

# ARAPUCA

A new light detector concept for LArTPC

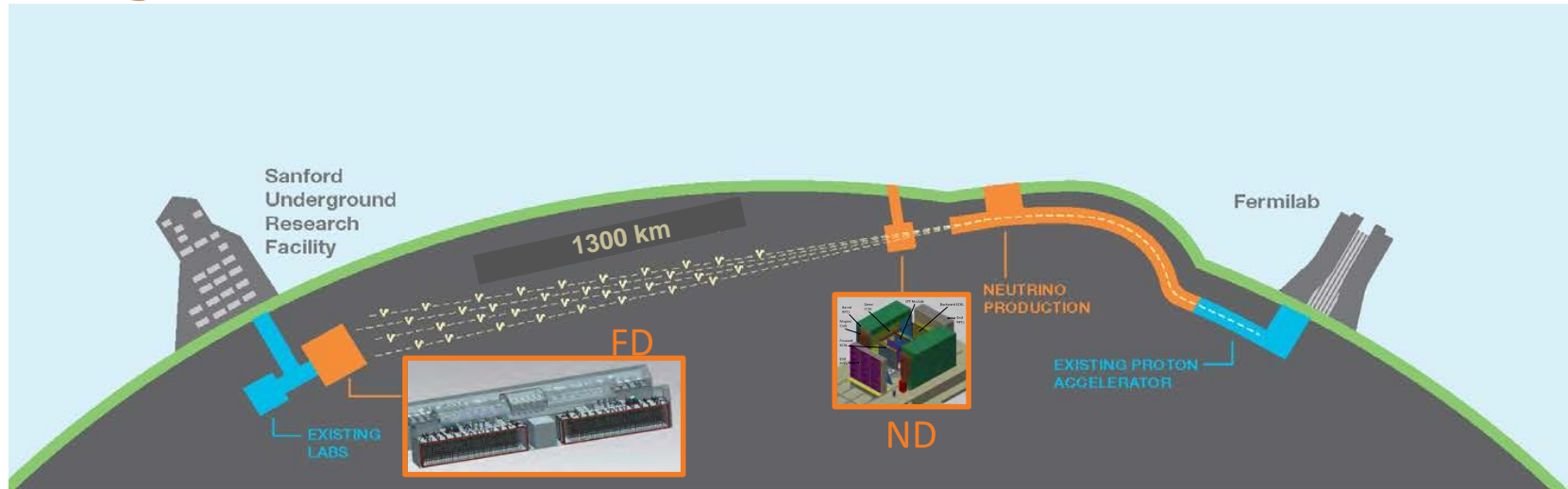
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Apresentado por Anderson Fauth



# DUNE EXPERIMENT



## Key DUNE features:

- High-intensity wide-band neutrino beam originating at FNAL
    - 1.2 MW proton beam upgradable to 2.4 MW
  - Highly capable near detector to measure the neutrino flux
  - A ~40 kt fiducial mass liquid argon far detector
    - Located 1300 km baseline at SURF's 4850 ft level (2,300 mwe)
    - Staged construction of four ~10 kt detector modules. First module installation starting in 2021.
-

# DUNE experiment: science program

Fundamental open questions in particle and astroparticle physics:

- **Neutrino oscillation physics**
  - ✓ CP violation in the leptonic sector (related to matter anti-matter asymmetry)
  - ✓ Mass hierarchy
  - ✓ Precision oscillation physics to test the 3-flavour paradigm
- **Nucleon decay**
  - ✓ Predicted in beyond the Standard Model theories [but not yet seen]  
$$p \rightarrow K^+ n$$
  - ✓ e.g. the SUSY favored mode:
- **Supernova burst physics and astrophysics**
  - ✓ Galactic core collapse Supernova, unique sensitivity to  $\nu_e$

# The DUNE Collaboration

As of today:

>60 % non-US

**970 collaborators** from **164 institutions** in **31 nations**

Armenia, **Brazil**, Bulgaria,  
Canada, CERN, **Chile**,  
China, **Colombia**, Czech  
Republic, Finland, France,  
Greece, India, Iran, Italy,  
Japan, Madagascar,  
**Mexico**, Netherlands, **Peru**,  
Poland, Romania, Russia,  
South Korea, Spain,  
Sweden, Switzerland,  
Turkey, UK, Ukraine, USA

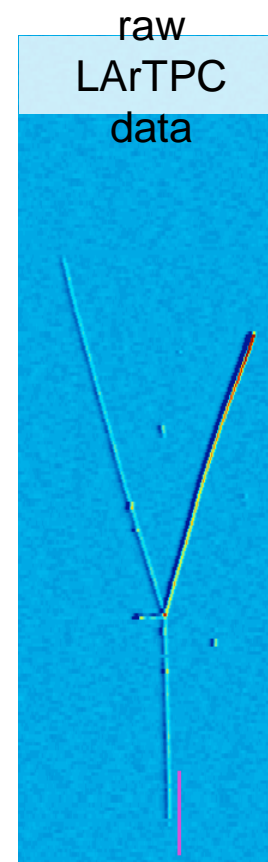
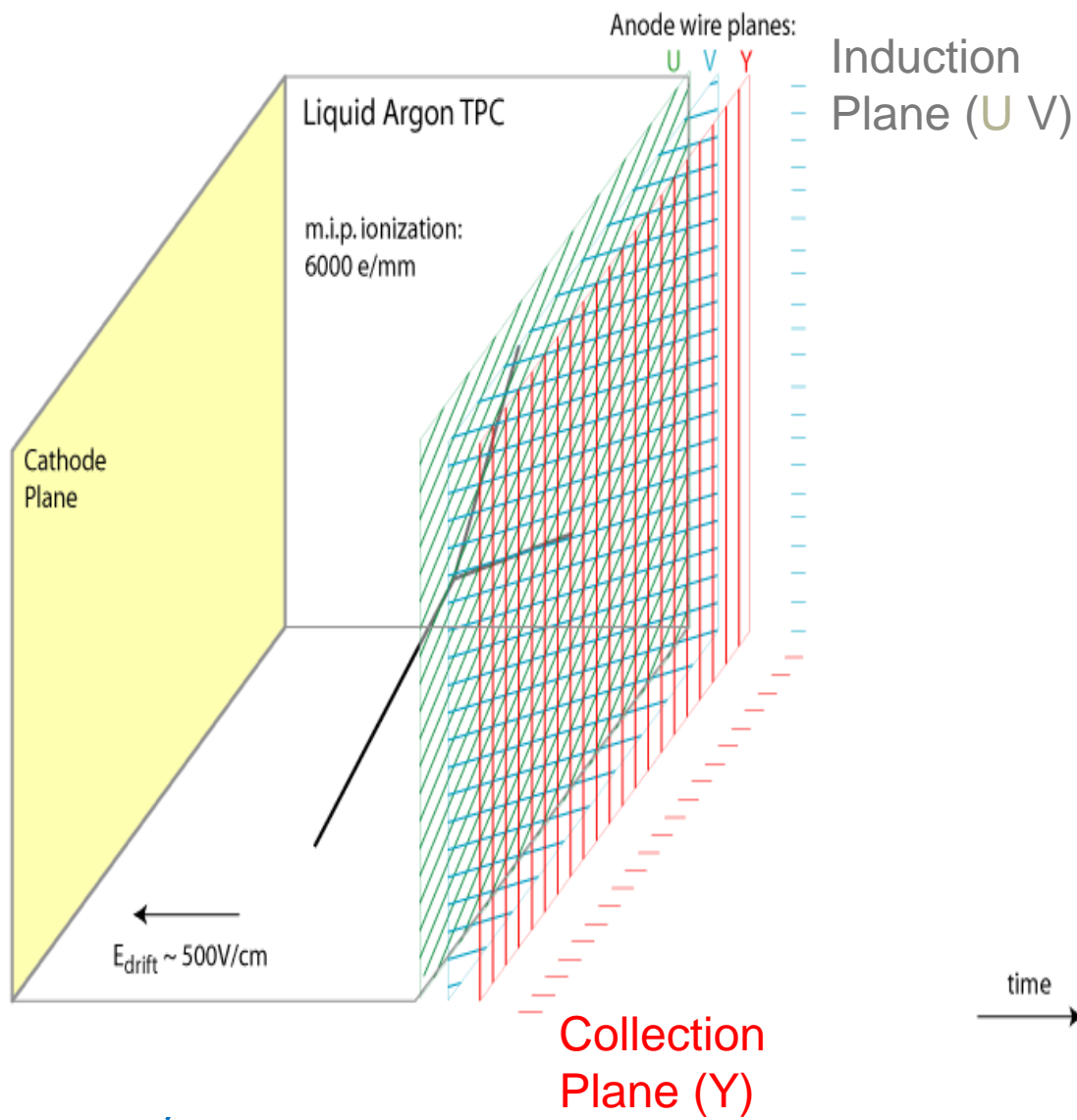


DUNE has broad international support and is growing  
brought together by the exciting science....

# LArTPC

- **Massive detector** -> LAr is a dense medium ( $1.4 \text{ g/cm}^3$ )
- **Imaging detector** -> allows a **3D reconstruction** of the interaction with extremely high resolution (below 1 mm)
- **Precise calorimetric reconstruction** -> allows to **measure the energy deposited by the incoming (charged) particle** and by all the charged particles produced by its interaction with Argon.
- **Particle discrimination** -> allows to **identify the type** of the **charged particles** that are detected

# LArTPC

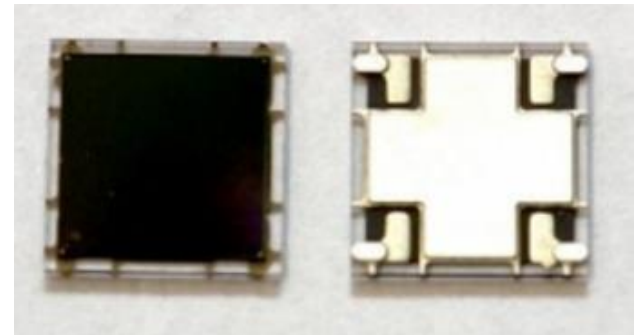


# Scintillation light in a LArTPC

- **LAr scintillation photons** are in the Vacuum Ultra Violet **127nm** and **need to be shifted** to be detected by common photo-sensitive devices.
- Scintillation light is shifted by **TetraPhenyl Butadiene** (TPB) that absorbs VUV scintillation light and re-emits it around **430nm**.
- It is used for triggering and  $T_0$  determination in LAr TPC for neutrino physics
- If properly detected it could significantly **improve** the performances of the TPC in terms of **energy resolution** and **particle discrimination**.

# Photon Sensors

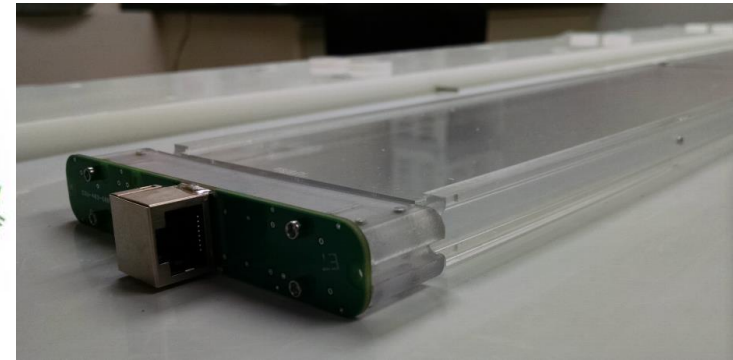
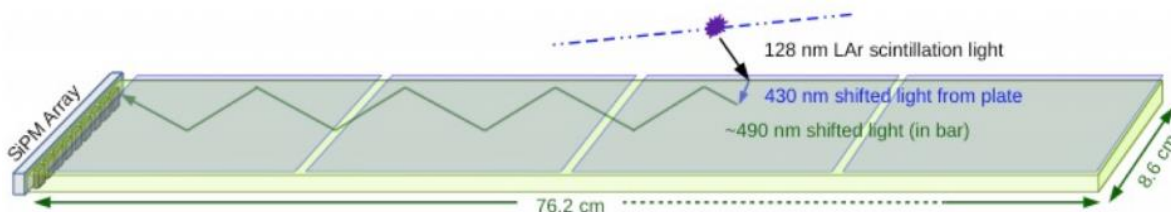
- The usual photon sensors used in particle detection are **PMTs**. But they are vacuum tubes which require space, high voltage, not stable in liquid argon environment
- **SIPMs** (Silicon Photomultipliers) are a new generation of devices based on the silicon technology which are replacing traditional PMTs. Flat devices, low voltage (tens of Volts), extremely high Quantum Efficiencies (up to 50%).





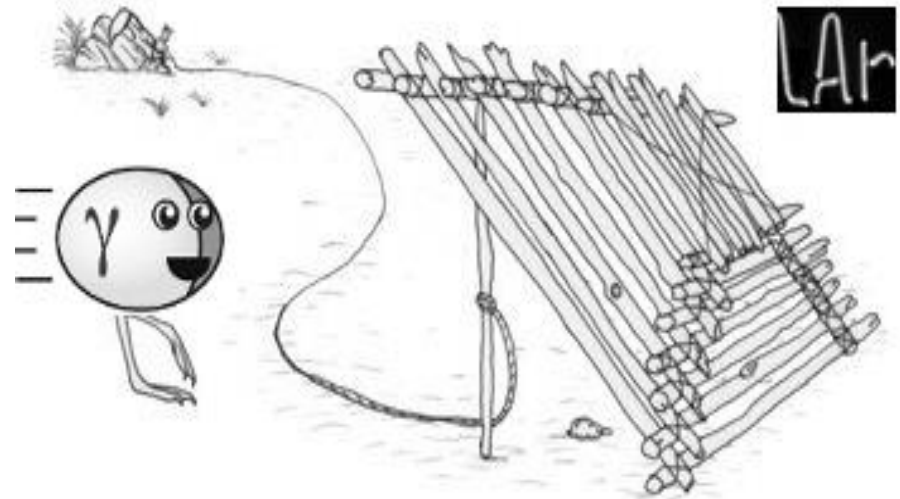
# Photon Detectors

- The scintillation light detection system for a massive LAr TPC, **needs** to be extremely flexible and versatile since it should allow to **detect and trigger high energy** - beam induced - events, **together with low energy interactions** down to tens of MeV for supernova neutrino interactions.
- One of the light detection system proposed for DUNE is based on guiding bars, coupled with SIPM at one end.
- **HOWEVER** the efficiency is low (around 0.1%) => difficult to observe low energy interactions.



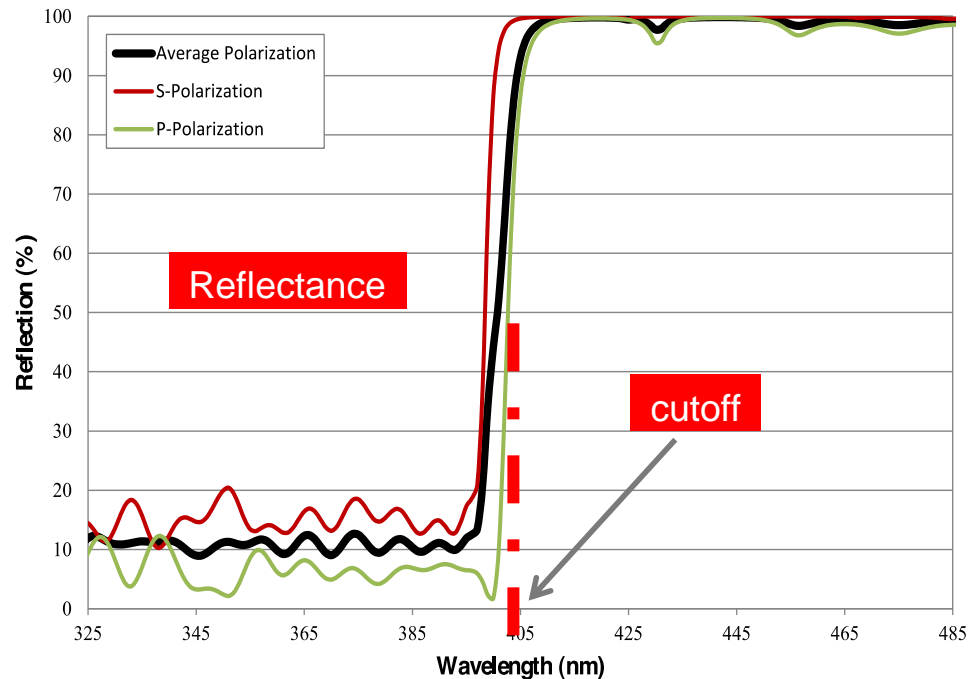
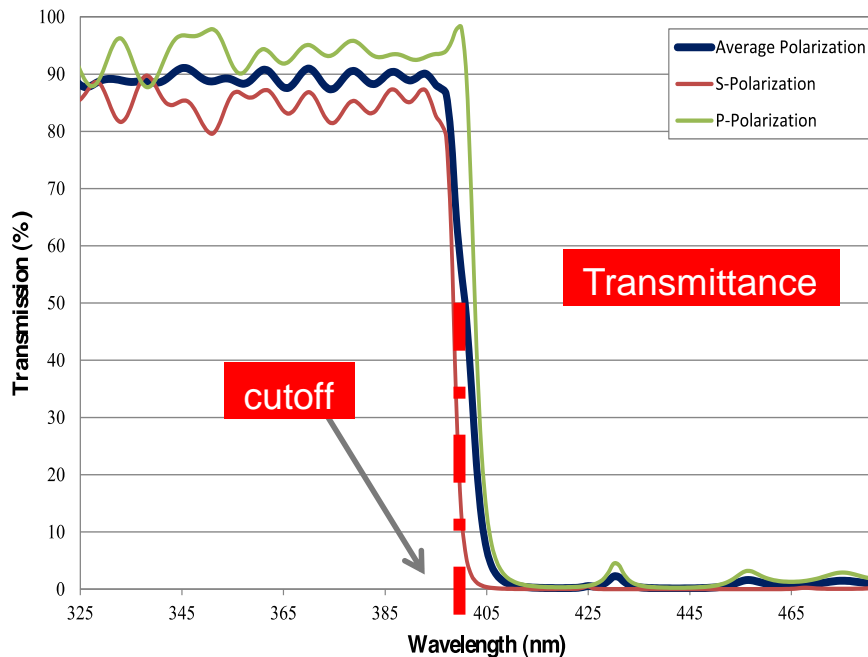
# The ARAPUCA light detection

- **ARAPUCA** the acronym was  
(**A**rgon **R**&**D** **A**dvanced **P**rogram @ **U**ni**C**amp)
- The idea at the basis of the Arapuca (proposed by E.Segreto and A.Machado) is to **trap photons** inside a box with highly reflective internal surfaces, so that the detection efficiency of trapped photons is high even with a limited active coverage of its internal surface

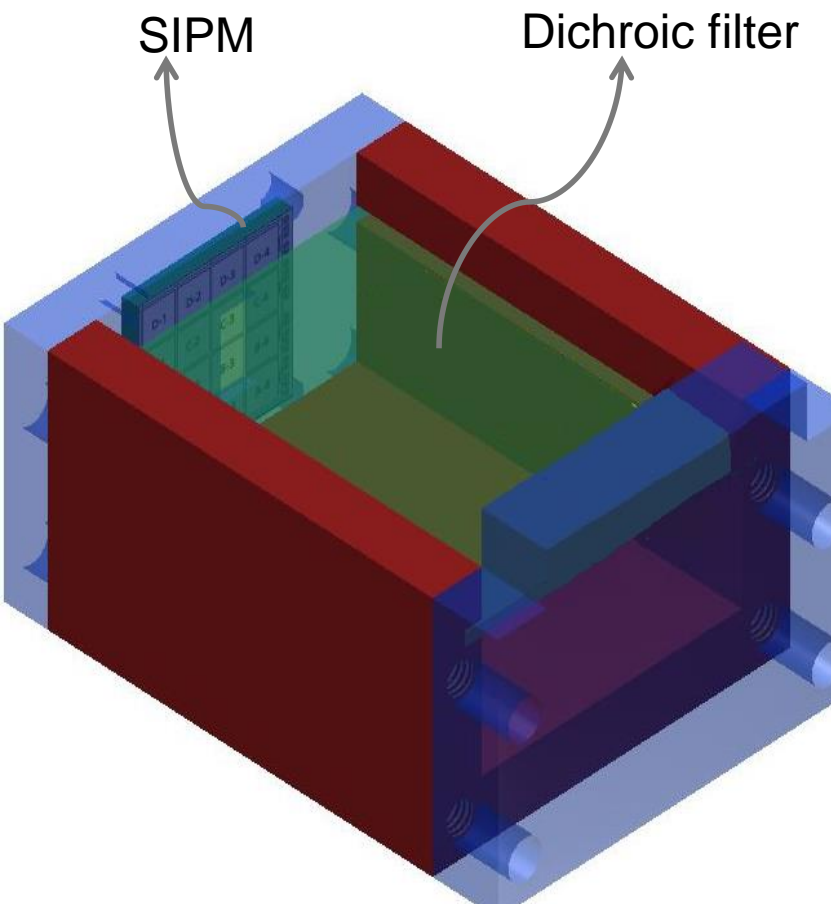


# The Dichroic Filter

- The core of the device is a **dichroic filter**. It is a **multilayer acrylic film** - same technology used to produce reflective plastic foils like 3M VIKUITI or VM2000.
- It has the property of being **highly transparent** for wavelength **below a cutoff** and **highly reflective above it**.



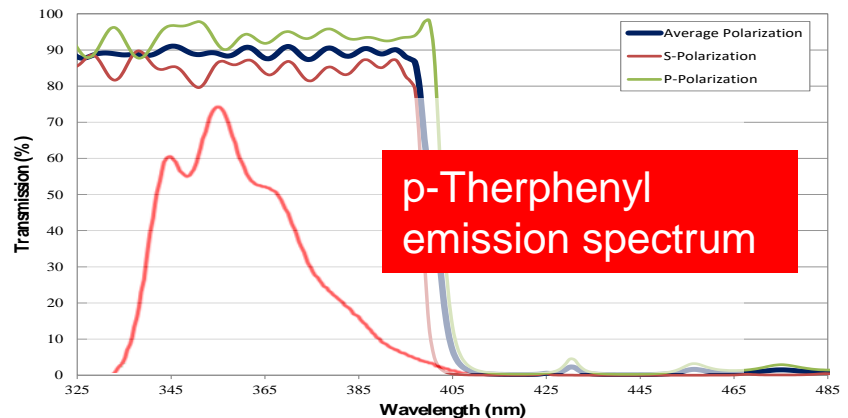
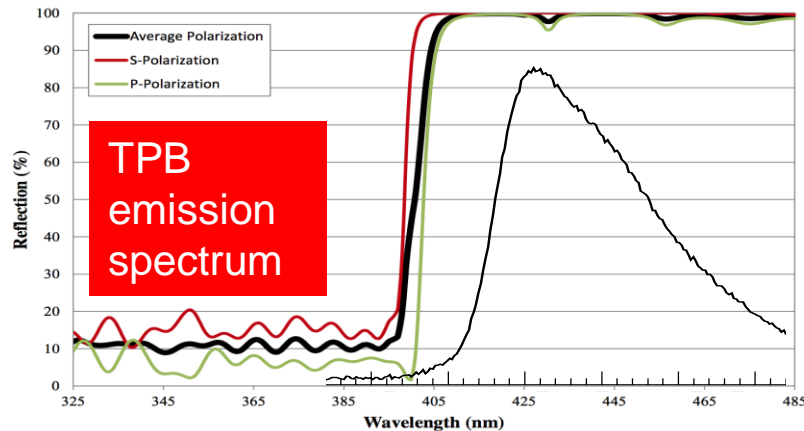
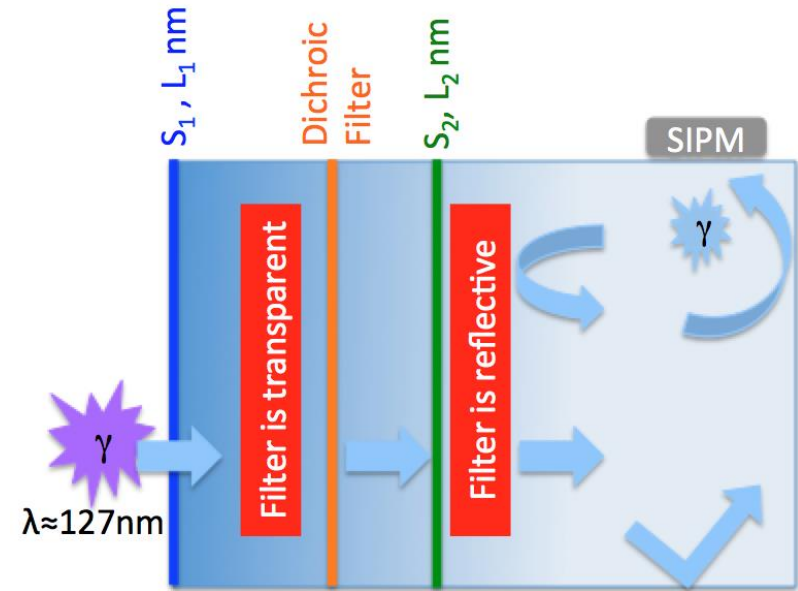
# Operating Principle I



- The simplest geometry is a **flattened box** with highly reflective internal surfaces (Teflon) with an open side.
- The open side hosts the **dichroic filter**
- The filter is deposited with **TWO SHIFTERS** – one on each side
- The **external side shifter**, S1, converts LAr scintillation light to a wavelength L1, with  **$L1 < \text{cutoff}$**
- The **internal side shifter**, S2, converts S1 shifted photons to a wavelength L2, with  **$L2 > \text{cutoff}$**
- The **internal surface** of the ARAPUCA is observed by **one or more SiPM**

# Operating Principle II

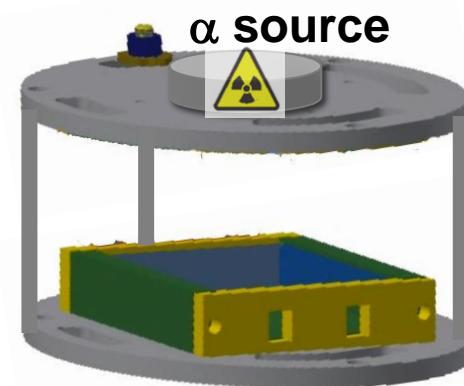
- After the **first shift** the light enters the ARAPUCA since **the filter is transparent**
- After the **second shift** the **photon gets trapped inside the box** because the filter turns to be **reflective**



# Liquid Argon Performances

- **FERMILAB 2016**

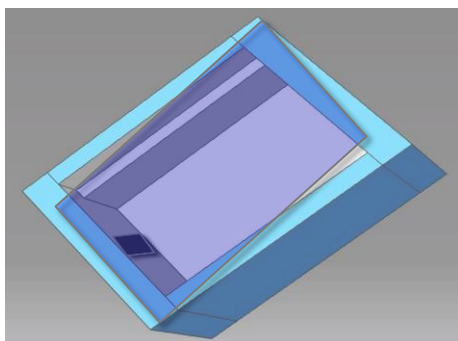
- Efficiency around 1.0%
- 2 SIPMs 6X6mm<sup>2</sup>
- Window 5X5cm<sup>2</sup>



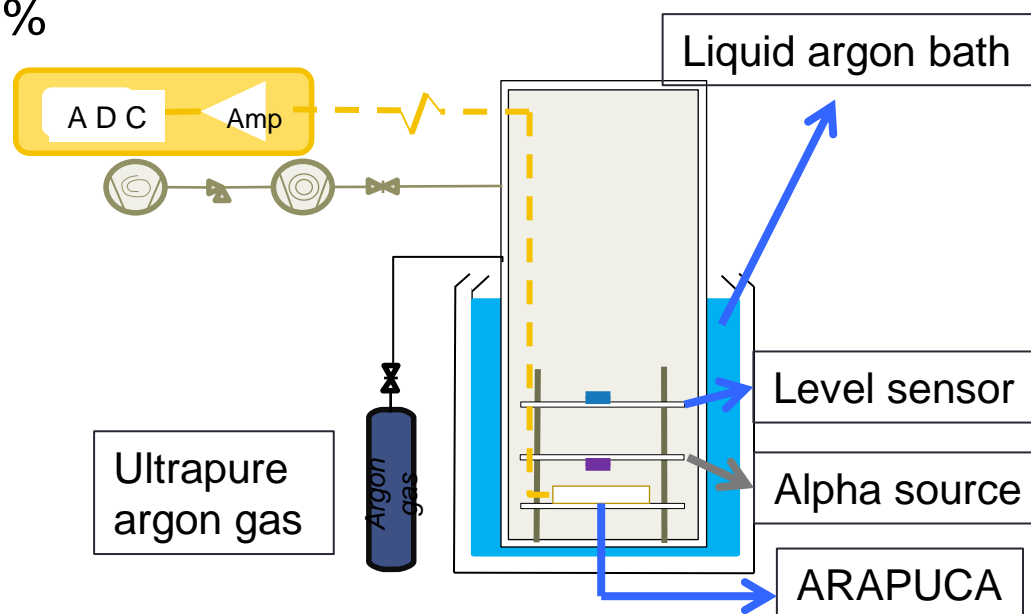
- **LNLS 2016 (First LAr test in Brazil)**

- Efficiency measured  $1.8 \pm 0.3$  %
- Efficiency simulated  $1.7 \pm 0.1$  %

SIPM  
6X6mm<sup>2</sup>



Dichroic Filter (2.5X3.6cm<sup>2</sup>)  
Coating with pTP and TPB



# Wavelength shifter characterization

- Wavelength shifting is an important step for LAr scintillation light detection since common devices are not sensitive to 128 nm
- Relevant improvements can be done in this field => only few materials have been deeply investigated
- A strong collaboration has been set-up with the National Laboratory of Synchrotron Light (LNLS) to characterize wls materials (we are particularly grateful to Douglas Galante and Veronica Teixeira)
- We became users of the TGM line which can deliver monochromatic light with energy ranging from 3 to 300 eV (wavelength from 400 to 4 nm)
- Two weeks of measures up to now. Two more foreseen for the present year

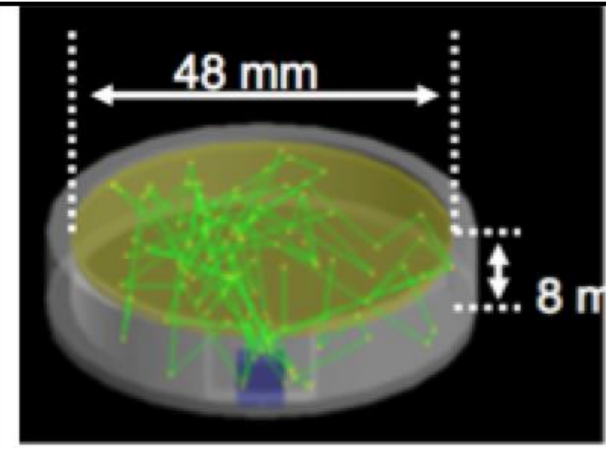
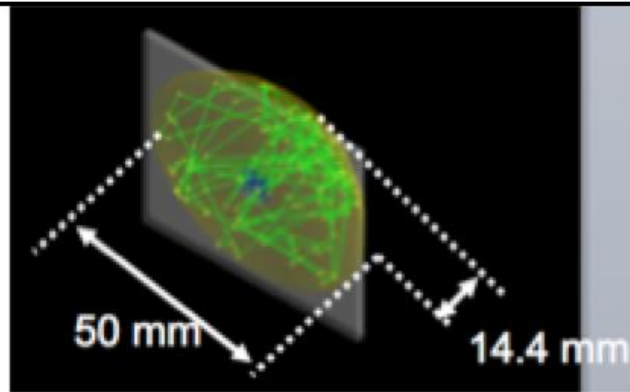
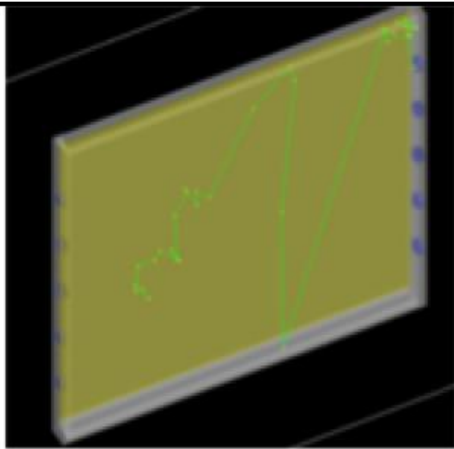






# New Geometries studies

- Studies using Monte Carlo Simulation are underway in order to reach a reasonable compromise between efficiency and feasibility.



# Lab. Leptons



*90 m<sup>2</sup> clean room*

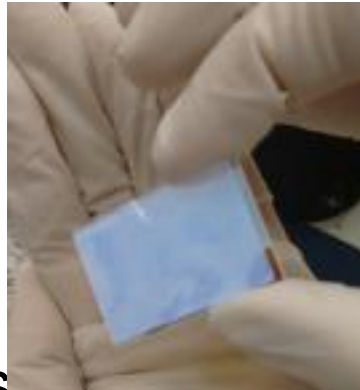


# Lab. Leptons

- Laboratory devoted to develop **LAr technology**
- Many equipment acquired and arriving from Germany, France, Italy and Brazil.
- **Big evaporator** to produce organic films (wavelength shifters)
- **Vacuum monochromator** with deuterium lamp -> light down to 110 nm
- **Cryogenic facility** with pulse tube refrigerator -> test prototypes in a *LAr environment*
- **3D printing station** to build prototypes to be tested

# Evaporation tests at UFABC

- TPB
- p-terphenyl – pTP
- Bis-MSB
- PPO
- POPOP



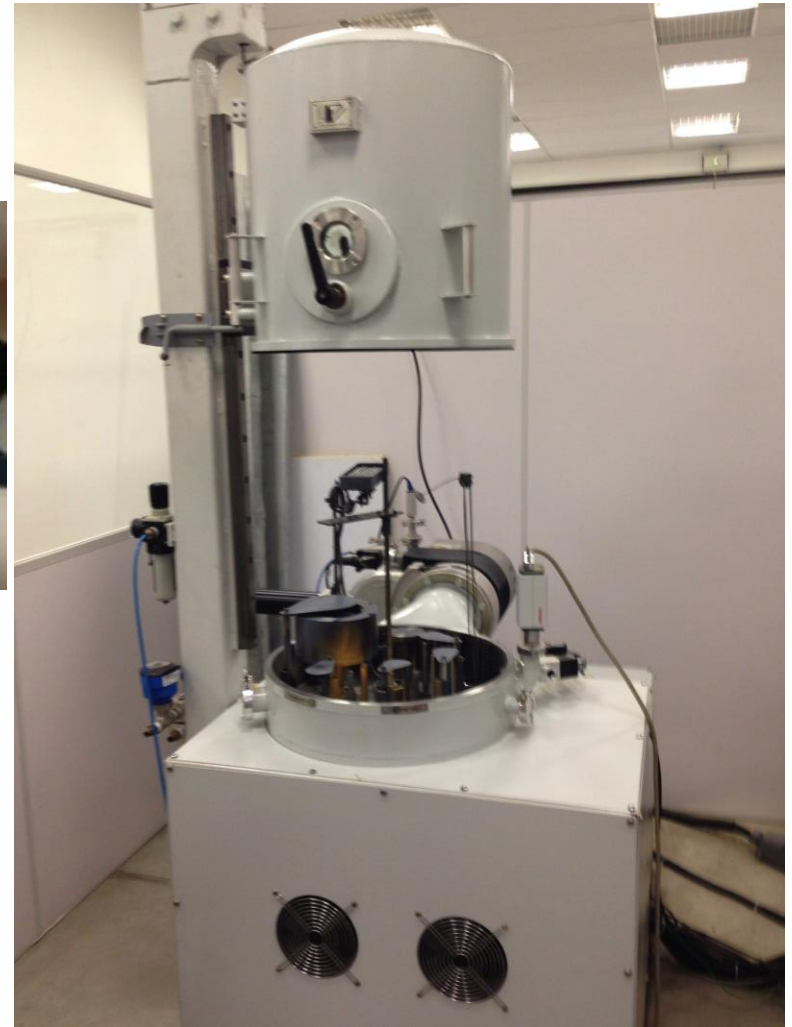
Different thicknesses

Different Substrates

Dichroic filter

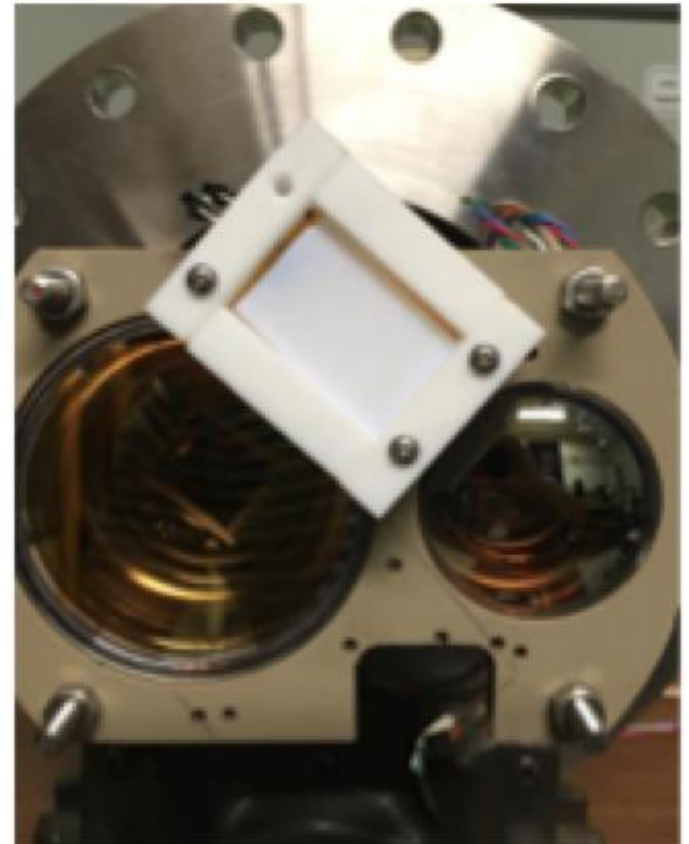
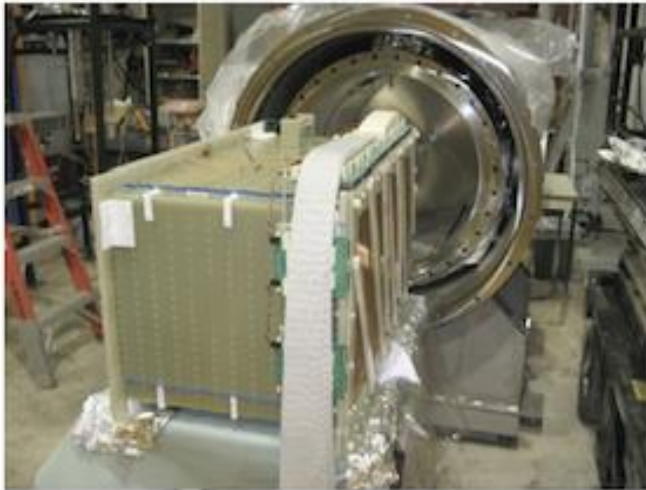
VIKUITI

Glass



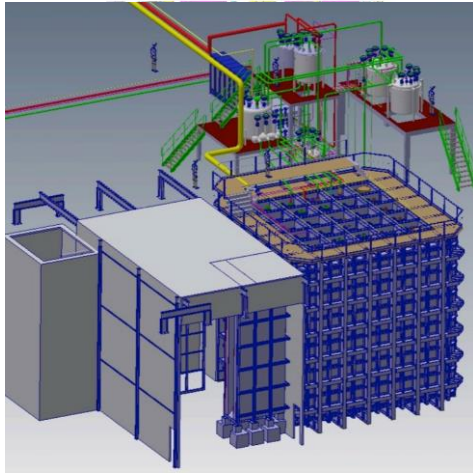
# ARAPUCA in LArIAT

- The Liquid Argon in a Test beam, is running at FNAL.
- Was installed an ARAPUCA made in Brazil for run 3

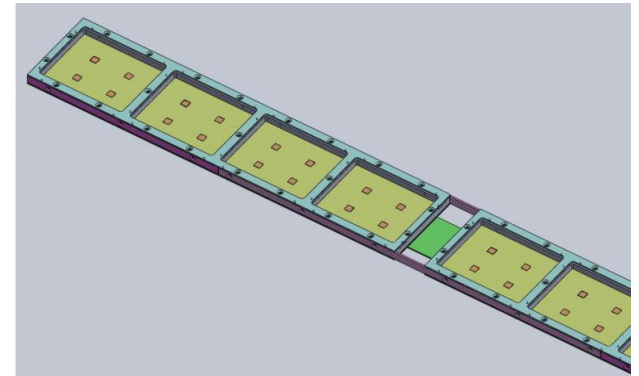
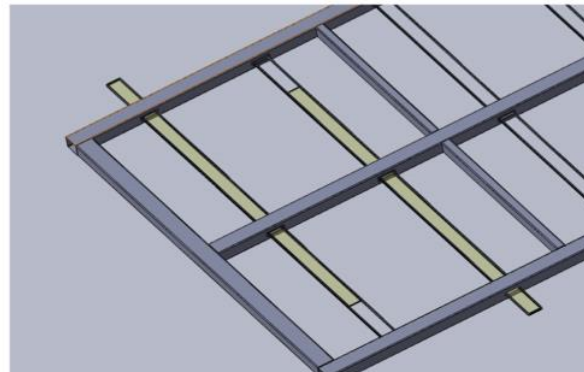
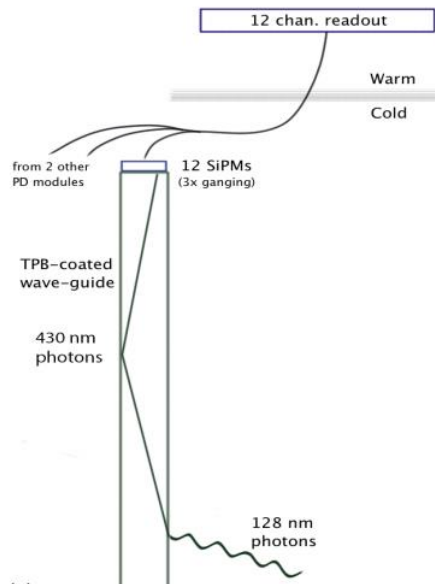
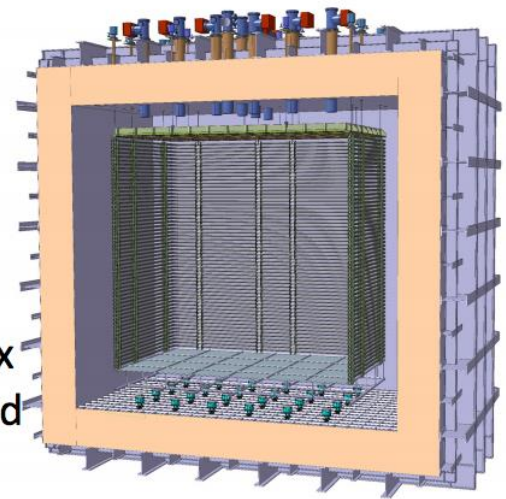




# ARAPUCA array protoDUNE



- Photon Detection system inserted between anodic wire planes
- Ten bars per anodic planes (10 planes in total)
- 58 standard guiding bars + 2 ARAPUCA arrays
- ...but the efficiency of each ARAPUCA box is expected to be equivalent to a standard bar



# ARAPUCA in SBND

- SBND is one of the three experiments that make part of the short baseline program of FNAL.
- It is under construction
- 24 ARAPUCAs will be installed.
- Will be placed 2 ARAPUCAs per mounting frame.

PDS Module with 4 each  
ProtoDUNE Scintillator Bars and  
2 each ARAPUCA Detectors



Outward Looking PMT Relocated for  
ARAPUCA Detectors

# ARAPUCA related activities

- Test to check the trapping effect
- Liquid Argon performance
- New geometries
- Lab. Leptons at UNICAMP
- Arapuca in LArIAT
- Arapuca Array (protoDUNE)
- Arapuca in SBND
- Arapuca for DUNE – Working Group

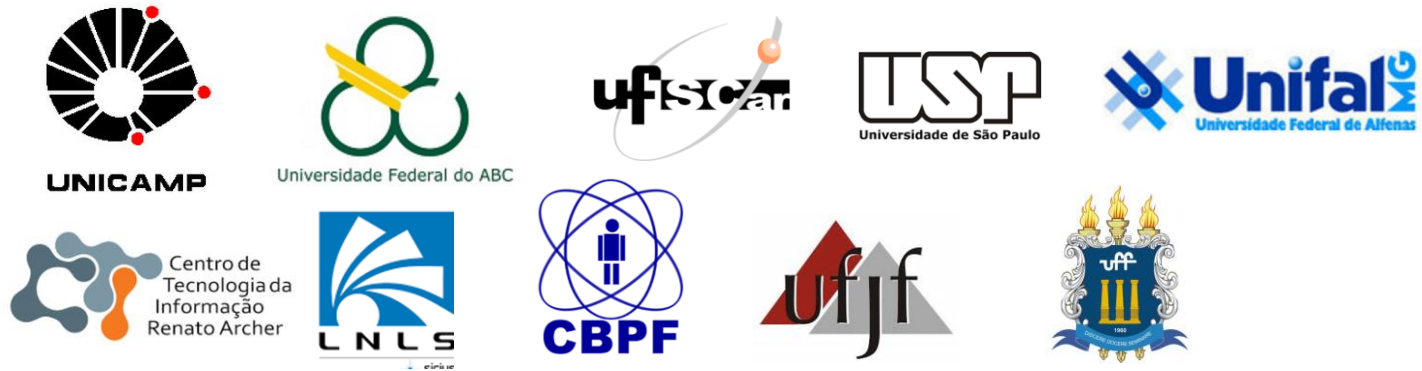
**Acknowledgement** - We thank FAPESP (State of Sao Paulo Research Foundation for financial support, process no. 2016/01106-5





# ARAPUCA for DUNE - working group

Brazil



Colombia  
Paraguay  
Mexico  
Peru



UK, Italy  
France



USA

