Vertical Drift PD system: R&D Plan

PD Consortium Session

exploiting abundant LAr scintillation light *(complementary to ionization charge)* is the most “natural” way to enhance/extend DUNE detection sensitivity for UG low-energy rare events.

- **this requires to extend PD Optical Coverage close to 4π**

- **to embed a 4π PD into LArTPC layout is a big technological challenge**

the R&D plan toward a ~ 4π PD system
is taking shape
now, here - inside the DUNE PD Consortium

Where is the challenge ?

Operating PD on HV surface requires Power (IN) and Signal (OUT) for Photo-sensors and r/o Electronics transmitted via non-conductive cables

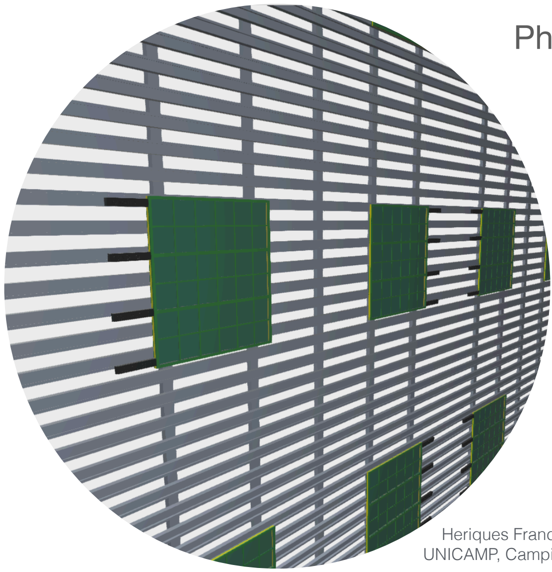
PoF and Optical Transceiver Technology provide solutions for transmission via optical fibers

but

none of these (commercially available) technologies is rated to operate in Cold (at LAr Temperature)

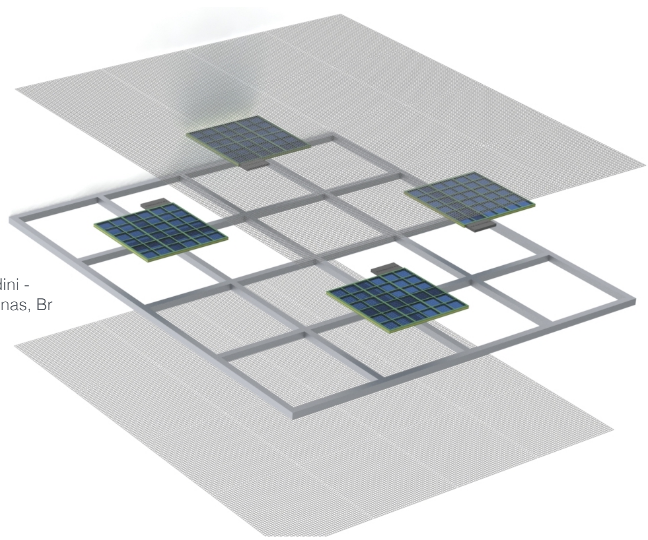
A highly specialized R&D is needed to validate existing technology in Cold or develop Cold custom technology for this application

~ 4π PD System design for the VD LAr Volume



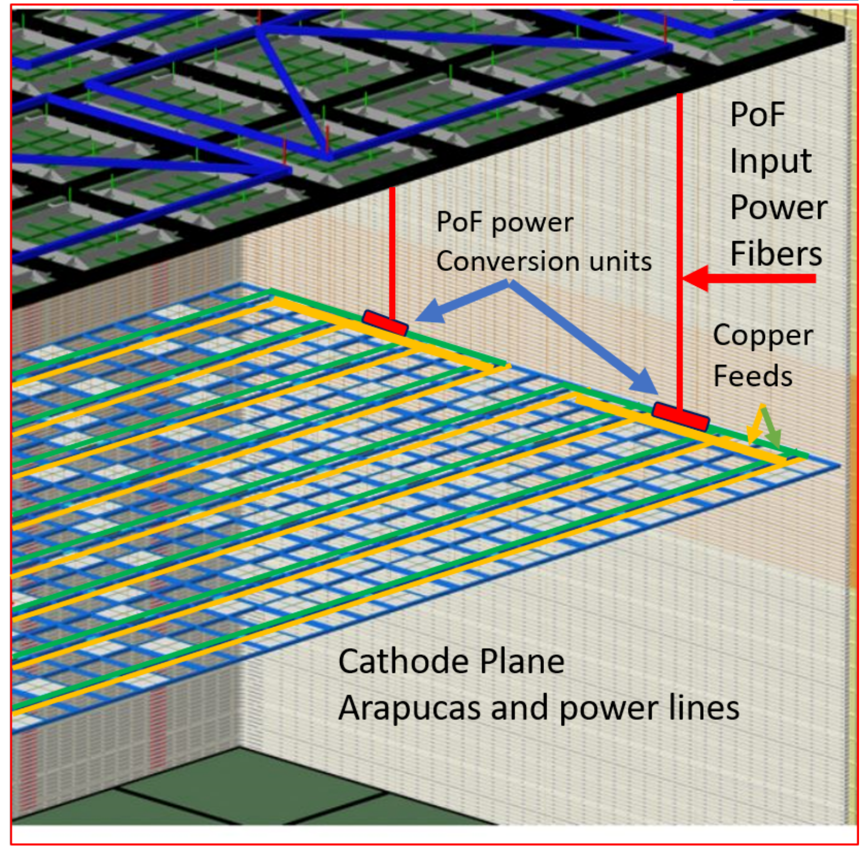
Photon Detectors hanging on Field Cage Walls

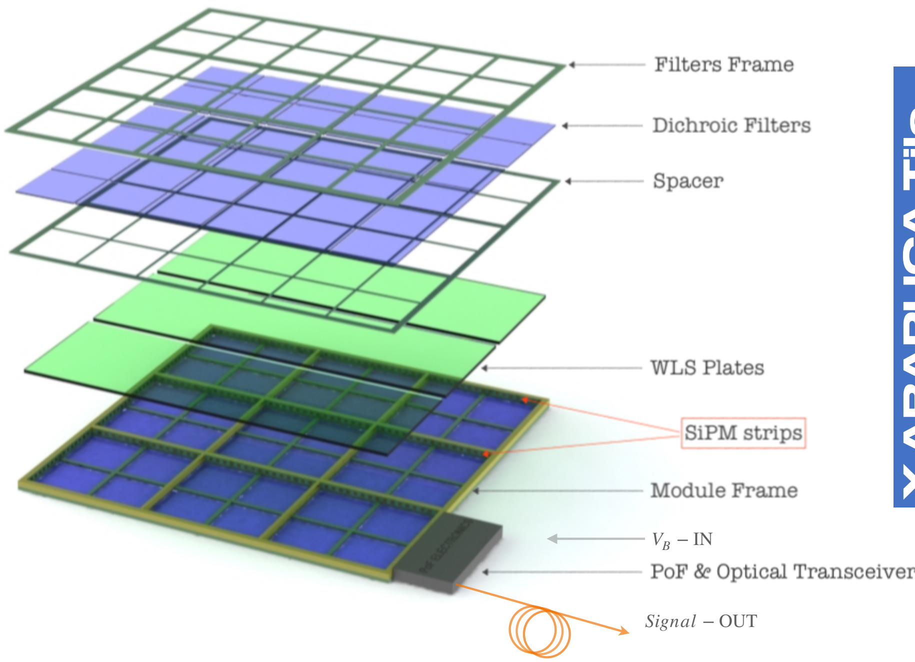
Heriques Frandini - UNICAMP, Campinas, Br



Photon Detector into the Cathode frame under conductor mesh (exploded view)

Power Transmission





D. Totani, F.Terranova, H. Chen, M. Verzocchi, D. Christian, G. Cancelo, B. Yu, W. Pellico, FLC

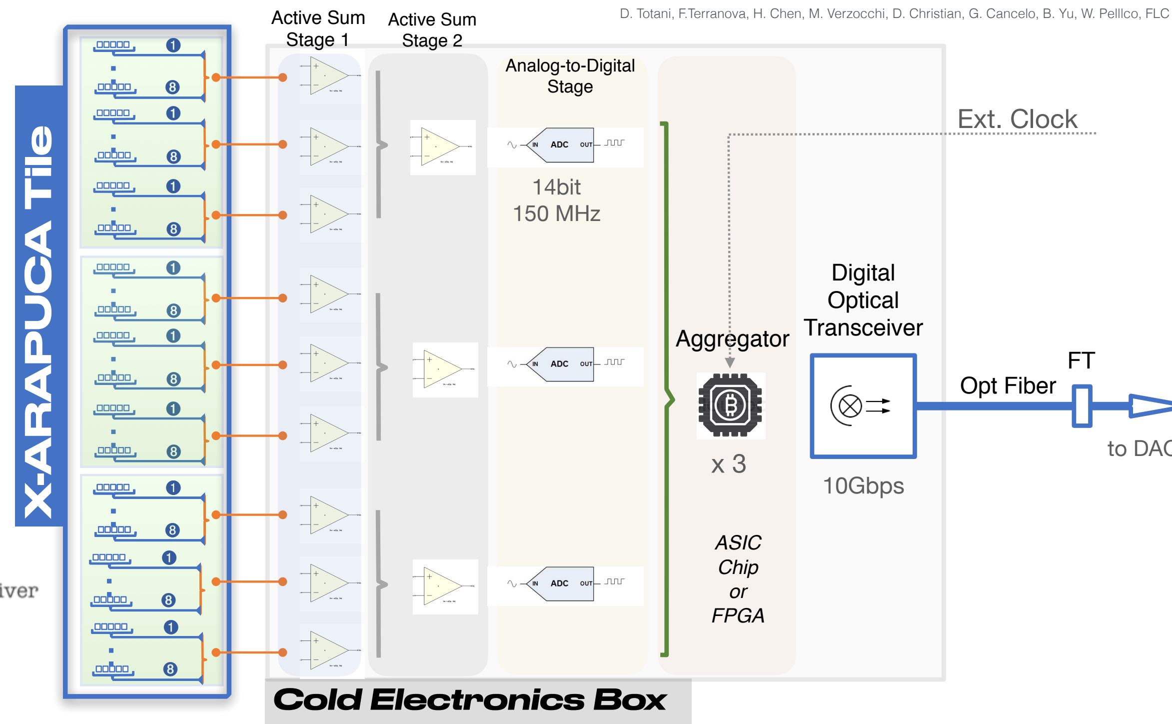
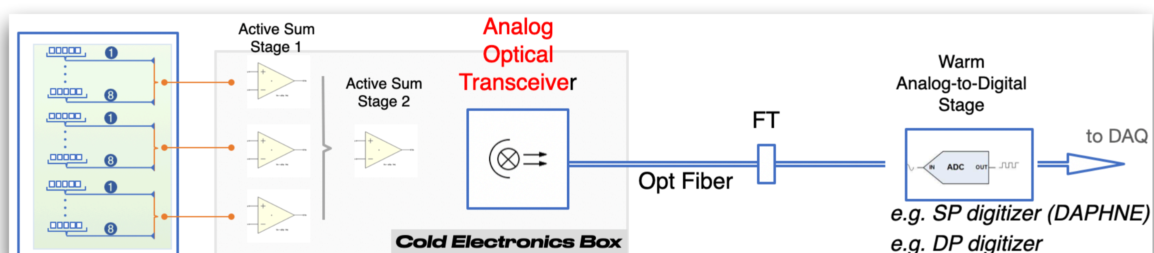


TABLE V. PD basic unit: X-ARAPUCA Tile

	Quantity	Dimensions
Area	1	630×630 mm^2 = 0.4 m^2
Thickness	1	22 mm
Weight	1	∼ 4.5 kg
Optical Area	2 (two-sided)	600×600 mm^2 = 0.36 m^2
Sectors ("MegaCell")	3	600×200 mm^2 = 0.12 m^2
Dichroic Filters	36×2	100×100 mm^2
WLS plates	3	600×200 mm^2 = 0.12 m^2
PhotoSensors (SiPM)	360	6×6 mm^2
Read-out Channels	3	
SiPMs per channel	120	

OR *(alternative)*
depending on available solution for Optical Transceiver



VD PD R&D

Activity	FY21 (Cold Box prototype at CERN)	FY22 (Optimization, more Cold Box at CERN and VD *Module-0* prep)
ARAPUCA Detector	Prototype Fabrication (2 units - standard Ar + Xe): 1 Two-sided (Cathode), 1 One-sided (FC). Component Production at UNICAMP, Mi Bicocca + … many grp.s in Eu, UK and US interested • Dichroic Glass • WLS bar • SiPM • Tile mechanics	Prototype Fabrication (2 units): optimized for Xe light • Dichroic Quartz Glass • WLS bar (cutoff) • SiPM (PDE)
PoF power transmission	Prototype Fabrication (2 units - 60 W) - pre-test at FNAL (PAB) and CERN (50l) • PPM (Photonic Power Module) • Fiber & FT • Cold Receiver • Regulator	Optimization for Power distribution to Cathode PDS • PD Calibration • Fiber & FT for NP02
Cold Electronics	Design and Prototype development - pre-test at FNAL, BNL, UCSB, Mi Bicocca + … • SiPM Passive Ganging Board • Cold Active Ganging & Shaping Stage (analog Signal) • Cold ADC Stage (digital signal) • Clock distribution • Cold Aggregator Stage (FPGA, ASIC)	CE Board Optimization • Cold ADC + Aggregator in one single stage
Electro-Opto Signal transmission	Prototype development - pre-test at FNAL, CERN, Mi Bicocca, APC Paris + … • Cold (Analog or Digital) Transmitter • RF/WiFi Transmitter • Fiber & FT	Layout optimization and DAQ interface - Bristol • Fiber & FT • Fiber Warm Interface to DAQ
PDS Performance(*)	MC simulation - ABC, SC, TFPR (Br), FNAL, Edinburg, UCSB, Syracuse, CIEMAT, Mi + … • Implement DUNE FD detailed • PDS detector simulation in standard LArG4/ LArSoft framework. • Standalone MC simulation of Arapuca Efficiency. • Xe light emission and propagation simulation.	MC simulation - optimization • CE signal processing in standard LArG4/ LArSoft framework. • Xe light emission and propagation simulation.

Total requested from DoE (M&S, Engineering/Tech FTE for US/FNAL+BNL)	**$56k, 2.85 FTE Technical + 0.25 FTE Managerial**	**$33k, 1.65 FTE Technical**

DOE support for vertical drift development near-term is being incorporated into the DOE LBNF/DUNE project and is proceeding immediately

Total needed from DUNE / PD Cons (M&S, Engineering/Tech FTE + postDoc)	**$12k, 1.9 FTE Technical + >> 1 FTE PD**	**$20k, 1 FTE Technical, > 1 FTE PD**

(*) PDS Performance Simulation effort not included in estimate of FTE needed

VD PD R&D

- The R&D design team is tasked to design the delivery of power over fiber (PoF) to power the SiPMs in the x-ARAPUCAs. This includes bench testing at FNAL and use in LArTPCs at the 50L at CERN and in the full-scale cold box test at EHN1.
  - FNAL/AD (EE Dept) + CERN/50 lt (&Mi-Statale) + UCSB + FNAL/PAB

- The R&D team is tasked to demonstrate designs for readout of the SiPM signals over fiber:
  - ★ Signal Transmission (on Fiber)
    - ★ Digital Data Links: FNAL/PPD & SCD (EE Dept) + SMU + FNAL/AD
    - ★ Analog Opt. Transceiver: APC Paris, Mi-Bicocca (in connection with DS Exp. R&D grp.)
    - ★ Possible development of coordinated effort with specialized Industries
  - ❖ development of Cold Electronics (SiPM passive ganging, front-end/active ganging, digital conversion, data aggregator
    - ❖ FNAL/SCD (EE Dept) + Mi-Bicocca + FNAL/ND + BNL + UCSB + APC Paris
    - ❖ Interest shown from groups in Eu (S, I, Cz) and UK

- The R&D team is tasked to deliver TWO x-ARAPUCA modules for readout in the NP02 cold box test by the end of 2021 (including SiPMs and PD Calibration)
  - UNICAMP (+ABC, SC, TFPR) Br + CSU + Mi-Bicocca + FNAL/ND + UCSB + ANL
  - Interest shown from groups in Eu (S, I, Cz) and UK

- The R&D team is tasked to optimize the existing x-ARAPUCA designs for Xe light read-out for use in vertical drift (VD Module-0) and demonstrate with prototypes in the 50L test stand at CERN and in the NP02 cold box test in 2022.
  - t.b.d. (UNICAMP, Mi-Bicocca, ..)

R&D kick-off mtg in early Feb

Welcome to any Group or Individuals potentially interested in this effort.

Please subscribe email-list and join the kick-off mtg

(8) the PDS system operating on the cathode or FC looks challenging. What is the plan for testing in a realistic environment? Will the heat load of the optical powering give rise to bubbles? (Bill Pellico)

The PDS system operating on the cathode and FC consists of three parts:

1) The ARAPUCA, which is using a design that very similar to previous operating Arapuca's

2) Delivering power via power over fiber (PoF) and distribution to cathode electronics

3) PD data collection and transmission

- The powering of the 117,000 SiPMs on the cathode has been estimated to require between 6 to 30 Watts. Although this is not significant power, the power system, including distribution and connections, require significant viability and reliability testing. The initial concept testing was completed successfully at FNAL and now moved to prototype unit testing at CERN. The prototype system will test the delivery of sufficient power for one quarter of the Arapucas on the cathode. The first part of this test, using a small dewar filled with liquid nitrogen to power a dummy load, is underway. This will provide the optimum load match and prove thermal stability.
- After reaching sufficient power levels with acceptable heat loss (minimal to no bubbles), step two of the testing will be to put the PoF prototype with an upgraded SiPM circuit board onto the cathode at voltage in the CERN argon cryo test stand. During step two, SiPM calibration and performance will be done under PoF conditions.

- Our present testing is showing very good results but more needs to be done on the prototype housing. The design is modular with a series of small PoF units summed to reach desired power. Figure1 below show the result of scanning a load using single PoF cell (sub-unit) in an argon bath. We expect each PoF power unit to use 6 to 8 PoF cells. Figure 2 shows PoF voltage at SiPM in liquid argon (with no regulation unit).

- After meeting the power needs of the SiPMs, a similar system will be built to supply power to the data processing electronics. The collection and transmission electronics is still in the planning stage. Once, chip selection is firmed up, the build up the PoF will done. The power is expected to be on the same order as the SiPMs, but will depend heavily upon data rates. Planned use of a dual 14 bit ADC at approximately 125 MHz is being planned for each FC Arapuca unit. Transmission will be via a digital-fiber link. However, the cold electronics are still in early stages and firm power numbers are not yet generated.

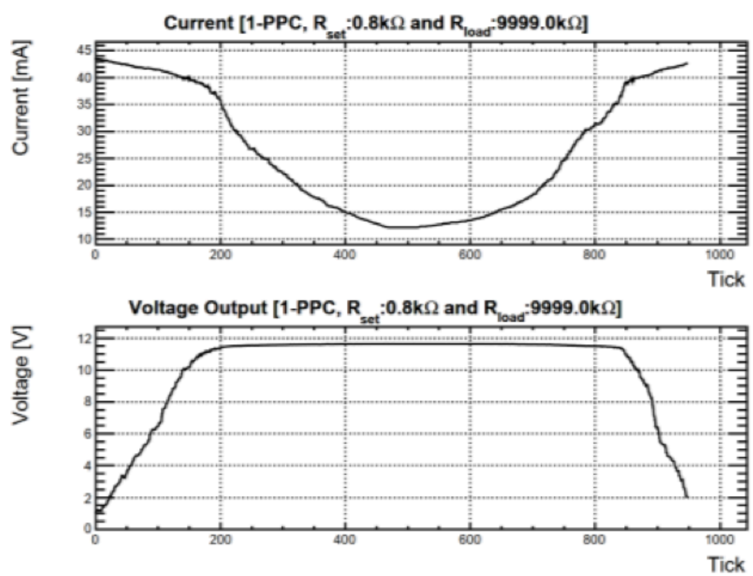
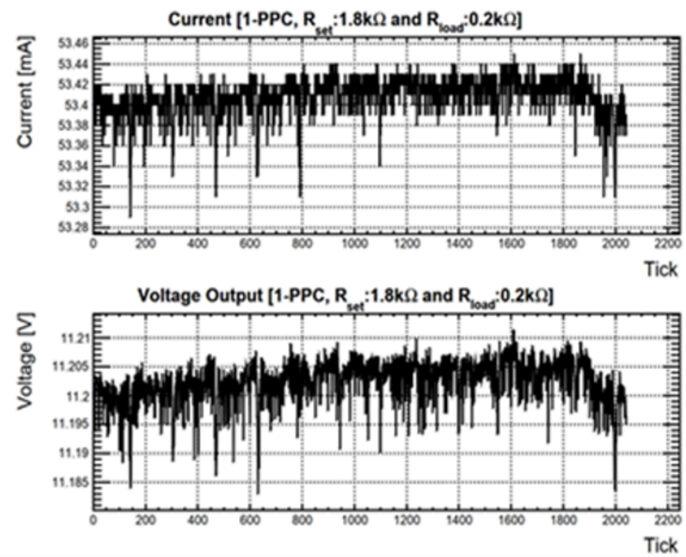


Figure 1 Power scan of PoF sub-unit

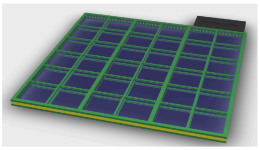


From tests at CERN
U. Kose, D. Totani

Figure 2 Voltage and current of PoF sub-unit

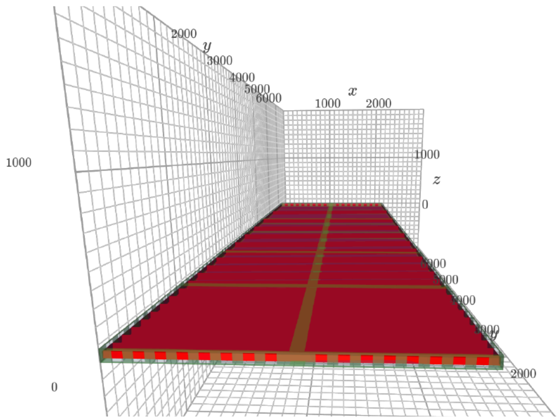
PDS vDrift: recent software developments

Arapuca-Açu (by Heriques Frandini)

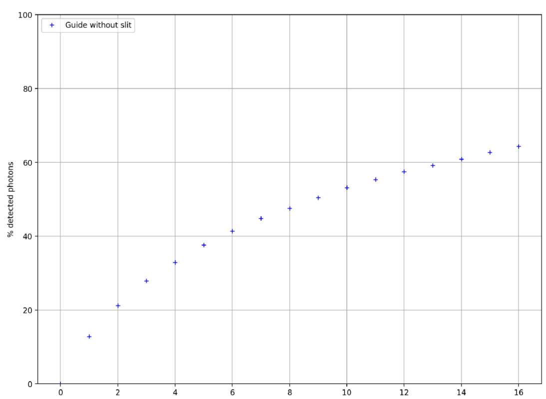


Arapuca-Açu with a 4mm thick light guide.

Standalone simulation for X-ARAPUCA efficiency



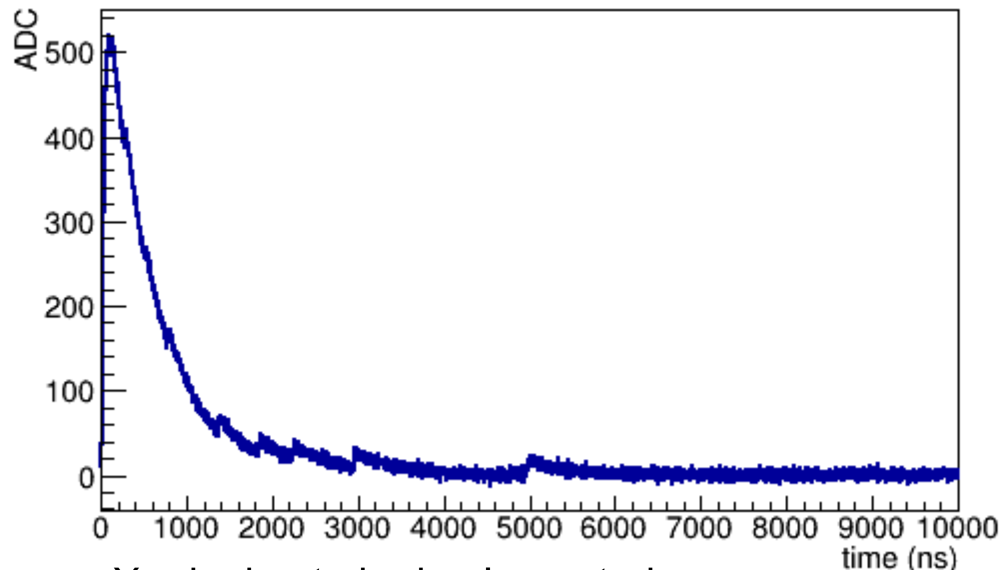
% of detected photons vs number of SiPM per side of dichroic filter



M. Adames, F.Ganacim, A. Steklain

Standalone photon time profile simulation:

Accounts for LAr scintillation + light propagation + wavelength shifting + SiPM readout effects

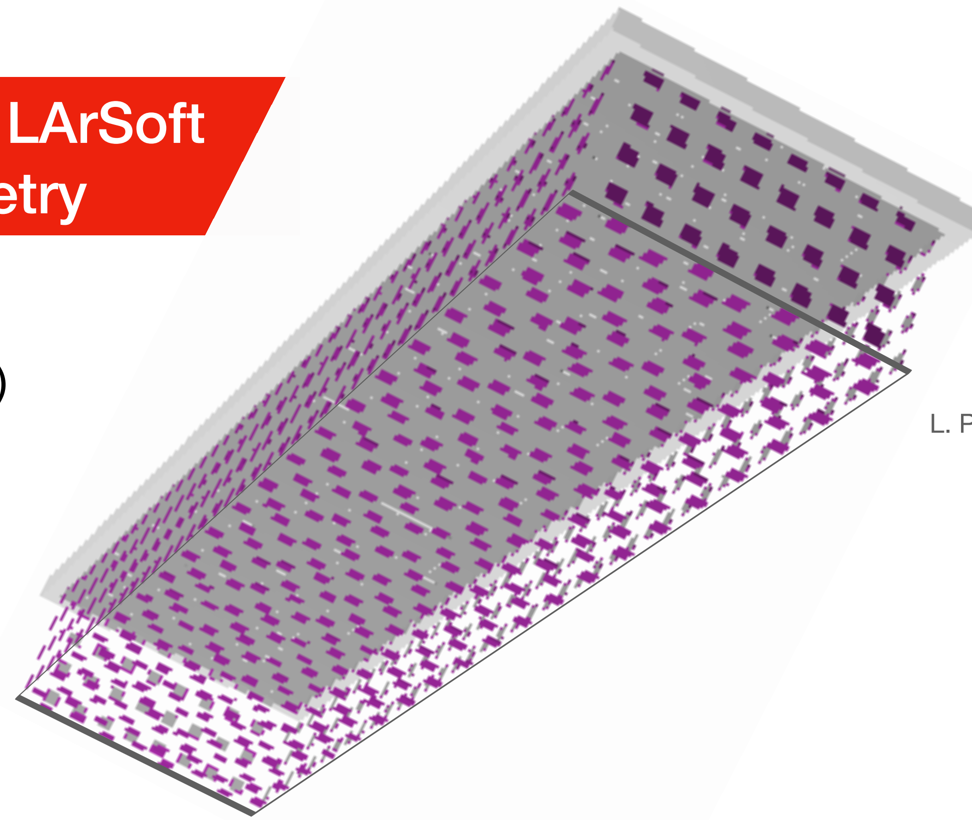


Xe doping to be implemented

F. Marinho

VD PDS: recent software developments

VD PDS in LArSoft geometry



L. Paulucci

“VD $\sim 4\pi$” configuration (upper Volume)

“SP mirror” configuration (cathode only coverage) also available

Simulation of mixed Ar and Xe light in LArSoft in progress/close, some additional technical work is needed and Xe time profile validated from experimental tests (protoDUNEs) results

A.Himmel & PD SW Grp.

Back Up

POF Technology for VD application

Two Parts

R&D activity

R&D ongoing at CERN and at FNAL

W. Pellico - FNAL

Warm

- **(1) Power to fiber**
  - Convert electrical power to light
    - Four Laser modules to generate 48 V
    - Each are **4 watt** laser systems
    - Individual adjustable output power
    - Interlocked – to protect laser/personnel

- Transmit via fiber

Cold

- Fiber optic Receivers
  - Four receivers tied in series ⇒ 48 volt for SiPM and power for LEDs for calibration
  - Typical conversion efficiency 22 %
  - 14 W dissipation (heat)

Cold

- SiPMs cold electronics module
  - Gang some number of SiPMs
  - Passive or/and Active (w/ preAmp&Shaping)
  - **(2) Signal to fiber**
    - Convert electrical to light
    - Eleds – analog light Transmitters

- Transmit via fiber

Warm

- SiPMs warm electronics module
  - Fiber to copper
  - Signal conditioning
  - Signal processing

TABLE VIII. Power estimates for PoF cathode SiPM system.

Approx. Power Capability W* **+ STATUS**	**# of PPC modules**	**Current mA**	**Est. Voltage V****	Approx Power
< 4 **Tested**	1	80	12	4 W
20 **Testing Underway**	5	400	62	20 W
4 sets each capable of 20 **Plan**	4 sets of 5	4 sets each 400	4 sets of 62	80 Watts

* The power delivered is not all converted to usable power. Efficiency is about 22 % in LAr.
** Each PPC module voltage can vary about 3 %.

TABLE IX. Power estimates for PoF field cage SiPM system.

Number of Pof System *	**Power per PoF Unit**	**Power per field cage row**	**Total power top or bottom****
22 Top and Bottom	24 watts per unit	24 watts	528 watts
Usable power	6 watts	6 watts	116 watts

* The total number of PoF systems will depend upon how many rows of the field cage will contain ARAPUCAs
** The total power can be increased by adding additional laser power receivers. Each receiver contributes 4 watts with 1 usable watt