Analog optical Signal Transmission for the VD-PDS

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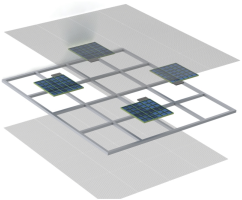
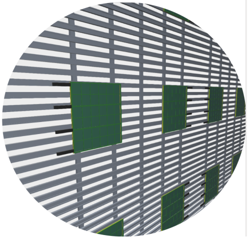
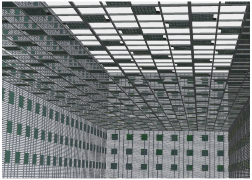
Introduction

- Within the Vertical Drift concept, PCB anode raises the need of a different placement for the photo-detection system
- Placing the PDS on the cathode will require both power and signal transmission with non-conductive materials
  - Power-over-Fiber
  - Optical Signal transmission, digital or analog → option analyzed in this talk
- The investigation of the analog optical transmitter option is motivated by:
  - similar pre-existing projects
  - low power consumption
- The feasibility of signal-over-fiber readout is key to extend the reach of the PDS system







Previous/Parallel investigations

- Readout for the presampler layer of the ATLAS LAr calorimeter
  $\rightarrow$ enable higher granularity thanks to use of fiber ribbons
  $\rightarrow$ found encouraging results with VCSEL[1] diodes
- Readout for LAr-TPCs (SMU)
- Analog optical transmitter working within HV surface @200 MHz
  $\rightarrow$ developed by an electrical engineering lab in France
- **DarkSide experiment has developed an analog optical transmitter** at a single channel level
  $\rightarrow$ motivated radio-purity requirements of the experiment
  $\rightarrow$ we have opened a collaboration on analog transmission R&D

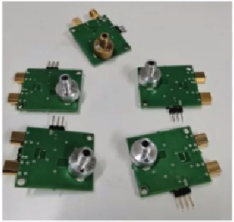
[1] Vertical Cavity Surface Emitting Laser

DarkSide readout system

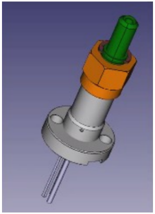
The DarkSide collaboration has developed analog optical signal readout for:

- the signal readout from their SiPMs
- readout of the veto system

- custom driver with cryogenic components
- LED @1310 nm with special lens
- custom SMA connector



Single channel prototypes



- Good performance in terms of linearity and stability, but
- does not meet DS radio-purity requirements yet
- Investigations on-going:
  - LED biasing and non-linear effects
  - choice of radio-pure materials (connector, epoxy, fibers)
  - improvement to minimize instabilities in LED-fiber coupling

Pictures taken from L. Rignanese's presentation

Requirement comparison DS vs DUNE

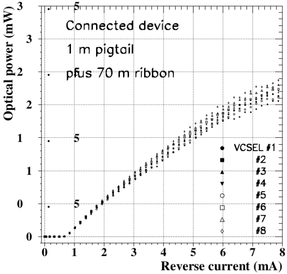
	DS	DUNE
Low power consumption		
Bandwidth $\sim$ 50 MHz		
Single Photo-Electron	SNR$>$ 10	SNR$>$ 4
Rise-Time (10-90)%	$<$ 8ns	$\sim$ 100 ns
Dynamic Range	200PE (0-2V)	2000PE **

- ** 2000PE corresponds to the largest possible signal of a beam ν event
  $\rightarrow$ could be cut or covered with a non-linear transmitter
- DarkSide PDS electronics requirements are more stringent
- and their choice further limited by the radio purity requirements

$\rightarrow$ The DarkSide solution could be immediately implemented by DUNE.
$\rightarrow$ DUNE can explore a wider range of options for optimization
(since radio-purity is not an issue).

Optical Transmitter for DUNE - light source

- Different types of lasers have been studied at cryogenic temperatures
- Available literature shows lasers can work well in cold
- Reported behaviour is varied, and does not seem to depend on the type of laser
  $\rightarrow$ searching for a candidate among different types of laser diodes and LEDs

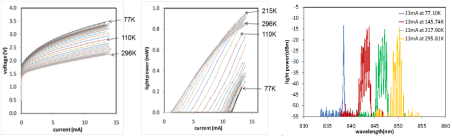


Two main concerns:

- biasing/power consumption
- coupled optical power at receiver end
  $\rightarrow$ coupling stability acknowledged as a key concern

Possible behaviours in cold:

- changes in I-V curves
- change of current threshold
- change in optical power efficiency
- shift in wavelength



Optical Transmitter for DUNE - light source

First tests done on a 850 nm VCSEL look promising, chosen based on colleagues advice and market availability:

Optical tests at warm:

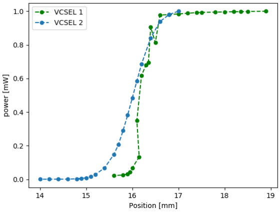
→ beam characterization

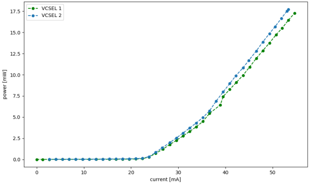
→ factory consistency

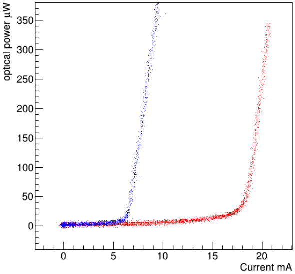
Tests in cold:

→ changes in properties

→ coupling possibilities







Coupled optical power output

→ Threshold current ∼7 mA

→ Reach 500 μW output at 10 mA

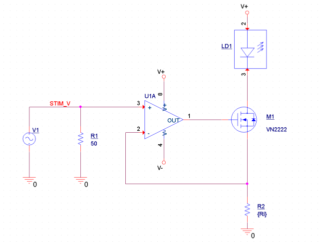
(with *modest* connection)

Laser driver

Starting design of a current driver for the laser diode:

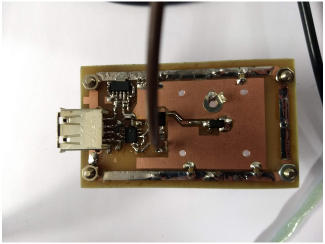
- selection of components based on
  - speed requirements ($\sim$100 MHz target)
  - probability to work in LAr
  - power supply
- low noise to achieve S/N $>$ 4 for SPE
- good linearity over the expected range of ARAPUCA SiPMs signal

Initial design of basic current source



Simulations done to optimize components combination

First set of test boards for high frequency and cryo tests



Laser driver status

- Gathering information on the type of components that are suitable for cryogenic applications
  - DUNE data base
  - DarkSide
  - experts in other fields (i.e. satellite applications)
- Procuring selected components
- Fabrication of test circuits and test boards
- Tests in LN_2: some components already tested and appear to work (LDO, MOSFET)
- Some challenges:
  - many parts previously used are discontinued
  - reduced choice of fast, discreet components
  - information on technology used in the fabrication of each component is sometimes hard to find

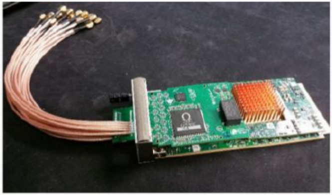
Receiver - outside cryostat

- First tests carried out with off-the-shelf receiver & oscilloscope:
  - PIN Photodiode with max sensitivity @ $\sim$ 800 nm
  - 200 MHz - 20 mV noise

- To be followed up in-house SFP-like receiver:
  - low dark current PIN Photodiode
  - 450 MHz ultra low-noise TZ preamplifier

Digitization: either DAPHNE or readout developed for DualPhase

- μTCA standard
- commercial motherboard with a StratixIV FPGA
- Custom daughter board:
  - 14 bit ADC chosen (AD LTC2155-14)



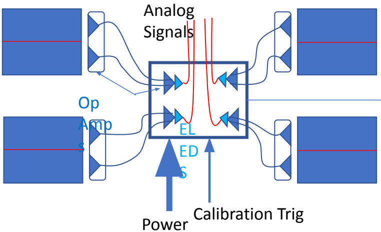
Previous development for Dual Phase

Conclusions

- Investigation of an analog optical transmission system is motivated by:
  - pre-existing similar systems
  - simplicity of design
    $\rightarrow$ adequate for the very short timescale
  - low power needs are well adapted to the PoF system
- Investigation of pre-existing attempts has proven very useful,
- as well as collaboration with colleagues from other experiments (DarkSide)
- R&D efforts have been ramping up during the past 2 months, with the main target being:
  - a preliminary choice of components that work in LN_2 (LAr)
  - design of a laser diode driver
  - an estimation of the optical power output expected at the receiver end
  - an estimation of the power requirements

Back Up

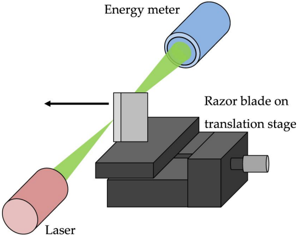
Electronics Box



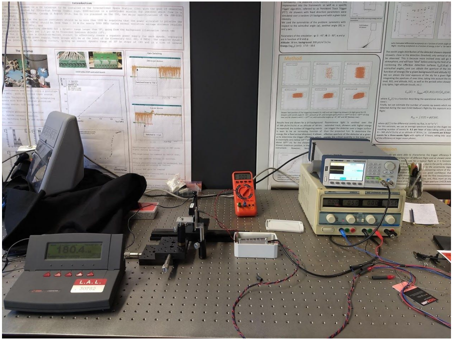
- Each Arapuca transmits two analog signals to the electronics box
- A summing amp combines both analog signals
- An analog transmitter, Tx (and conditioning electronics) transmits
- A calibration circuit (receives an ext. trig and plays a ramp into Tx)

This configuration will require 320 ELEDS/Cables Verses 640
Power for the op amps near the Arapuca will come from SiPM power
Power for Op amps on the electronic box will come from power voltage fanout

Optical tests at room temperature



Ophir Photonics PD300-UV:
1x1cm^2 10pW-300mW sensor



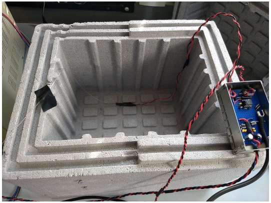
- Thorlabs 10mW VCSEL 850 nm - LP808010
- in-house current driver

Cold tests

- A first VCSEL 850 nm laser shows nice behaviour in cold: lower threshold and higher optical output. Will test second one tomorrow.
- A second 850 nm VCSEL that comes already with an ST connector shows no output in cold

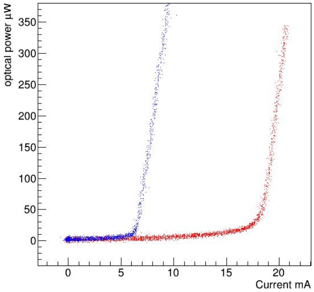
OPV314YAT: 850 nm, 1.4mW VCSEL with ST connector

No output in cold (or much higher threshold current)



Optical power measured by Femto Photoreceiver vs current:

- lower threshold
- larger power output (but diode saturates)



LED tests

- First toy setup to rehearse tests in cold
- LED (visible light) showed expected behaviour: larger light yield in cold
- Hand-made coupling was more stable than expected
  $\rightarrow$ motivation to test IR epoxy-case LEDs