VD Photon Detector Readout

- Different options described in the VD proposal for PD readout
  - https://edms.cern.ch/document/2429382/1
  - Optical transmission of analog signals, as DarkSide is developing
  - Optical transmission of digital signals, so called full cold electronics option

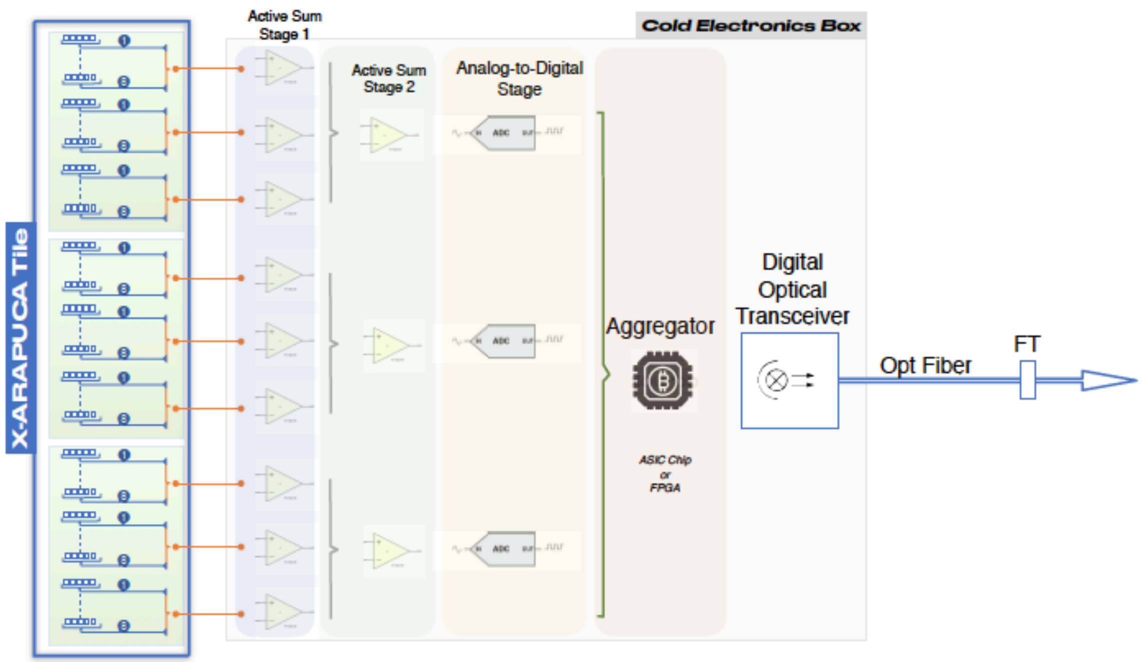
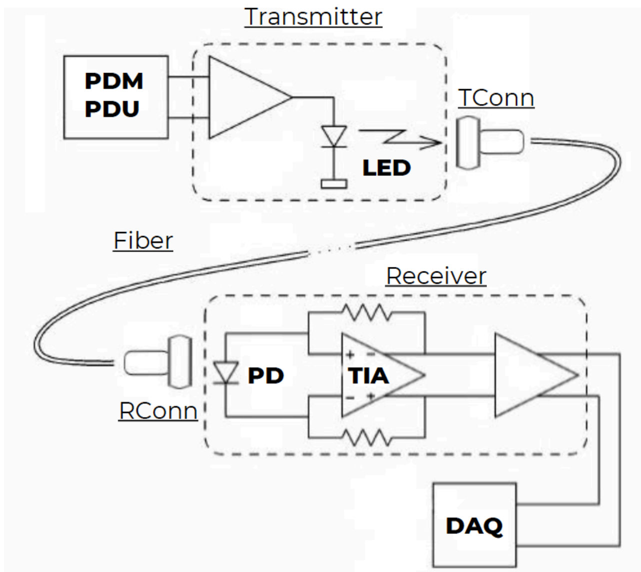


FIG. 44. Full Cold Electronics option.

Optical Transmission of Analog Signals



Transmitter

Tconn

Fiber

Rcon

Receiver

Requirements:

- rt(10-90) < 8 ns
- BW>50 MHz
- SNR > 10 (considering 1PE=20mV)
- Dynamic Range: 100PE=2.0V output

DarkSide Opto-Link
rignanes@bo.infn.it

- Meeting with DarkSide team on Feb. 10 about the latest progress of the development organized by Flavio and Cristiano
- Non-trivial R&D effort, linearity of LED output to be demonstrated

Optical Transmission of Digital Signals

- Full cold electronics option has several key R&D topics
  - Power distribution: PoF, being investigated by Fermilab/CERN
  - Analog front-end: HD PD amplifier or ASIC?
  - Digitization: COTS ADC or ASIC?
  - Data aggregation: FPGA or ASIC?
  - Optical transmitter: COTS or CERN VTRx+, being investigated by Fermilab
- ADC is a key device to enable the optical transmission of digital signals
  - SBND has successfully identified the COTS ADC solution, ADI AD7274, after ~1 year of studies with concentrated effort
  - Feb 2017: first SBND ADC committee meeting
  - Jul 2017: COTS ADC lifetime study plan
  - Mar 2018: conclusion of COTS ADC lifetime study

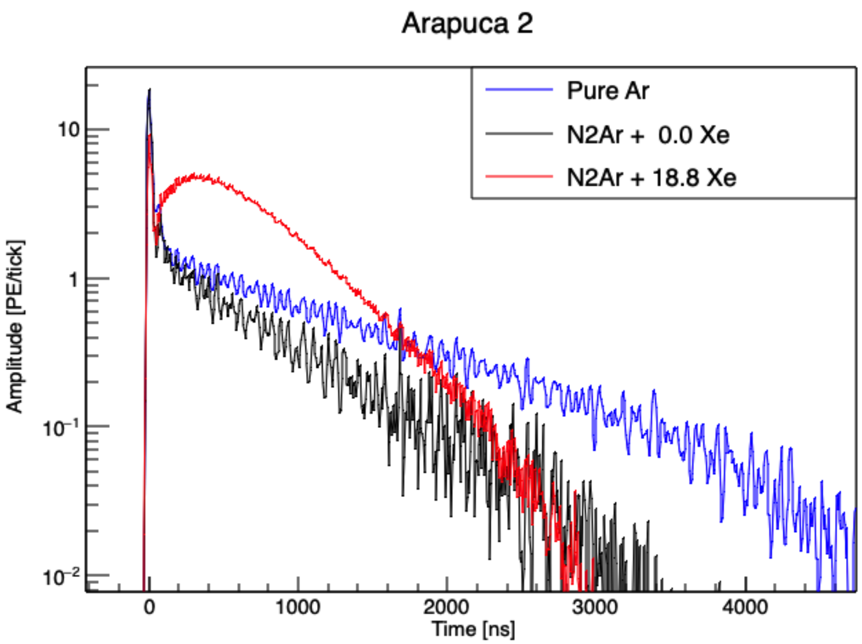
PD Requirement

TABLE V. Requirements and Physics purposes for the VD Photon Detector System - $\sim 4\pi$-configuration option

Detector Requirement	Value	Physics Purpose
Trigger efficiency for interactions with energy deposit $E_{dep} \geq 5$ MeV in 100% of detector fiducial volume	$\geq 99\%$	- SN burst trigger up to the Large Magellanic Cloud (50 kpc) yielding 10 interactions in 10 kt LAr - Low-energy background rejection
Spatial resolution for interactions with energy deposit $E_{dep} \geq 10$ MeV	≤ 1 m	- Background rejection for SN, solar, nucleon decay
Energy resolution for interactions with energy deposit $E_{dep} \geq 5$ MeV	$\leq 8\%$	- Identification of SN spectrum features from different SN dynamical models
Time resolution	≤ 200 ns	- SN burst triggering - Identification of SN time features due to standing accretion shock instabilities - Identification of neutrino "trapping notch" (SN dip in luminosity)

- How can we make the connection of PD requirements based on the physics studies with readout parameters?
  - Timing resolution, signal dynamic range, S/N ratio etc.

Timing Resolution

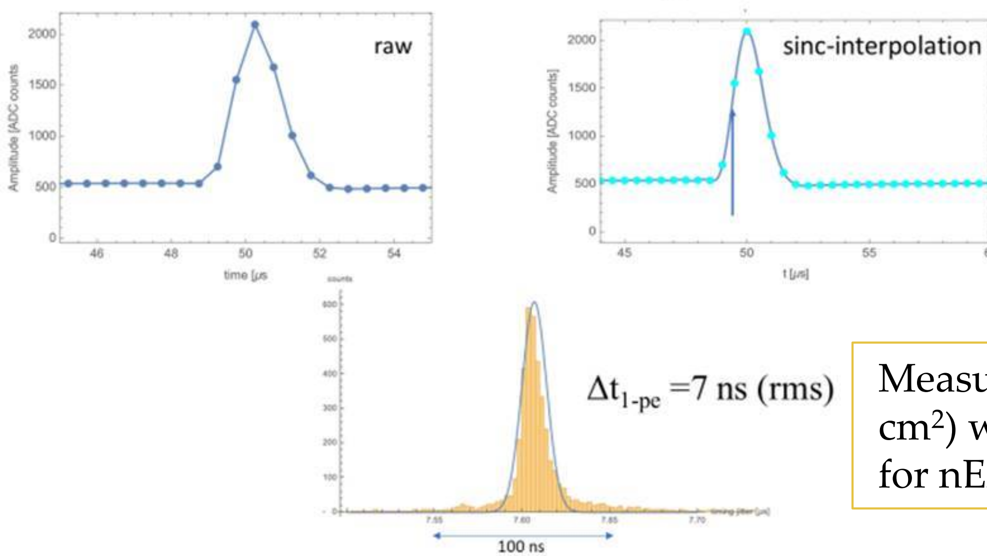


- Timing resolution is a critical parameter to define the readout chain design
  - We need to understand the requirement of < 200 ns timing resolution, and implication to the readout design
  - Can spatial resolution be much better than 1 m with improved timing resolution?
- Flavio's talk in Jan DUNE collaboration meeting
  - https://indico.fnal.gov/event/46502/contributions/205927/attachments/139204/174615/VD-PDS-4pi-RandD-Jan25-2021-DUNECollMtg-v2.pdf
  - Time feature of photons detected by ARAPUCA in ProtoDUNE with Xenon doping (N2LAr + 18.8Xe) is ~20 ns for the fast component, and most photons detected between 200 - 800 ns
  - What a typical signal waveform looks like, and what information is of interest?

- How can we quantify the timing resolution requirement in the VD proposal?
  - Scintillation light yield in LAr: spread in arrival times of photons from a track to X-ARAPUCA, with scattering and reflections included
  - Contribution from X-ARAPUCA: area of WLS plate, area of SiPMs per WLS plate, intrinsic photon spread etc.
  - Contribution from the readout electronics: electronics noise can be made negligible, timing resolution can be one to two orders of magnitude better than the sampling interval

Timing Resolution → ADC Sampling Rate

Detail waveform reconstruction and timing resolution

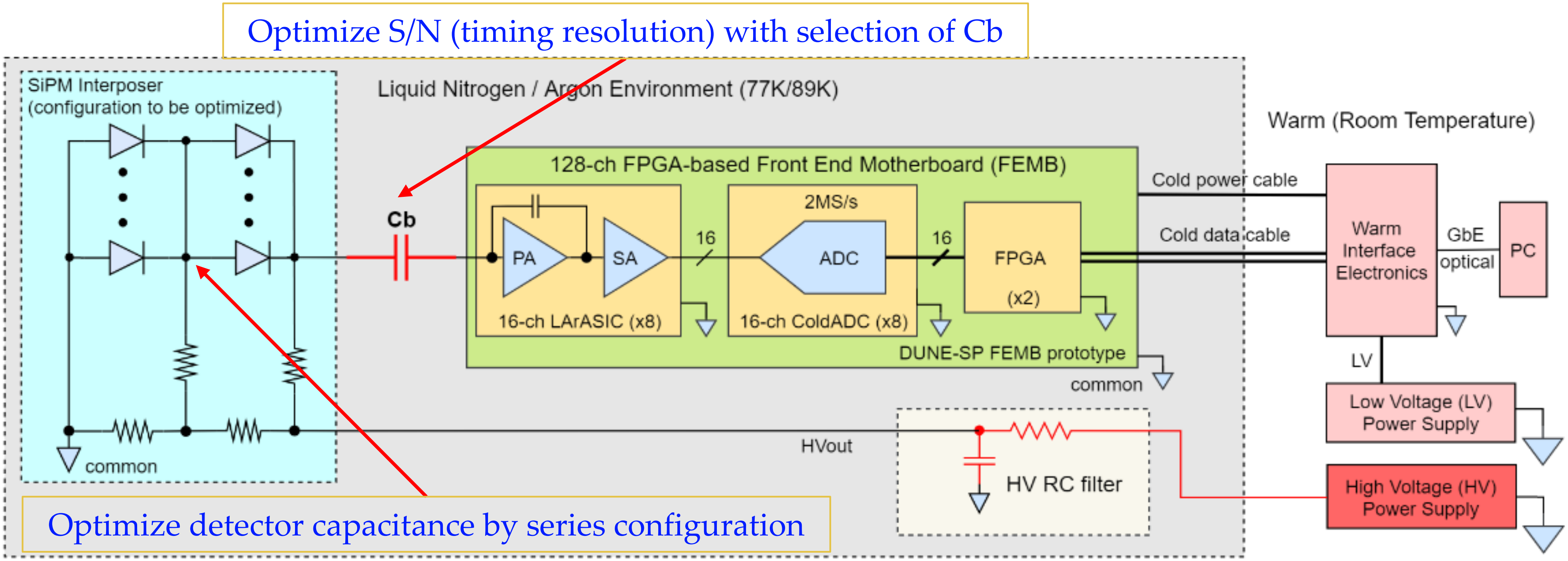


Measurement of SiPM (16 x 0.6 x 0.6 cm^2) with SBND readout electronics for nEXO at BNL

Using sinc-interpolation + 'digital' constant fraction discriminator, leads to a better timing analysis

- How is the timing resolution related to the sampling interval/sampling frequency?
  - Sampling and reconstruction of the signal: sampling with Nyquist theorem and anti-aliasing filter, followed by reconstruction of the signal. Very few samples (~6) are needed to reconstruct the signal in this case (semi-gaussian shaping with t_p ~ 1 us). After reconstruction, one cannot tell from the reconstructed waveform what was the sampling frequency
  - Given a signal waveform (SiPMs single photon response is constant), the timing problem reduces to finding the centroid of the semi-gaussian response. It can be shown that the timing resolution is, as expected, inversely proportional to S/N, i.e., sigma ~ $(3/2)t_p/(S/N)$
- Measurement of nEXO SiPM with SBND readout electronics shows ~ 7 ns timing resolution
  - Timing resolution of 100 ns rms would require S/N ~ 15, which can be achieved for a single photoelectron
  - If the expected signals are more than a single photon electron that becomes easy to achieve

What does it Imply?



- With clear understanding of the PD requirements, one can devise the readout chain with better focus
  - COTS ADC identified for SBND, plus the SBND readout chain could be an option for PD readout demonstration
  - New set of ASICs may help with the overall power constraints
    - TPC charge readout chain (FE ASIC + ColdADC + COLDATA) could be a basis for the new development of PD readout
    - Need further optimization on ADC power consumption and possibly digital signal processing to ease readout link requirement
  - Effort could be put on optical transmission of digital signals, depends on the data volume required for various measurements