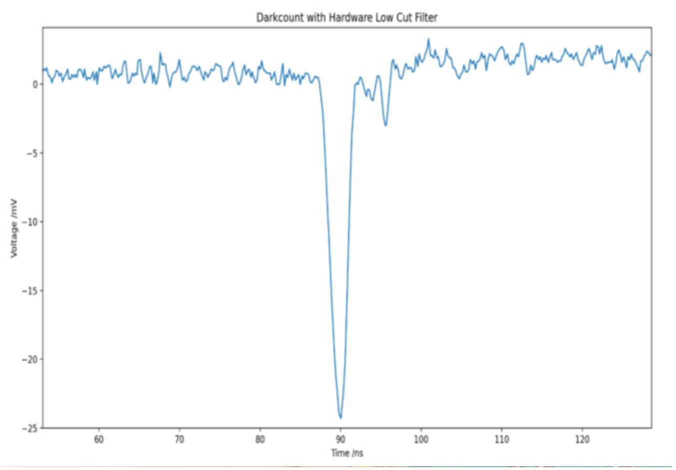
- Since the important part is the coupling with a scintillator the spacing is chosen to match a high level of coverage (exemplary shown for one SiPM+scintillator)

- Some example plots for dark counts for different channels

Status of the electronics development for SiPM arrays

- The bias voltage is thereby supplied via a high density cable by a custom designed voltage board, which features an individual voltage control and a temperature regulated voltage correction for every SiPM

- This gives a high level of control over the individual SiPMs' gain as well as information about the current temperature which will coincide with the dark count rate



Example plot of a dark count of channel 2

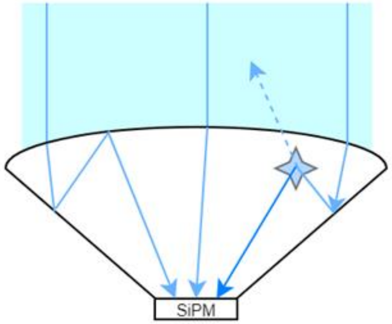
- Since the important part is the coupling with a scintillator the spacing is chosen to match a high level of coverage
(exemplary shown for one SiPM+scintillator)

- Some example plots for dark counts for different channels

Status of the electronics development for SiPM arrays

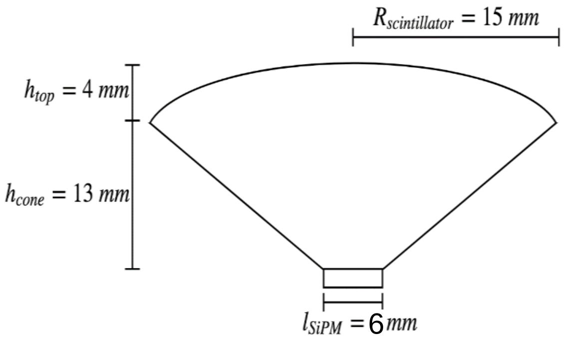
- The current design is scalable and will be expanded to feature up to 64 SiPM and will contain the following features:
  - Up to 64 individual bias voltages supplied by a separate voltage control board
  - A temperature sensor for each SiPM with a voltage correction for a stable gain
  - A low noise amplifier put very close to a SiPM to reduce the risk of picking up noise before the amplification
  - A very good signal to noise ratio compared to previous versions
  - A socket connection to easily replace a SiPM and/or remove it to mount a scintillator on the SiPM as well as clean it without the main board connected

Status of simulation of the scintillator shape



SiPM with (active) light guide principle

- The light guides will be active light guides to collect additional light as well as use the wavelength-shifting aspect of the scintillators
- Since the probability of detected photons is now a combination of PDE and collection efficiency both values need to be as high as possible

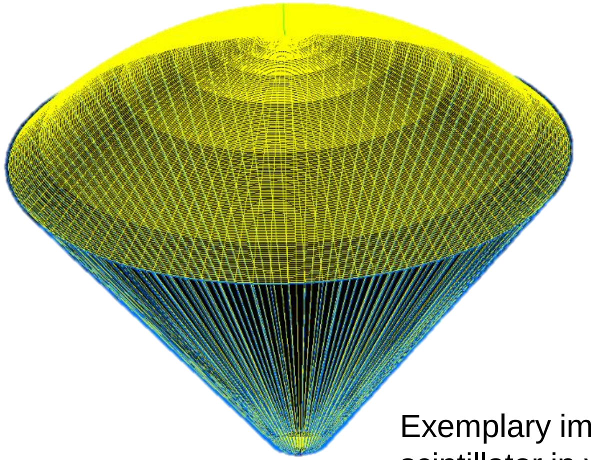


Basic ALG design as used for the prototypes

- Therefore a Ray-Tracing-Monte-Carlo was written to simulate different shapes and sizes and determine the highest collection efficiency
- This simulation resulted in the basic shape used for the prototypes, but a more detailed simulation containing all the material properties and scintillation characteristics is necessary to determine the final shape

Status of simulation of the scintillator shape

- To improve the simulation it will be imported into a framework, like Geant4, which will allow a more precise handling of the used materials as well as the scintillation mechanisms
- This simulation is part of the still undergoing master thesis about the SiPM electronics and will hopefully soon yield data about the final shape and more importantly the sizes that will be used



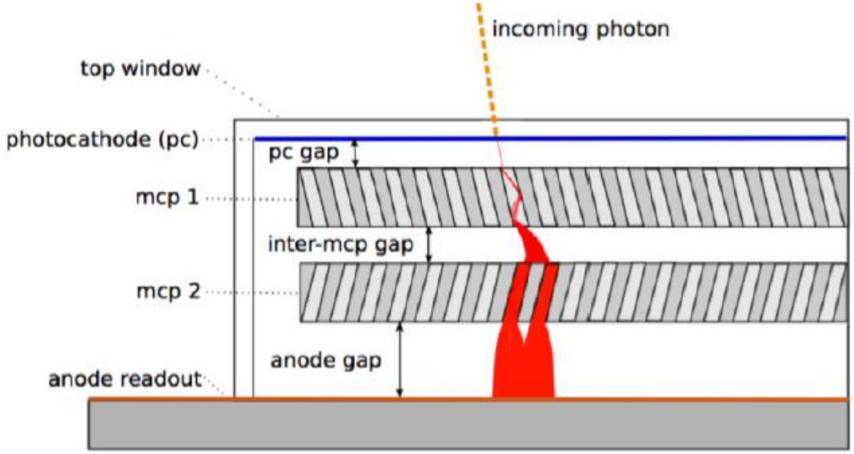
Exemplary implementation in Geant4,
scintillator in yellow and a reflective surface in blue

Status of other photodetectors in Tübingen

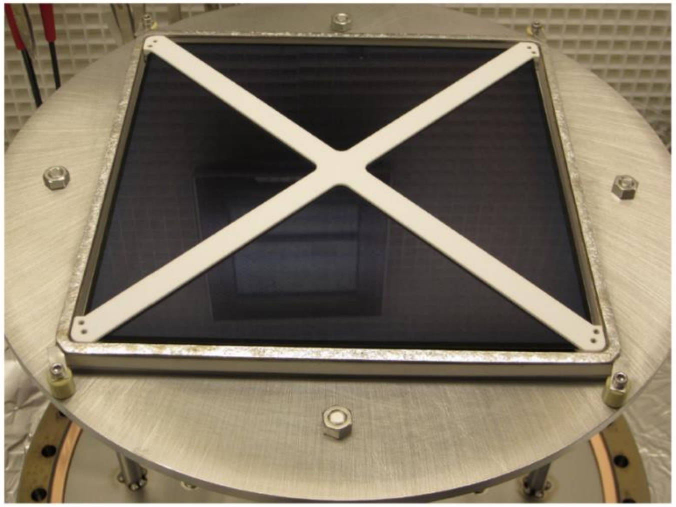
- Since the start of the year Tübingen is in possession of a Large Area Picosecond Photo Detector (LAPPD)

- LAPPDs consist of 2 micro channel plates within a vacated container with a photocathode on top and several so called strips which function as anodes

- This setup gives the LAPPD great spatial (of a few mm) and timing resolution (~60 ps) plus an effective area of 20x20 cm



arXiv:1809.05987: LAPPD side view with internal setup



arXiv:1603.01843: LAPPD top view

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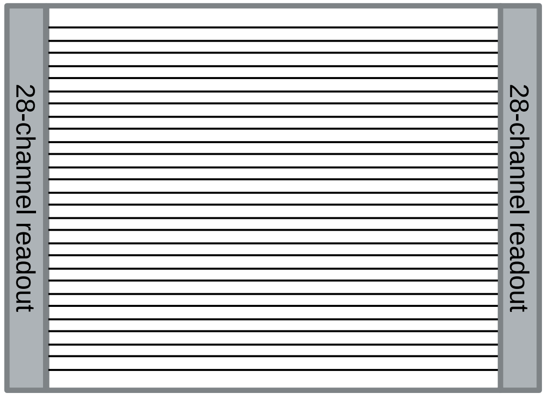
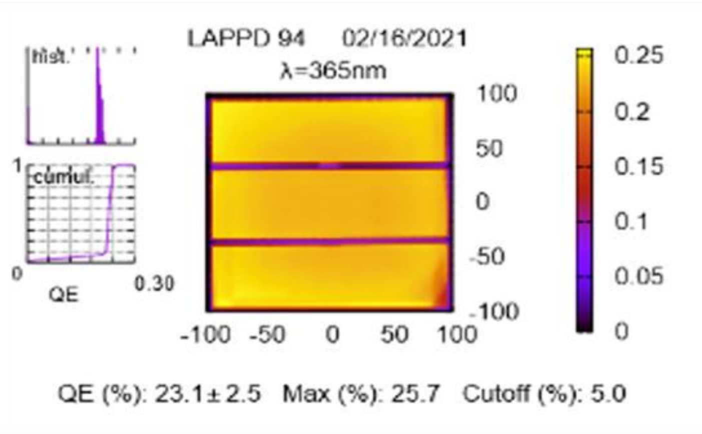
Status of other photodetectors in Tübingen

- This resolution can be reached by using 28 separate strips as anode instead of a solid, large anode
- The strips are a few mm apart giving it the spatial resolution in one dimension
- One strip is always read out on both sides (total 56 channels) giving the spatial resolution in the second dimension



LAPPD strip line principle



QE scan of an LAPPD done by manufacturer

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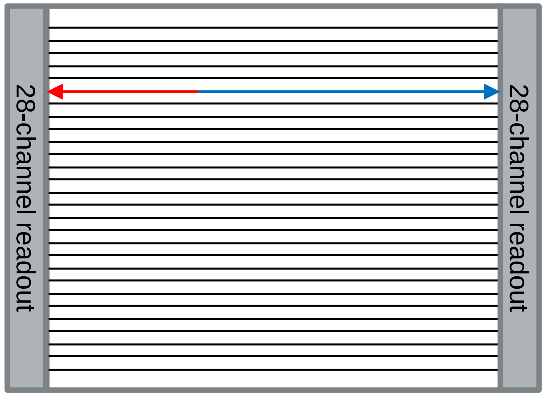
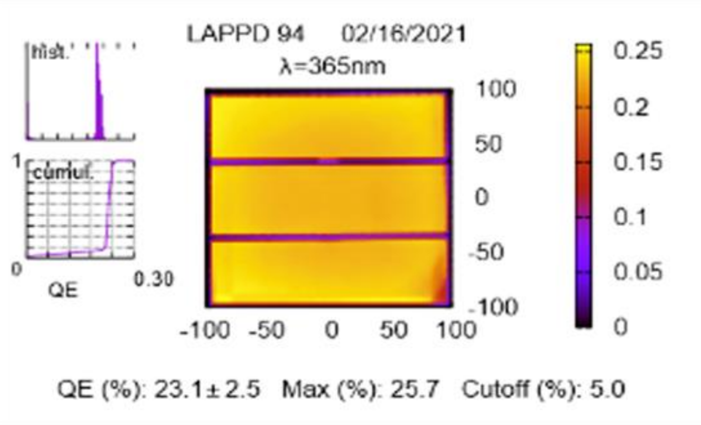


LAPPD strip line principle



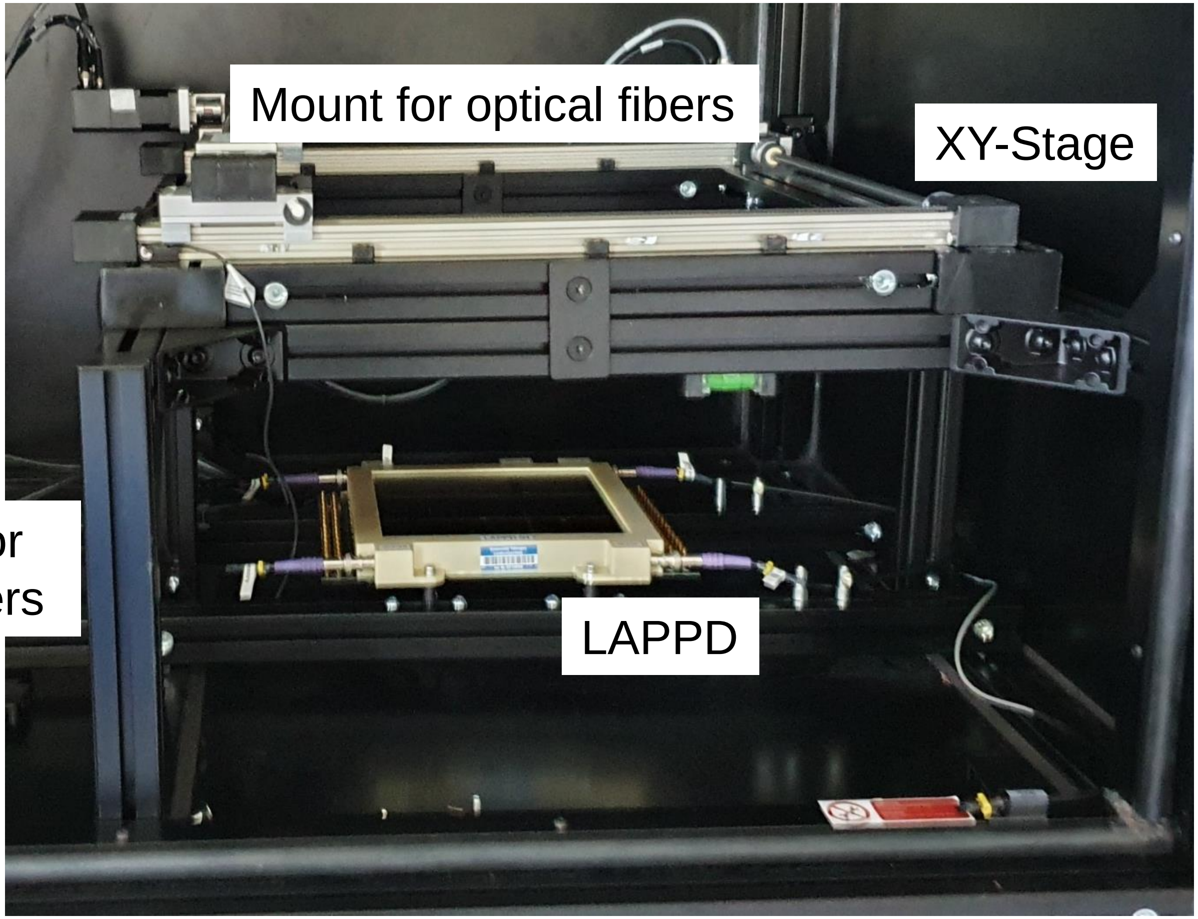
QE scan of an LAPPD done by manufacturer

Status of test setups available in Tübingen

Dark box with stage mounted inside

- To test photodetectors like our own SiALG arrays and the LAPPD a new dark box was designed by a Bachelor student to have an optimal environment to test the such sensors
- It features:
  - Two separate chambers for supply devices, light sources and read out electronics
  - A picosecond light source
  - A stage to move in the xy-plane
  - And an e/m shielding is in preparation
- With this a precise scanning of light sensors is possible and the characterisation of the LAPPD is being prepared by a PhD student

Status of test setups available in Tübingen



Feedthrough for cables and fibers

Example setup of a LAPPD inside the dark box

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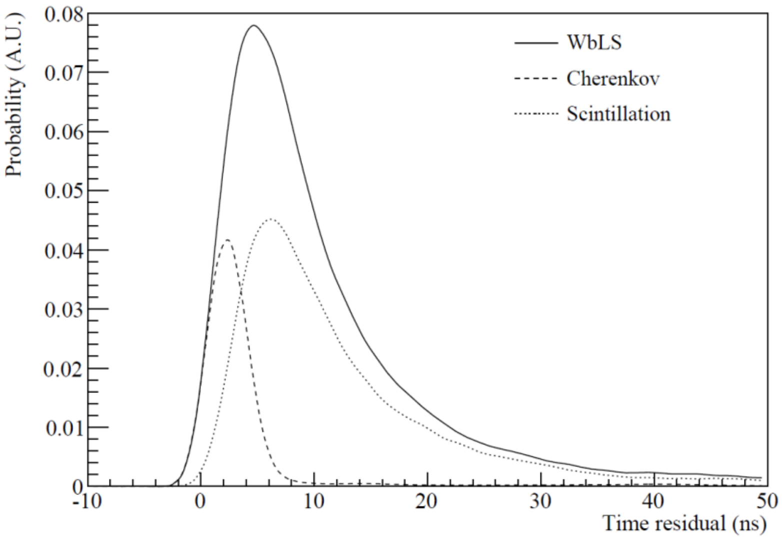
Status of test setups soon available in Tübingen

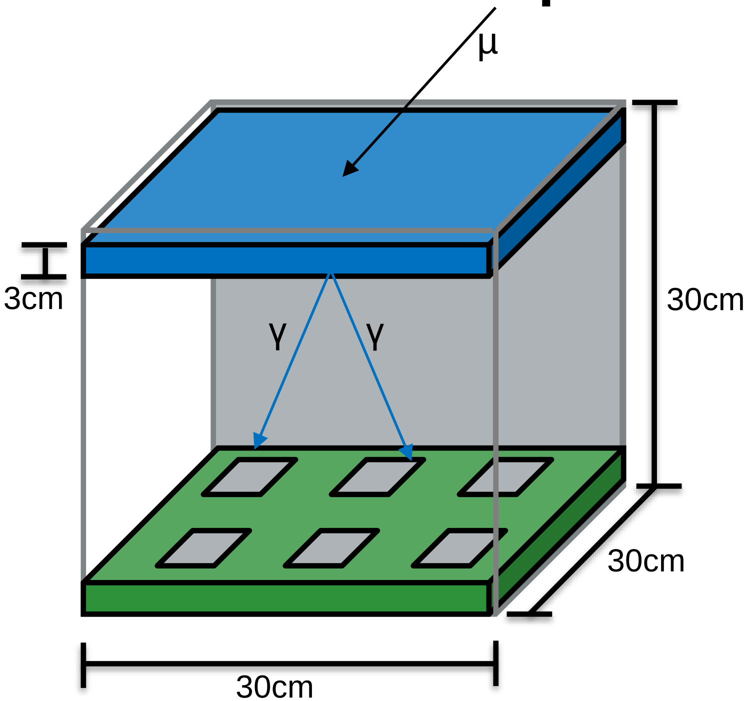


arXiv: 1409.5864: Light yield of scintillation and Cherenkov light produced by WbLS

- To have an alternate setup to test photodetectors a new setup is being designed right now.
- The basic idea is to have a light-tight cube in which we can mount a photodetector array as well as a test cell filled WbLS supplied by JGU Mainz
- A larger WbLS test cell like this will be build in cooperation with the JGU Mainz

- The WbLS will allow the production of scintillation photons as well as Cherenkov photons, but detectors with a very fast timing resolution are needed to separate them, giving us the perfect opportunity to test LAPPD and SiALG

Status of test setups soon available in Tübingen



Schematic setup of the WbLS test cell

- The goal is to have an incoming muon generate said Cherenkov/scintillation photons and produce characteristic Cherenkov ring and a homogenous distribution respectively with a slight difference in time

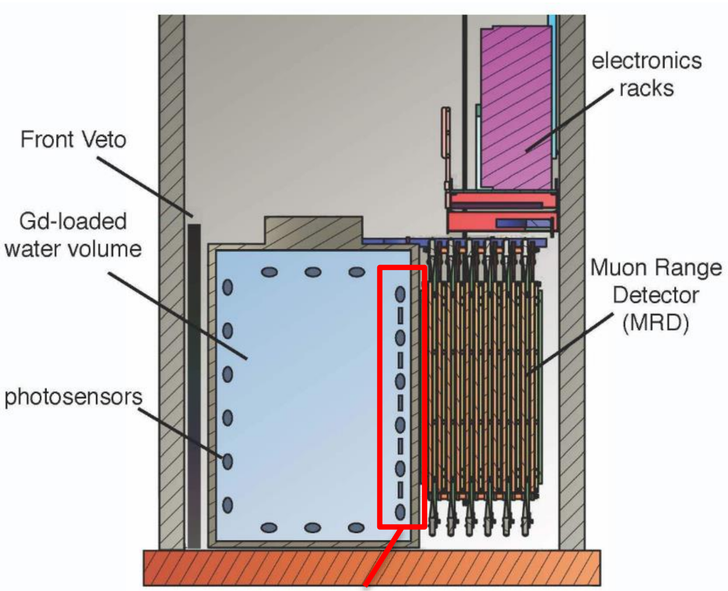
- It is important to have well known WbLS properties to actually achieve a separation of the two effects

- Since the setup will allow the WbLS test cell to be mounted at different heights data about the optimal height to get an optimal ratio between scintillation and Cherenkov photons is necessary to proceed

Status of test setups soon available in Tübingen

- Therefore a Monte-Carlo simulation is done to determine the setups exact properties
- It will simulate both photon producing events and generate a hit pattern seen by the SiPMs as well as timing distributions to determine if a separation is possible
- In a different mode the simulation will produce a file to read into the above mentioned Geant4 simulation to get an even more precise data set which includes the processes in the ALG as well

Opportunities with the ANNIE experiment



The rectangles represent the positions for LAPPDs

arXiv:1707.08222: ANNIE detector setup

- The Accelerator Neutrino Neutron Interaction Experiment (ANNIE) is a neutrino beam experiment at the BNB neutrino beam at Fermilab. Its goal is to measure the final-state neutron multiplicity of neutrino-nucleus interactions to improve the understanding of backgrounds in water-based detectors
- It is currently in Phase II, its physics run, and it will deploy 5 LAPPDs to increase vertex reconstruction
- Currently tests with LAPPDs and its own electronic readout system are in progress
- This is done parallel on a test stand in the UK and at FermiLab and will soon be joined by Tübingen with an independent characterisation of an LAPPD

Opportunities with the ANNIE experiment

- LAPPDs will play a big role in the ANNIE experiment but there will a good opportunity to test R&D technologies at the end of the physics run since a small vessel containing WbLS will be put into the tank

- The slots in which the LAPPDs will be mounted can be removed from the tank and one LAPPD can be replaced by for example a SiALG array

- An advantage of using ANNIE as a large scale experiment to deploy to is that Tübingen has a significant contribution in regards to the DAQ software used for the LAPPDs and thus an integration of a SiALG array would go hand in hand

Summary and Outlook

- The idea of fast photodetectors based on SiPM and scintillators was investigated in Tübingen and is being improved upon by additional simulations
- With the help of Master and Bachelor students a custom electronic system has been developed to control, supply and readout a large SiPM array
- With the help of the JGU Mainz a lab to produce custom scintillators for our needs is available and it will work on optimizing the production process
- In the next steps we will test the SiALG array and an LAPPD in a dedicated dark box as well as set up a new test cell for additional tests
- With the improved simulations and new electronics system available the next step is the construction of a full SiALG array and its potential deployment in ANNIE

Thank You.

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