DUNE Status

Deywis Moreno

Universidad Antonio Narino
Bogota, Colombia

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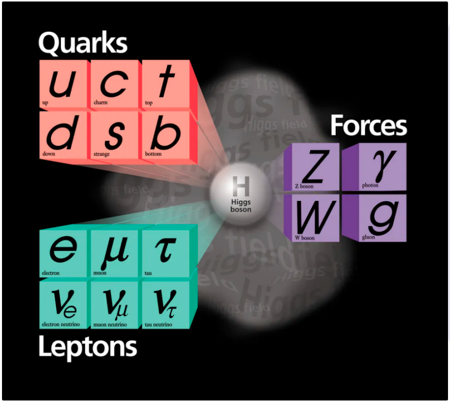
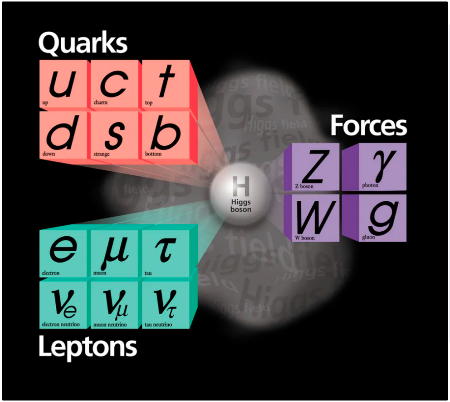
Content

The Standard Model of Particle Physics



- Ordinary matter is made of Fermions.
- Forces are carried by Bosons.
- Higgs Boson was the last piece of the SM to be found.
- Since the year 2012 the SM is completed
- But....

The Standard Model of Particle Physics

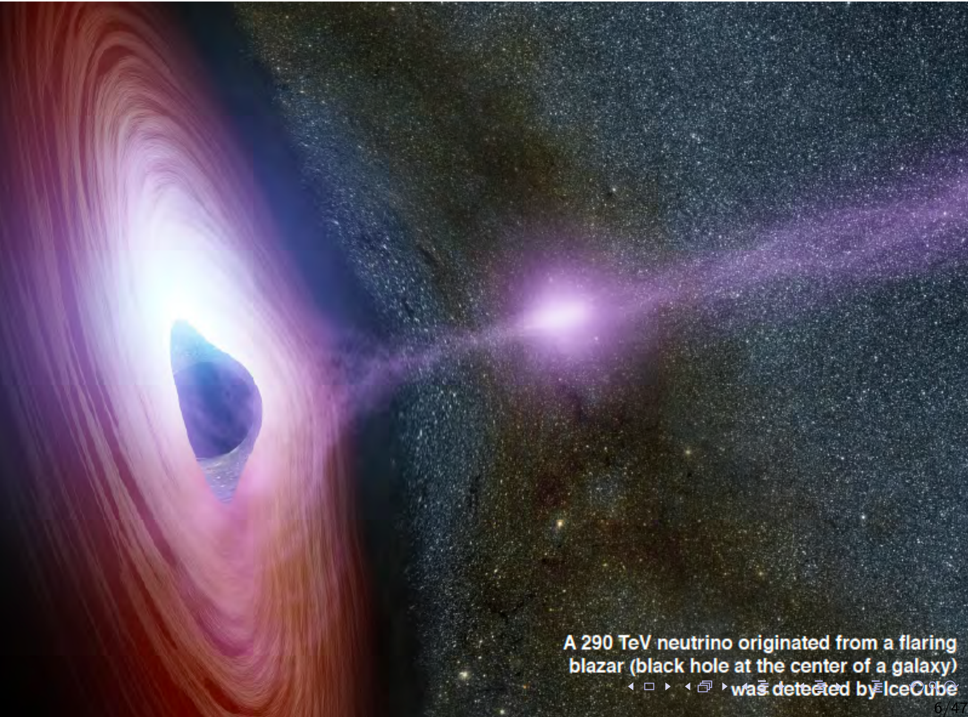


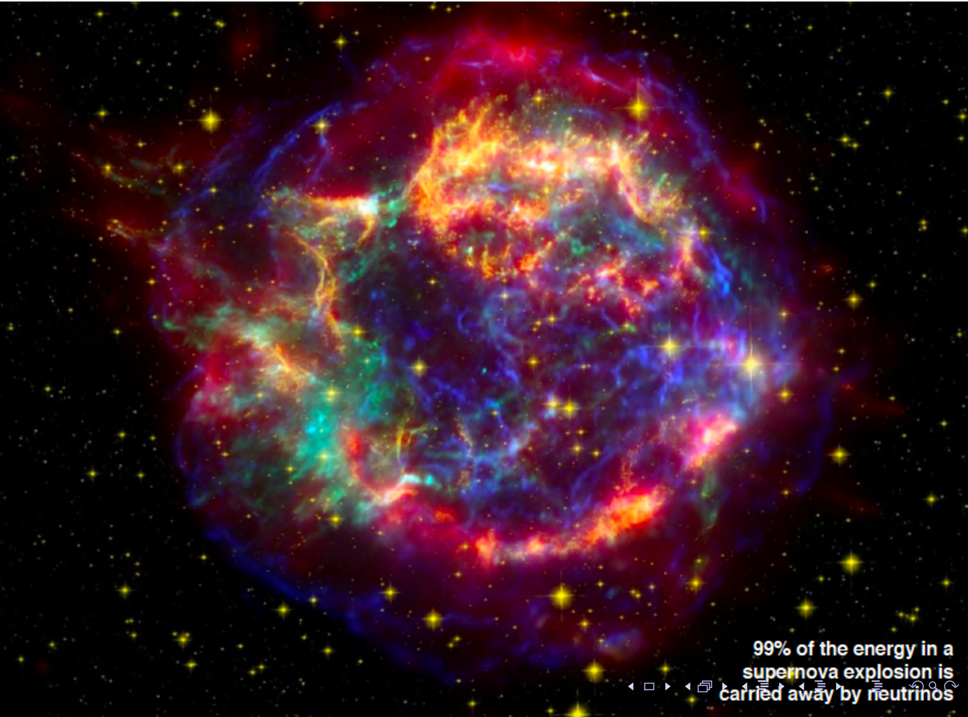
- Ordinary matter is made of Fermions.
- Forces are carried by Bosons.
- Higgs Boson was the last piece of the SM to be found.
- Since the year 2012 the SM is completed
- But....

We need physics beyond the Standard Model.

- Dark Matter
- Hierarchy problem
- Neutrinos are massive

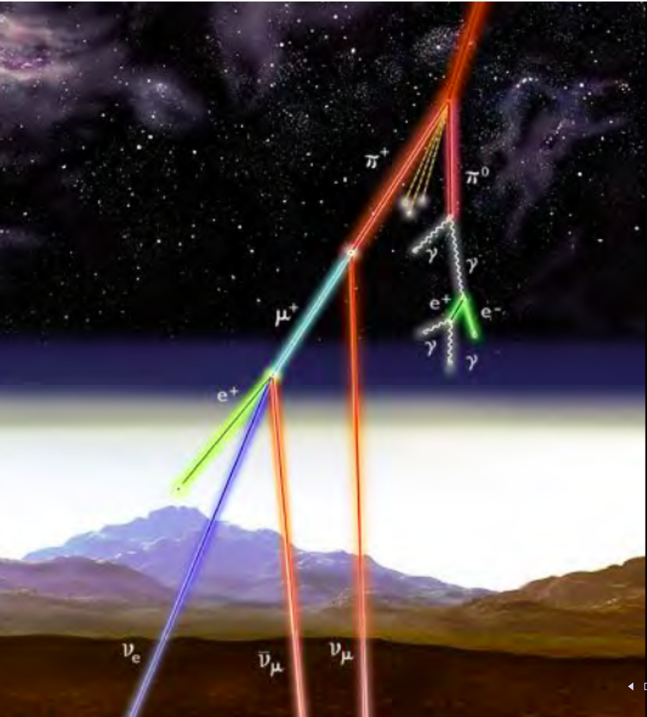

For every proton/neutron/electron
the Universe contains a billion of
neutrinos from the Big Bang


A 290 TeV neutrino originated from a flaring
blazar (black hole at the center of a galaxy)
was detected by IceCube


99% of the energy in a
supernova explosion is
carried away by neutrinos

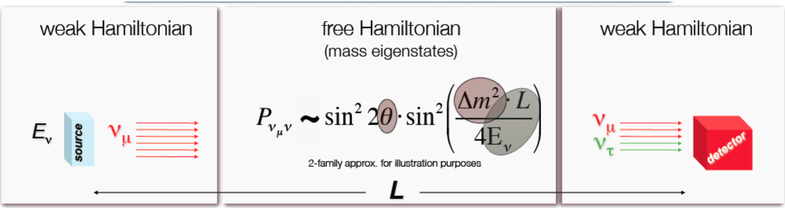
10^{38} neutrinos per second
are produced by the Sun

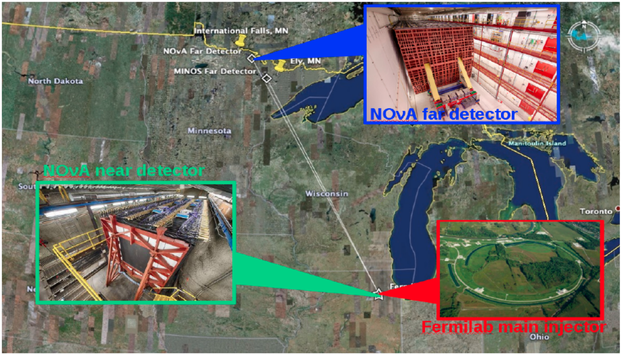
(with a flux of ~10^{11}/cm^2/sec at the Earth)



Neutrinos are also produced in the atmosphere

Neutrino Oscillations.



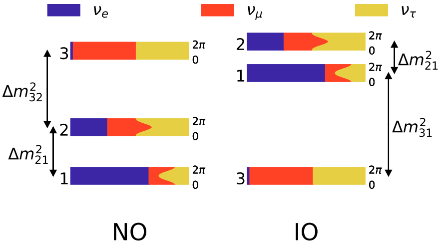


Introduction

flavour — atmospheric — accelerator/reactor — solar — mass

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix}=\begin{pmatrix}1&0&0\\0&c_{23}&s_{23}\\0&-s_{23}&c_{23}\end{pmatrix}\begin{pmatrix}c_{13}&0&s_{13}e^{-i\delta}\\0&1&0\\-s_{13}e^{i\delta}&0&c_{13}\end{pmatrix}\begin{pmatrix}c_{12}&s_{12}&0\\-s_{12}&c_{12}&0\\0&0&1\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

where $c_{ij}=\cos\theta_{ij}$, $s_{ij}=\sin\theta_{ij}$



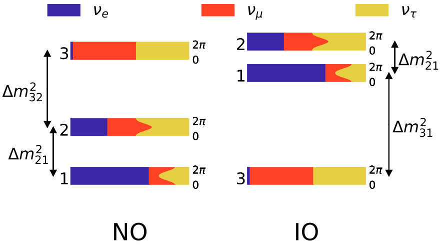
Standard Neutrino Picture

- Neutrinos are massive
- $\Delta m^2_{12} \approx 7.53 \times 10^{-5}\,\mathrm{eV}^2$
- $\left|\Delta m^2_{23(13)}\right| \approx 2.45 \times 10^{-3}\,\mathrm{eV}^2$
- $\theta_{12} \approx 33^o$
- $\theta_{13} \approx 8.3^o$
- $\theta_{23} \approx 46^o$

flavour | atmospheric | accelerator/reactor | solar | mass

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

where $c_{ij}=\cos\theta_{ij}$, $s_{ij}=\sin\theta_{ij}$



Standard Neutrino Picture

- $\theta_{13} \approx 8.3^o$ Why so small?
- $\theta_{23} \approx 46^o$ Maximal?
- What is the value of δ_{CP}?
- Absolut neutrino mass?
- What is the mass hierarchy? Sign of Δm^2_{31}?
- Dirac or Majorana?

Content

- Introduction
- Long-Baseline Neutrino Experiments
- DUNE Overview
- The DUNE Single Phase Photon Detection System (PDS-SP)
- The Contribution of Latin America to the PDS-SP
- Summary

LBL Recipe

- An intense beam of proton is focused onto a target
- Secondary particles produced from the target are focused by magnetic horns
- The focused particles traverse a long decay region where neutrinos are produced
- A Near detector is needed to measure the initial neutrino Flux
- A Far detector is used to measure the appearance/disappearance of a neutrino flavour

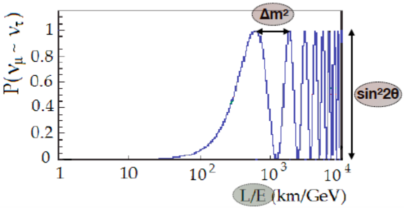
Neutrinos production via Kaon or Pion decay:

$$\pi^+ \to \mu^+ + \nu_\mu \qquad (1)$$

Oscillation Probability:

$$P(\alpha \to \beta) = \sin^2 2\theta_{ij} \sin\left(\frac{1.27\Delta m^2_{ij}(eV)L(Km)}{E_\nu(GeV)}\right) \qquad (2)$$

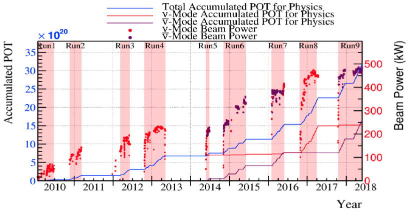
Experiment	Operational	Peak E_ν	Baseline
K2K	1999 – 2004	1 GeV	250 km
NuMI/MINOS	2005 – 2011(?)	3 GeV	735 km
CNGS/OPERA	2008–	17 GeV	732 km
T2K	2010–	0.7 GeV	295 km
NOνA	2012(?)–	1.8 GeV	810 km

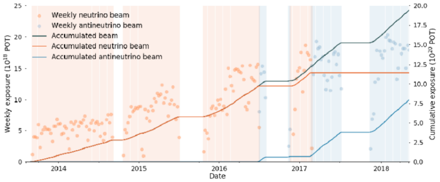


LBL Beamline

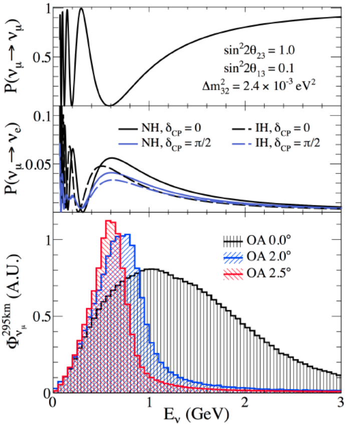
T2K
It uses the J-PARC beam
Achieves up to 500 kW
POT total: 3.16×10^{21}
The beam is $2,5^{\,0}$ off-axis with respect to the far detector.

NOνA
It uses the NuMI beam
Nominal 700 kW since 2017
POT total: 15.66×10^{20}
The beam is $0,84^{\,0}$ off-axis with respect to the far and near detector.



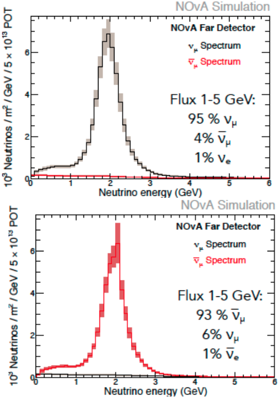


Off-Axis angle



The beam is 2.5 ^{0} off-axis with respect to the far detector in T2K

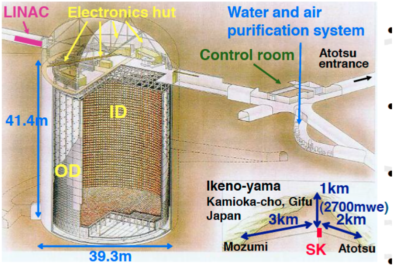
NOνA



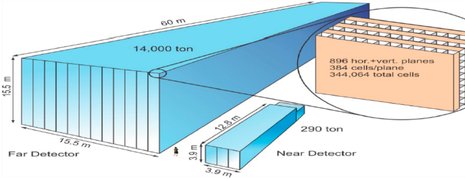
Around 1 % contamination of ν_e
Less that 10 % wrong ν_μ component in beam

LBL Detectors

T2K
Two Near detectors: ND280 and INGRID
ND280 is composed of trackers, a combination of fine grained detectors and Ar TPCs
INGRID: on-axis scintillator light detector
Far Detector: Water-Cherenkov detector with 50 kTon of ultra-pure water



NOνA
Two identical detectors (except for the size)
Detectors are made of 344000 cells highly reflective plastic PVC filled with liquid scintillator.
Near Detector: 0.3 kTon 1 Km from source
Far Detector: 14 kTon Readout made via WLS fibers to avalanche photo diode array



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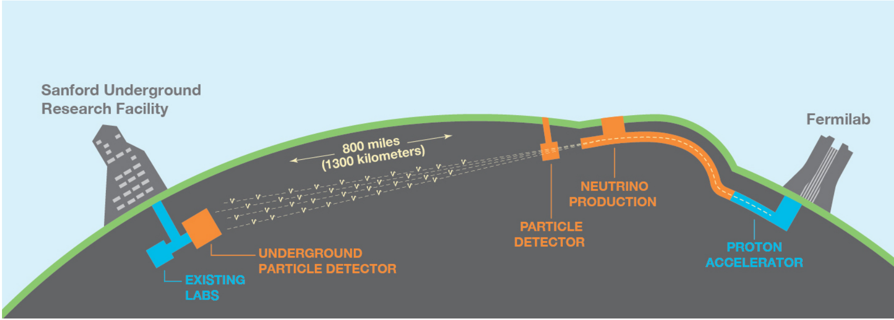
DUNE Project

Deep **U**nderground **N**eutrino **E**xperiment.

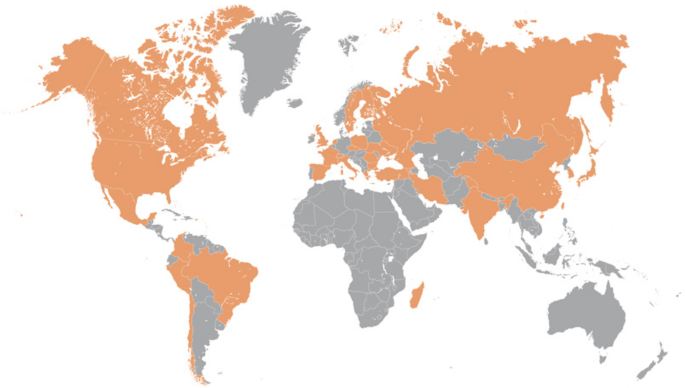
- Measure of ν_e and $\bar{\nu_e}$ appearance and ν_μ and $\bar{\nu_\mu}$ disappearance over a long baseline
- It will use a high-intensity neutrino beam and high-resolution massive detectors.

LBNF: Long-Baseline Neutrino Facility

- Provides Infrastructure for the experiment
- Neutrino Beam
- Detector facilities
- Cryogenic systems



DUNE an International Project



- International Collaboration
- 34 countries
- 192 institutions
- More than 1000 Collaborators

DUNE Physics Program

Program Physics with primary goals:

Supernova & Low energy neutrinos

Proton decay

neutrino oscillations

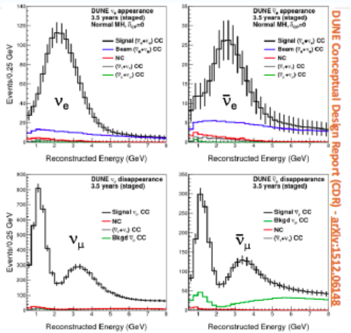
δ_{CP} and **mass hierarchy** in a single experiment

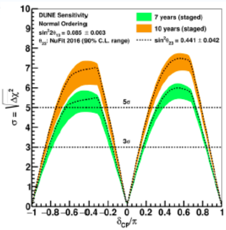
Beyond Standard Model

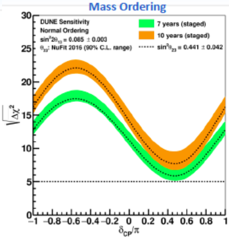
in the near and far detectors

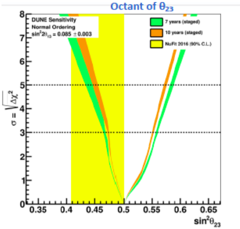
neutrino x-sections

in the near detector



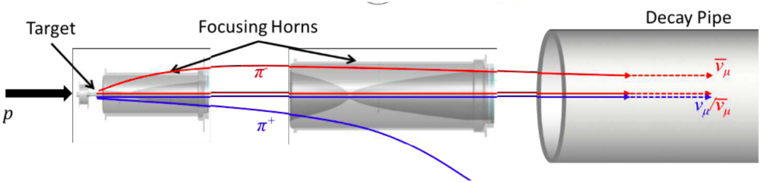






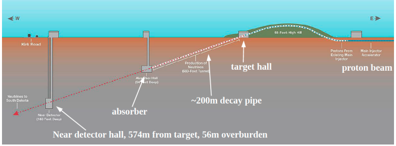
The LBNF Beamline

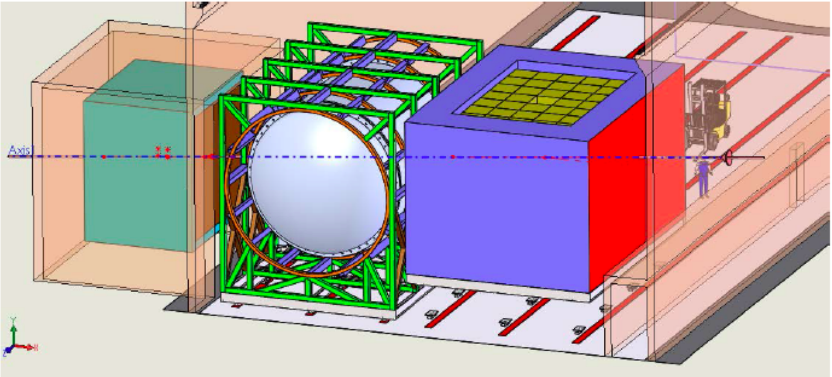
- The LBNF neutrino beam will be produced using $60 - 120\,\mathrm{GeV}$ protons from Fermilab's main injector
- Initial nominal power of $1.2\,\mathrm{MW}$ (10^{14} protons-on-target/sec)
- In the future upgradeable to $2.4\,\mathrm{MW}$
- Can run in neutrino (FHC) and antineutrino (RHC) modes by switching polarity of magnetic horns
- Wideband beam enables use of second maximum and enhances probing BSM phenomena



The DUNE Near Detector

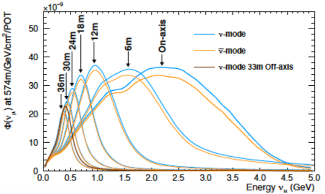
- ND located $574m$ downstream of production target
- dedicated to measure flux, cross-section and to constrain detector uncertainties
- System composed of multiple detectors:
  - LArTPC (ArgonCube)
  - Multipurpose detector (MPD)
  - Beam monitor (3D scintillator tracker-spectrometer 3DST-S)

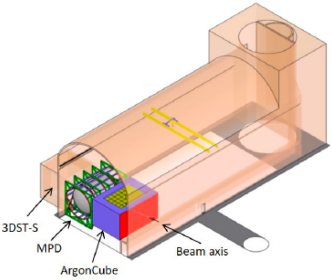


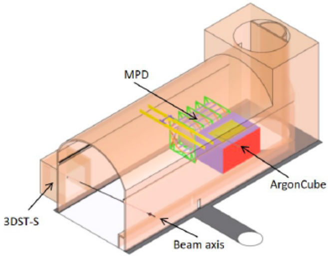


The DUNE Prism

- ArgonCube and MPD are on rail (Off-Axis)
- Up to 30 m side movement
- Allows to measure new flux







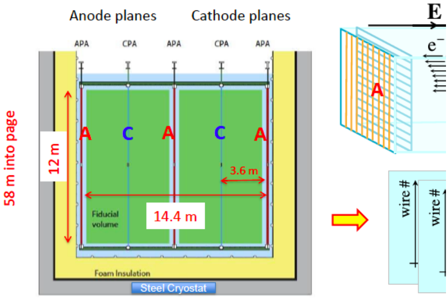
DUNE Far Site Facility

Gold mine repurposed into underground laboratory (1.5Km Underground)
5 main caverns: 4 detector caverns and one support cavern (Cryogenics and DAQ)

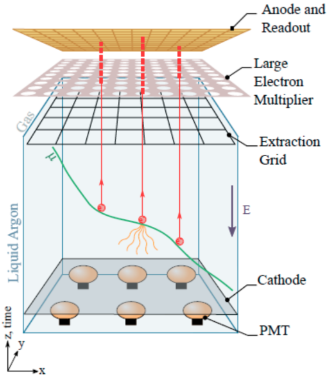
The DUNE Far Detector

- Liquid Argon Time projection Chambers (LArTPC)
- Two technologies: Single Phase and Dual Phase

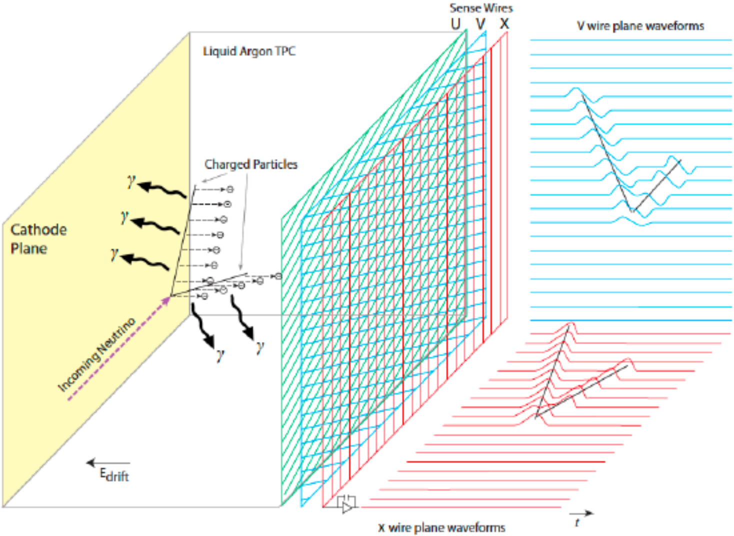
Single Phase TPC



Dual Phase TPC

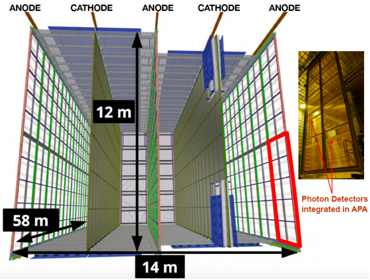


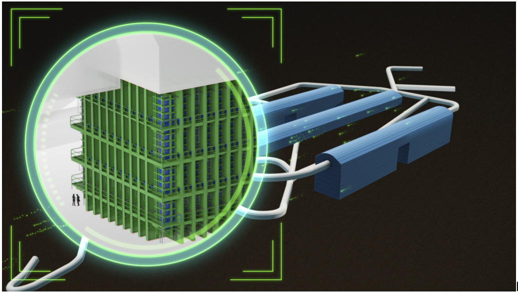
TPC Principle



Single Phase Detector

- $10\,\mathrm{kt}$ fiducial cryostat
- Width $= 14\,\mathrm{m}$, Height$=12\,\mathrm{m}$, Length$=58\,\mathrm{m}$
- 150 APAs, 200 CPAs
- PD system integrated
- 385000 Readout Channels
- Start of Construction 2022
- First Module ready by 2024
- LBN Beam by 2026





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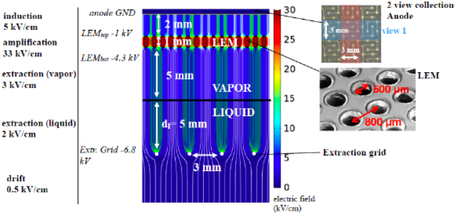
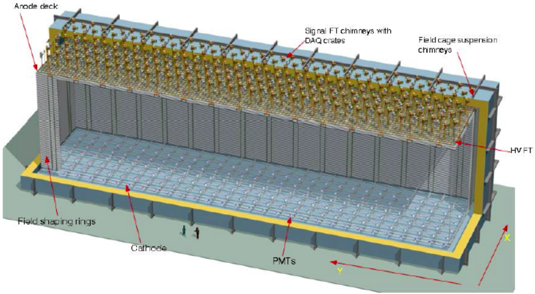
Dual Phase Detector

- Drift distance: 12 m
- E = 500 V/cm
- Cathode voltage: -600 kV
- Photon Readout: PMTs coated with TPB





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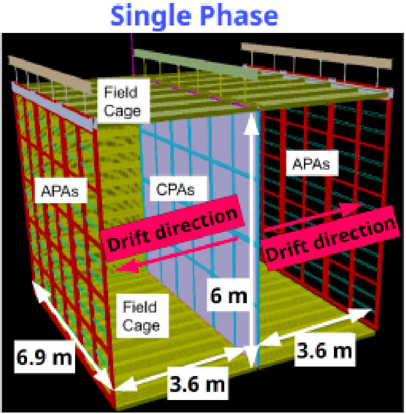
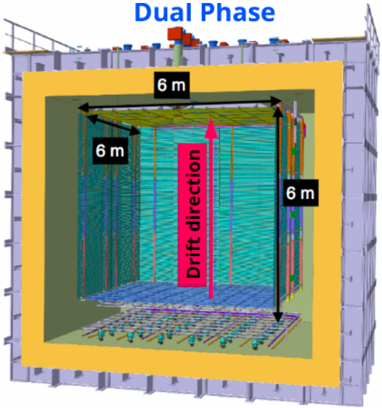
DUNE Prototypes

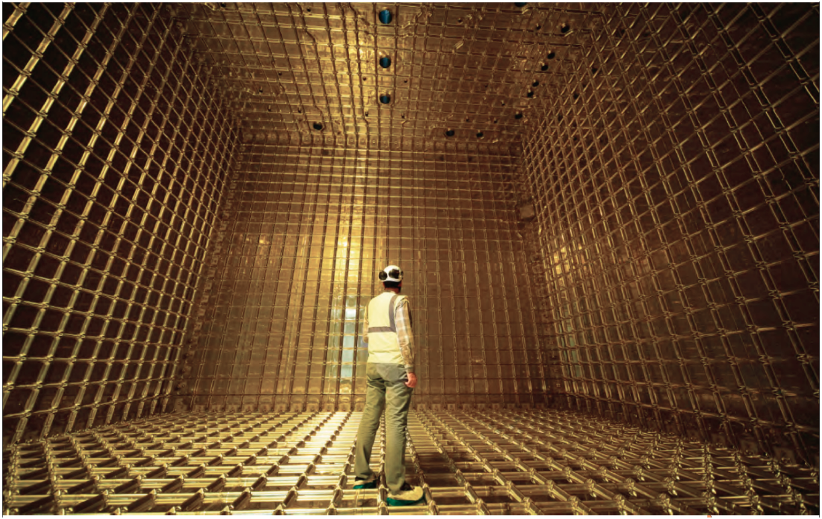
- At CERN there are builded two prototypes.
- ProtoDUNE SP was exposed to a test beam at CERN last autumn.
- Protodune single phase has 420 ton active LAr.
- A small TPC prototype is under operation at Fermilab (ICEBERG)





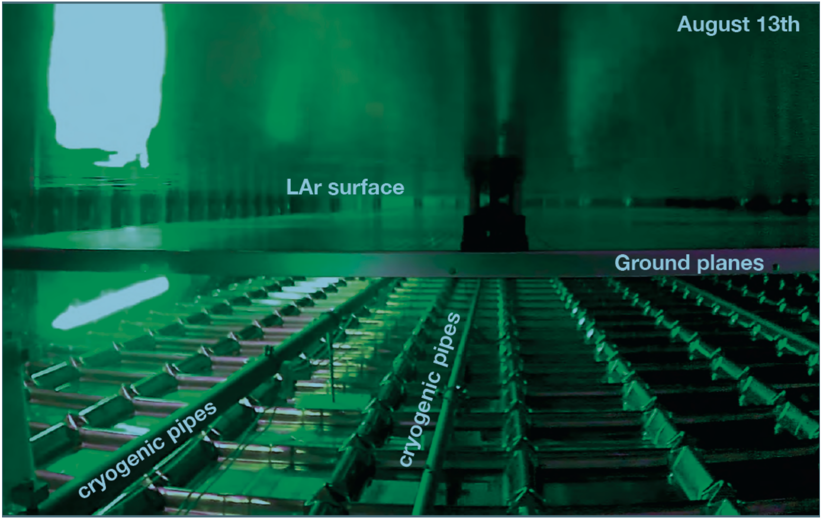
DUNE Prototypes

- ProtoDUNE SP was completed at end of June 2018



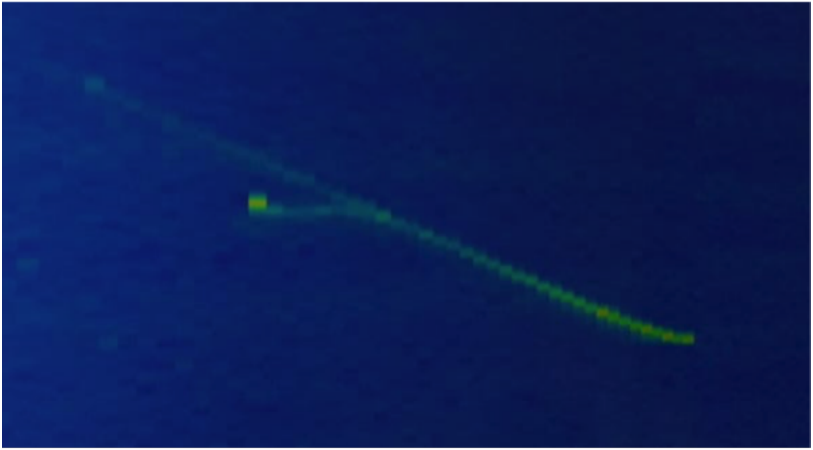
DUNE Prototypes

- Filling of the cryostat completed in Sep. 13th 2018



DUNE Prototypes

- Data taking since Sep 21st-Nov 11th.



First track recorded the 18th of October 2018.

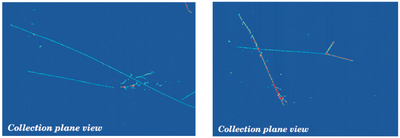
DUNE Prototypes

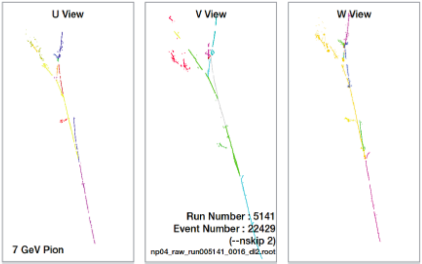
- Data taking Sep. 21st to Nov. 11th.
- Since Nov. runs with cosmics.

> 4 Million events collected

Momentum	Total Triggers	Expected Pi trig.	Expected Proton trig.	Expected Electr. trig.	Expected Kaon trig.
0.3 GeV/c	269K	0	0	242K	0
0.5 GeV/c	340K	1.5K	1.5K	296K	0
1 GeV/c	1089K	382K	420K	262K	0
2 GeV/c	728K	333K	128K	173K	5K
3 GeV/c	568K	284K	107K	113K	15K
6 GeV/c	702K	394K	70K	197K	28K
7 GeV/c	477K	299K	51K	98K	24K
All momenta	4175K	1694K	779K	1384K	73K

1 GeV pions





Pion Event recorded at Protodune

Content

Consortium Membership

Brazil	Federal University of ABC
Brazil	University Estadual de Feira de Santana
Brazil	Federal University of Alfenas Poços de Caldas
Brazil	Centro Brasileiro de Pesquisas Físicas
Brazil	University Federal de Goias
Brazil	Brazilian Synchotron Light Laboratory LNLS/CNPEM
Brazil	Universidade de Campinas
Colombia	Universidad del Atlantico
Colombia	Universidad Sergia Ablada
Colombia	University Antonio Nariño
Czech Republic	Institute of Physics CAS, v.v.i.
Czech Republic	Czech Technical University in Prague
Paraguay	UNA (Ascuncion)
Peru	PUCP
Peru	Universidad Nacional de Ingineria (UNI)
UK	Univ. of Warwick
UK	University of Sussex
UK	University of Manchester
UK	Edinburgh University
USA	Argonne National Lab

USA	Brookhaven National Lab
USA	California Institute of Technology
USA	Colorado State University
USA	Duke University
USA	Fermi National Accelerator Lab
USA	Idaho State University
USA	Indiana University
USA	University of Iowa
USA	Louisiana State University
USA	Massachusetts Institute of Technology
USA	University of Michigan
USA	Northern Illinois University
USA	South Dakota School of Mines and Technology
USA	Syracuse University
Italy	University of Bologna and INFN
Italy	University of Milano Bicocca and INFN
Italy	University of Genova and INFN
Italy	University of Catania and INFN
Italy	LNS Catania
Italy	University of Lecce Aand INFN
Italy	INFN Milano
Italy	INFN Padova

Photon Detector

Tasks of the PD

1. t_0 determination (Trigger System)
2. Calorimety: Collection of total light emitted
3. Reconstruction and particles identification
4. Catch Michel Electrons

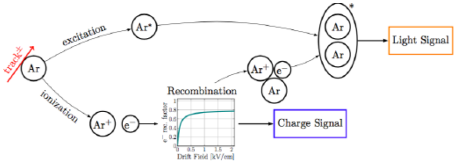
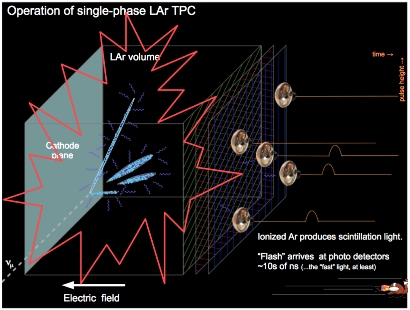
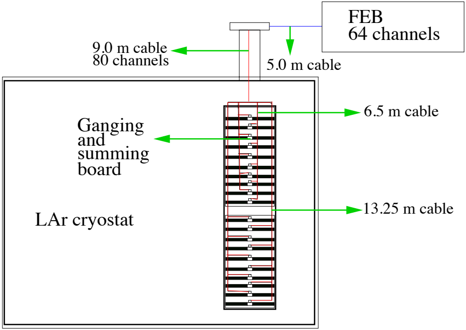


Figure: https://arxiv.org/pdf/1601.02984.pdf





Photon Collection Baseline

1. Light Collection System: Collects photons from a large area and drives towards the actives sensors. X-ARAPUCA is the baseline design
2. Silicon Photonmultipliers (SiPMs): MPPCs are currently the baseline. FBK is being strongly persued
3. Cold electronics: 48 SiPMs plus Summing boards
4. Warm electronics: Cost-effective waveform digitization system developed by the Mu2e experiment that relies on commercial ultrasound chips (12-bit, 80MS/s)

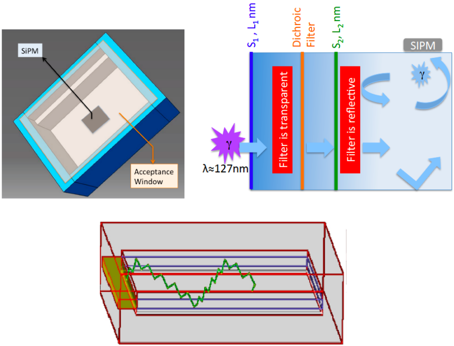


Figure: https://arxiv.org/pdf/1601.02984.pdf

Content

- Introduction
- Long-Baseline Neutrino Experiments
- DUNE Overview
- The DUNE Single Phase Photon Detection System (PDS-SP)
- The Contribution of Latin America to the PDS-SP
- Summary

UNIVERSIDAD NACIONAL DE ASUNCIÓN
FACULTAD DE INGENIERÍA

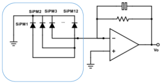
Design of the Active Ganging boards

Esteban Cristaldo, Jorge Molina
Carlos Montiel, Diego Aranda

DUNE-SP Photon Detection System
Conceptual Design Review

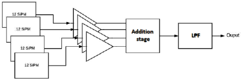
November 12th, 2018

We want to know if we can amplify **12** SiPM in paralell (active *ganging*) with one output channel.



Design scheme

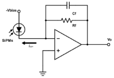
Three stages of the circuit for 48 SiPM:



Charge integrators
or transimpedance

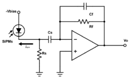
3

Two preamps models studied



Transimpedance model

- This is a first order low pass filter
- Rf and Cf establish the bandwith and frequency cut point
- Eliminates high frequency noise



Charge integrator model

- This is a second order band pass filter
- Cf and Cs establish the bandwith and frequency cut point
- Eliminates low and high frequency noise

4

Digitalization Parameters

DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

UAN UNIVERSIDAD ANTONIO NARIÑO

ELECTRONICS SIMULATION

Maritza Delgado

Nov. 5 , 2018

1

Introduction

Dynamic Range

Goal: Find the maximum number of true photons with different time windows and quantum efficiency.

- Data generated by module **SPCounter_module.cc,** based on SimPhotonCounter_module.cc.
- Sample: Beam Neutrinos prodgenie_nu_dune10kt_1x2x6_323_20171227T183346_merged1.root
- The first step was to identify the maximum number of true photons by each Optical Detector per event from PhotonsLite.

2

1.Scale factor

The scale factor was determinated using the effective detector areas and QE values.

- 4.05 cm² (0.00287) (current standard in vanilla larsoft. Close to the current dip-coated design)
- 5.1 (0.00361) (Close to lowest ARAPUA measurement and potential improved dip-coated design)
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https://indico.fnal.gov/event/16848/contribution/4/material/slides/0.pdf

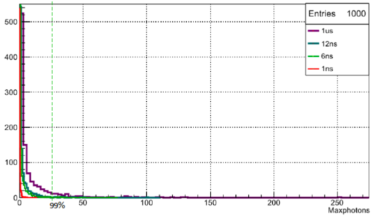
Area (cm²)	QE	QE/4
15	0,01063	0,002658
30	0,021231	0,005308
45	0,031847	0,007962
60	0,042462	0,010616

One Optical Detector have 4 Channels.

4

1000 EVENTS

2. Effective Area: 15cm²

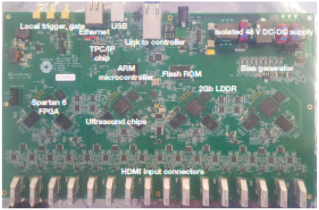


DAPHNE development

DAPHNE: Detector electronics for Acquiring PHotons from NEutrinos

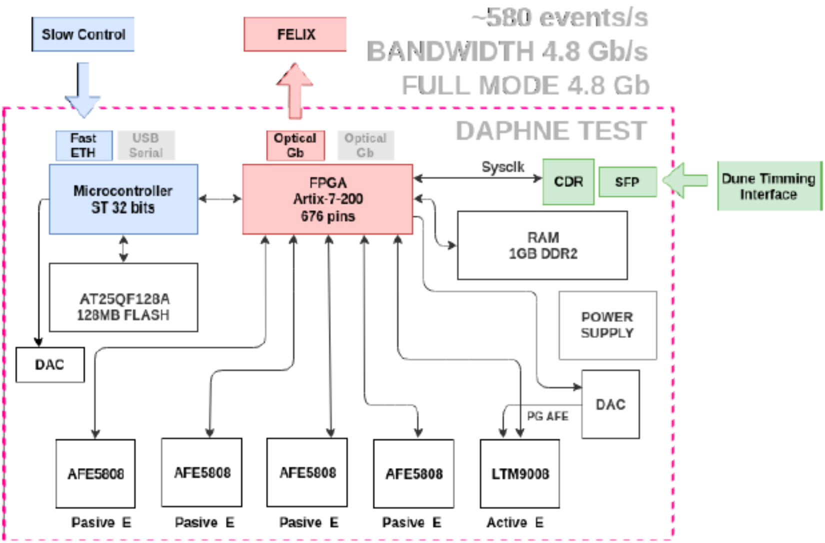
Electronics requirements

- Signal to noise Ratio > 4
- Less than 1 μs time resolution
- Less than 1 kHZ dark noise rate
- 2000 PE dynamic range



Prof Javier Castaño (UAN) working at Fermilab in the design of the board.

DAPHNE development



EIA: Escuela de Ingenieros de Antioquia

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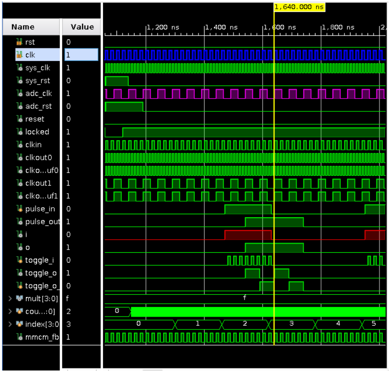
EIA-FTA group members:

- Amalia Betancur
- Juan Suárez
- Guillermo Palacio
- Manuel Arroyave

Activities:

- FPGA control automatization.
- Formal Verification
- Gateware granularity
- Zero suppression algorithms
- Soft Core emulation
- Embedded digital modules



Simulation of the clock system.

Expected timeline

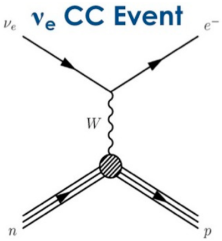
1. 2020: Test of First DAPHNE Prototypes at ICEBERG
2. 2021: Test of DAPHNE boards at ProtoDUNE II
3. 2024: Start installing first SP module
4. 2025: Start installing second module and DUNE physics with atmospheric neutrinos.
5. 2026: Beam operation at 1.2 MW
6. 2027: Add third FD Module
7. 2029: Add fourth FD Module
8. 2032: Upgrade to 2.4 MW beam

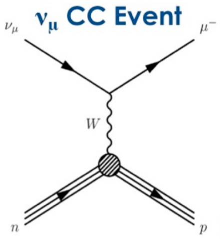
Summary

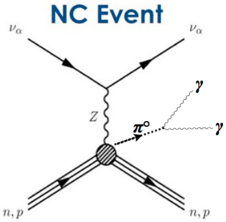
1. LBL experiments are ideal tools to test the neutrino physics
2. LBNF/DUNE has become a global international collaboration
3. DUNE has a broad and rich physics program including CP violation probes, mass ordering determination, precision neutrino oscillation measurements. SN neutrinos and BSM searches
4. DUNE prototypes funcional and taking data
5. Strong participation of LA in the Single PD module
6. Looking forward for first DUNE far Detector data in 2024

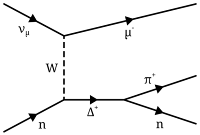
Backup Slides

Neutrino-Nucleon Interactions









2.3 Proton Decay

Proton decay is expected in most new physics models

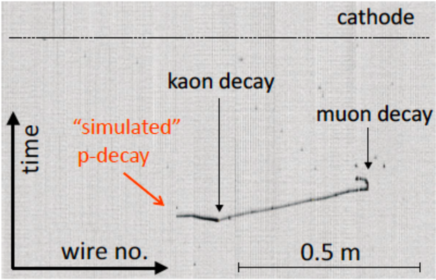
- But lifetime is very long, experimentally $\tau > 10^{33}$ years
- Watch many protons with the capability to see a single decay
- Can do this in a liquid argon TPC
  - For example, look for kaons from SUSY-inspired GUT p-decay modes such as $p \to K^+\bar{\nu}$

- Clean signature
  ➡ very low backgrounds

Decay Mode	Water Cherenkov		Liquid Argon TPC	
	Efficiency	Background	Efficiency	Background
$p \to K^+\overline{\nu}$	19%	4	97%	1
$p \to K^0\mu^+$	10%	8	47%	< 2
$p \to K^+\mu^-\pi^+$			97%	1
$n \to K^+e^-$	10%	3	96%	< 2
$n \to e^+\pi^-$	19%	2	44%	0.8

1 Mt.yr

Remove incoming particle



Why Argon?

- Inert – since need to avoid anything electronegative
  - In pure argon, ionization electrons can drift long distances (metres)
- Good dielectric properties, supports high-voltages/fields: 500 V/cm
- An excellent **scintillator** (128 nm) and transparent at this wavelength
- Argon is cheap and readily available (1% of atmosphere)

	Water	He	Ne	Ar	Kr	Xe
Boiling Point [K] @ 1atm	373	4.2	27.1	87.3	120.0	165.0
Density [g/cm³]	1	0.125	1.2	1.4	2.4	3.0
Radiation Length [cm]	36.1	755.2	24.0	14.0	4.9	2.8
Scintillation [γ/MeV]	-	19,000	30,000	40,000	25,000	42,000
dE/dx [MeV/cm]	1.9		1.4	2.1	3.0	3.8
Scintillation λ [nm]		80	78	128	150	175

DAPHNE development

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- Deywis Moreno
- Yohany Rodriguez
- Maritza Delgado

UAN
UNIVERSIDAD
ANTONIO NARIÑO

Prof Javier Castano is working at Fermilab in the design of the board.

Determination of Digitalization Parameters

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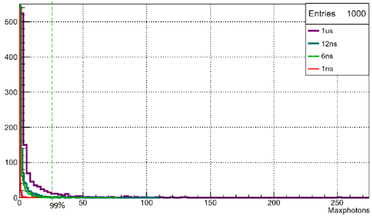
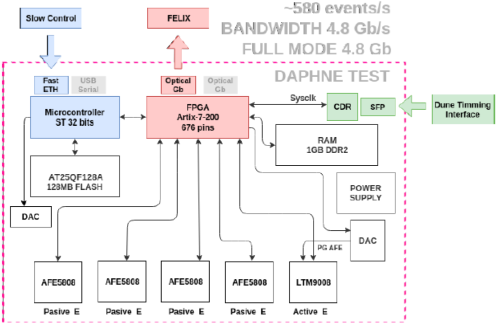


DAPHNE development



DAPHNE development

Universidad Antonio Nariño (2017)

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ANTONIO NARIÑO

UAN group members:

- Deywis Moreno (Group leader)
- Javier Castaño
- Yohany Rodriguez
- Maritza Delgado (Graduate student)

Activities:

- Definition of the electronics for the Photon Detection System.
- Hardware design.

Prof Javier Castano working at Fermilab in the design of the PDS electronics.

DAPHNE Firmware Development.

EIA: Escuela de Ingenieros de Antioquia (2019)

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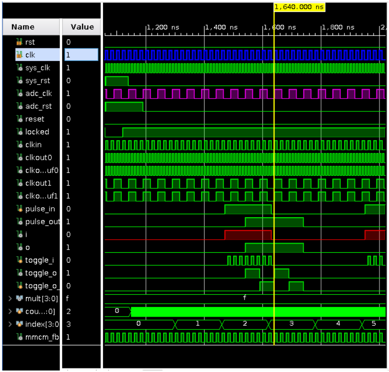
EIA-FTA group members:

- Amalia Betancur (Group leader)
- Juan Suárez
- Guillermo Palacio
- Manuel Arroyave (Researcher)

Activities:

- FPGA control automatization.
- Hardware design.



Simulation of the clock system.

DUNE data analysis.

Univ. Sergio Arboleda (2017)

EIA-FTA group members:

- Luz Gomez (Group leader)
- Laura Gomez
- Andres Castillo
- Nestor Pachon (Undergraduate student)

Activities:

- Searches for Physics beyond the Standard Model at DUNE
- Reconstruction and identification tools.