

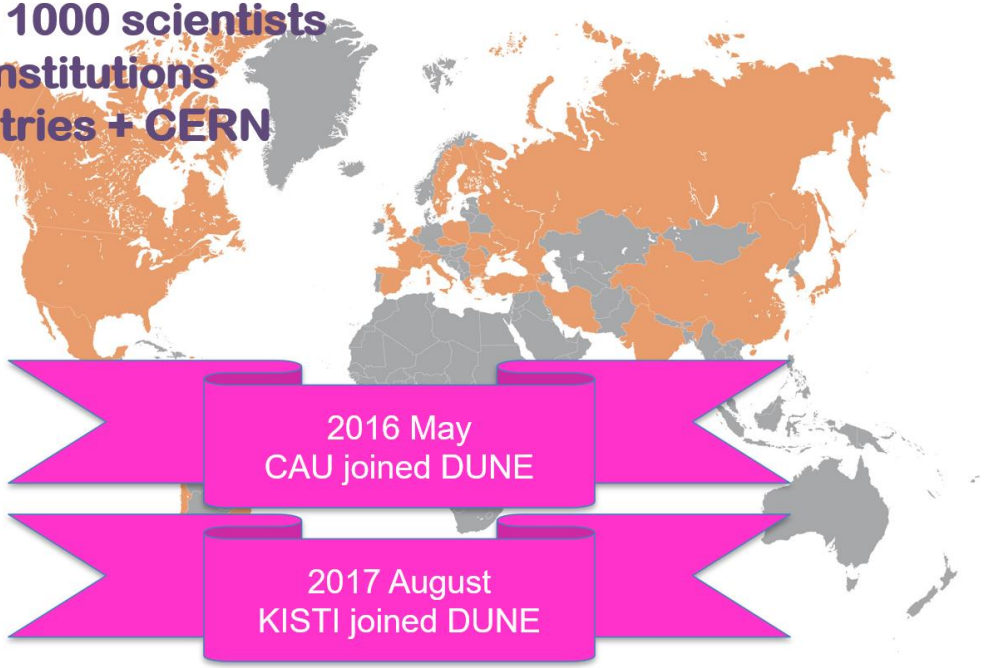
Korean Contribution to the DUNE

Kim Siyeon
Chung-Ang University

KPS 2026 Fall, Jeju

Korean Participation

More than 1000 scientists
from 175 institutions
in 32 countries + CERN



de Lyon; APC-Paris; CEA/Saclay
Greece Univ. of Athens
India Aligarh Muslim University; Banaras Hindu University; Bhabha Atomic Research Center; Indian Inst. of Tech. Bombay; Univ. of Delhi; Indian Inst. of Technology, Guwahati; Harish-Chandra Research Institute; Indian Inst. of Technology, Hyderabad; Univ. of Hyderabad; Univ. of Jammu; Jawaharlal Nehru University; Koneru Lakshmaiah University; Univ. of Lucknow; Panjab

Peru Univ. Nacional de Ingineria; PUCP
Poland Inst. of Nuclear Physics, Krakow; National Centre for Nuclear Research, Warsaw; Warsaw Univ. of Technology; Univ. of Warsaw; Wroclaw University
Romania Horia Hulubei National Institute
Russia Inst. for Nuclear Research, Moscow
South Korea Chung-Ang University
Spain Inst. de Fisica d'Altas Energias, Barcelona; CIEMAT; Inst. de Fisica Corpuscular, Madrid; Madrid Autonoma Univ.

Univ. of California, Davis; Univ. of California, Irvine; Univ. of California, Los Angeles; California Inst. of Technology; Univ. of Chicago; Univ. of Cincinnati; Univ. of Colorado; Colorado State University; Columbia University; Cornell University; Dakota State University; Drexel University; Duke University; Fermi National Accelerator Lab; Univ. of Hawaii; Univ. of Houston; Idaho State University; Illinois Institute of Technology; Indiana University; Iowa State

Technology; South Dakota Science And Technology Authority; South Dakota State University; Southern Methodist University; Stanford University; Stony Brook University; Syracuse University; Univ. of Tennessee; Texas A&M University, Corpus Christi; Univ. of Texas at Arlington; Univ. of Texas at Austin; Tufts University; Valley City State University; Virginia Tech; Wichita State University; College of William and Mary; Univ. of Wisconsin; Yale University

DUNE, 진동하는 중성미자 그 이상을 찾아서...

DOI: 10.3938/PhiT.26.016

김 시 연

DUNE, Beyond Neutrino Oscillation

Siyeon KIM

The Deep Underground Neutrino Experiment (DUNE) is an oscillation experiment with two detectors, one at the Sanford Underground Research Facility in South Dakota and the other at Fermilab near the source of the neutrino beam. A high-intensity beam flows along the 1300-km-long baseline, expecting that solutions to the problems of mass hierarchy and CP violation in the three-neutrino model can be found at some stage of the experiment. At an Intensity frontier, the DUNE project features high-power beam, liquid-argon time-projection-chamber detectors, and pattern-recognition data analyses using a convolutional neural network. The physical targets overcome the framework of three-neutrino oscillation, aiming for groundbreaking discoveries. The far detector will be patiently waiting for neutrinos from a core-collapse supernova in our galaxy and proton decays inside the detector. The near detector, in scanning the high-density beam, helps in understanding neutrino interactions exclusively. In this article, the potential and the current progress of the DUNE is briefly discussed.

중성미자의 질량과 진동실험의 남은 숙제

전자중성미자, 뮤온중성미자, 타우중성미자는 표준모형의 입자이다. 짝을 이루는 경입자들과 약하게 결합하거나, 스스로 중성적 커플링을 하는 정도로 표준모형이 예측하는 반응과정들에서 일관적으로 나타난다. 약한 상호작용에 근거한 반응에서 어떠한 기여를 하는가 계산하고 확인은 가능했으나, 입자의 존재자체를 표현할 정보는 표준모형의 범주에서 구하지 못했다. 중성미자의 질량을 정의할 수 없고 오른손지기(right-handed helicity)가 없다는 비대칭성은, 충돌실험에서 획득한 성공적 정확성에도 불구하고, 표준모형이 여전히 도전해야 할 제한적 유효성을 가지고 있음을 의미했다.

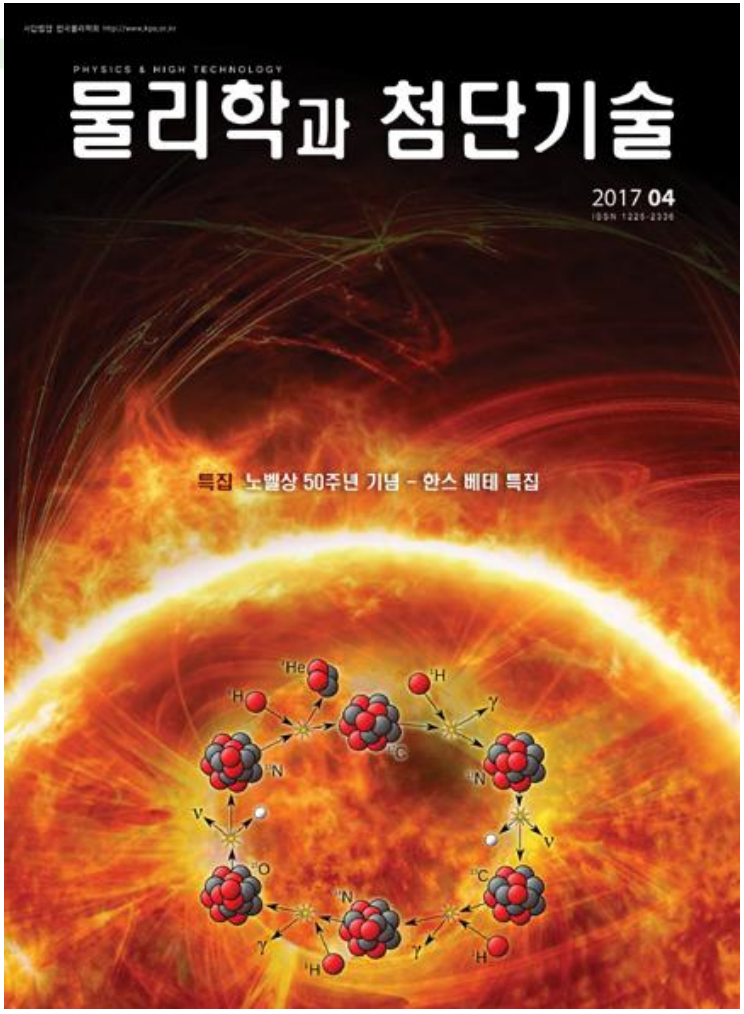
쿼크의 질량을 물리학적으로 표현하기 위해서 약한상호작용하는 쿼크로부터 살짝 변환시켜야 하는데, 이 변환 장치를 CKM[1] 행렬이라고 한다. 즉, 상호작용으로부터 만들어진 쿼크는 바로 질량이 얼마라고 말할 수 없는 양자역학적 사정이 있어서, 변환을 시킨 고유상태들에서 질량을 정의할 수 있다. 물론 이들도 쿼크는 쿼크이다. 같은 논리로, 질량을 정의할 수 있는 중성미자와 상호작용 중성미자는 동일하지 않고, 변환시켜 표현할 수 있다. 중성미자의 변환행렬은 PMNS[2]라고 부른다. 그런데, 이렇게 질량을 특정할 수 있는 1번, 2번, 3번 중성미자는 더 이상 표준모형의 입자가 아니다. 중성미자는 오른손지기가 없는 까닭에 표준모형은 중성미자의 질량이 없다는 이론이기 때문이다.

실험을 통해서 중성미자 질량을 확인한다는 것은 표준모형의 범주를 벗어나 새로운 기본입자 세계의 발견을 의미한다. 표준모형에서 탈피하는 현상인 중성미자의 질량을 확인하고 현대물리학에 근거하여 이해한 것은 태양중성미자 검출실험 SNO[3] 와 대기중성미자 검출실험 SK[4]에서 시작되었다. SNO 실험은 태양핵융합의 결과물인 전자중성미자가 태양모델의 예측에 비해 검출량이 많이 부족하다는 미스터리를 풀었다. 태양에서 만들어지지 않은 뮤온중성미자와 타우중성미자도 함께 검출하여, 중성미자의 총량을 고려하면 이론적으로 예측된 중성미자의 입사량과 같고, 종류에 국한하면 3분의 1 정도만 전자중성미자라는 사실을 확인하였다. SK 실험은 우주선(cosmic rays)의 붕괴 결과 지구에 입사하는 대기중성미자를 검출하였다. 파이온이 붕괴하는 과정에서 뮤온 중성미자와 전자 중성미자의 비율이 정해져 있는데, 지구를 관통하기 전후 비율이 달라진 것을 확인한 실험이다.

위와 같은 종류의 실험으로 중성미자의 질량을 이해하는 방법은 다음과 같다. 예를 들면, 태양에서 방출되는 전자중성미자는

저자약력
김시연 교수는 미국 Indiana University, Bloomington(2002)에서 박사학위를 취득하고 대만 Academia Sinica 국립물리학연구소 연구원(2002-2003)을 거쳐 2003년부터 현재 중앙대학교 물리학과 교수로 재직 중이다. 현재 IBS 지하실험연구단 자문교수(2014-), 중앙대학교 기초과학연구소 소장(2015-)을 맡고 있다. (siyeon@cau.ac.kr)

1) CKM: Cabbibo-Kobayashi-Maskawa
2) PMNS: Potecorvo-Maki-Nakagawa-Sakata
3) SNO: Sudbury Neutrino Observatory
4) SK: Super Kamiokande



PHYSICS and HIGH TECHNOLOGY
by Korean Physical Society

Korean Participation

CAU visited Fermilab. Sept.20, 2018



- **iCRADA between CAU and Fermilab for "Scientific and Technical cooperation in the Field of Neutrino Physics: LBNF and DUNE"**
- **The agreement can be extended to include other institutes.**

Korean Participation

INTERNATIONAL

COOPERATIVE RESEARCH AND DEVELOPMENT AGREEMENT

FOR

BASIC SCIENCE COOPERATION

(HEREINAFTER "CRADA") NO. FRA-2017-0044

BY AND AMONG

FERMI RESEARCH ALLIANCE, LLC
UNDER ITS U.S. DEPARTMENT OF ENERGY CONTRACT
NO. DE-AC02-07CH11359
TO MANAGE AND OPERATE
FERMI NATIONAL ACCELERATOR LABORATORY
(HEREINAFTER "LABORATORY")

AND

CHUNG-ANG UNIVERSITY

(HEREINAFTER "PARTICIPANT")

LABORATORY AND PARTICIPANT COLLECTIVELY REFERRED TO

AS THE "PARTIES" AND SEPARATELY AS A "PARTY"

ANNEX A
Scientific and Technical Cooperation in the Field of Neutrino Physics:
Long Baseline Neutrino Facility (hereinafter "LBNF") and
Deep Underground Neutrino Experiment (hereinafter "DUNE") Activities
(hereinafter, individually referred to as "Project" or collectively as "Projects")

May 2018

Section 1
Purpose

1.1 This purpose of this Annex is to describe the framework under which the Parties will cooperate in the field of neutrino physics, including enabling technologies for neutrino detectors and particle beams. The cooperative activities covered by this Annex are the Projects known as the Long-Baseline Neutrino Facility (LBNF) and the Deep Underground Neutrino Experiment (DUNE). This Annex will be further amended by Project-specific Task Orders (e.g. A-1, A-2, A-3, etc.) that define the specific contributions of the Parties in support of either Project or both Projects described in this Annex.

1.2 This Annex and all Task Order amendments are subject to and governed by the CRADA (Agreement No. FRA-2017-0044) between the Parties and all the terms, conditions and provisions of said CRADA are hereby incorporated by reference. The Parties agree to perform their respective obligations related to these Projects in accordance with the terms and conditions of this Annex and other documents attached or incorporated by reference, which together constitute the entire Annex. In the event of any conflict between the provisions of this Annex and the provisions of the CRADA, the CRADA terms shall control.

Section 2
Scientific Goals

2.1 The scientific goals of the Parties' co-operative activities in neutrino physics include, but are not limited to, the following:

(a) A comprehensive investigation of neutrino oscillations to test charge-parity violation in the lepton sector which could explain the absence of antimatter in the universe;
(b) A determination of the ordering of the neutrino masses;
(c) Testing of the three-neutrino paradigm;
(d) Measurement of neutrino scattering cross sections with various nuclei;
(e) A search for nucleon decay; and
(f) Measurement of astrophysical neutrinos, particularly those from core-collapse supernovae.

Korean Participation

INSTITUTION	COUNTRY	ACTIVE INST	ACTIVE COLLABORATORS	TOTAL INACTIVE MEMBERS	REPRESENTATIVE	CREATED
5	1	5	10	11	5	5
	Korea	Y				
Chung-Ang University	Korea, South	Y	6	10	Kim Siyeon	2017-11-30
Jeonbuk National University	Korea, South	Y	1	1	Seodong Shin	2020-05-20
Jeju National University	Korea, South	Y	1	0	Young Ju Ko	2025-10-10
Seoul National University of Science and Technology	Korea, South	Y	1	0	Myeonghun Park	2025-10-10
Han-Yang University	Korea, South	Y	1	0	Sungbin Oh	2026-10-14

INSTITUTION	COUNTRY	ACTIVE INST	ACTIVE COLLABORATORS	TOTAL INACTIVE MEMBERS	REPRESENTATIVE	CREATED
2	1	0	0	5	2	2
	Korea	N				
Korea Institute of Science and Technology Information	Korea, South	N	0	1	Kihyeon Cho	2017-11-30
Ulsan National Institute of Science and Technology	Korea, South	N	0	4	Moses Chung	2020-05-20

Korean Participation

- DUNE Theses
  - Ph. D. Sunwoo Gwon (CAU, 2024)
    > Neutron Kinematic Detection and Its Applications in Long-Baseline Neutrino Experiments
    > Currently Postdoc at CNU
  - M. Sc. Chang Hwan Jang (CAU, 2018)
    > Muon and Antimuon Discrimination in the DUNE Near Detector
    > Currently researcher at Dongnam Power Plant
  - M. Sc. Suhyeon Kim (CAU, 2025)
    > Probing Large Extra Dimensions in DUNE Using Beam Tuning
    > currently at PUCP-Harvard Joint Ph. D. Program
  - M. Sc. Hokyeong Nam (CAU, 2026)
    > DNN-Based Signal Processing for ProtoDUNE
    > currently at Ph. D. Program at U. Minnesota

Korean Participation

- Phenomenological Works related to DUNE
  - Seodong Shin (JBNU, 2018)
    > Searching for Boosted Dark Matter at ProtoDUNE
    with A. Chatterjee et al. PhysRevD.98.075027
  - Seodong Shin (JBNU, 2020)
    > Probing Energetic Light Dark Matter with Multi-Particle Tracks Signatures at DUNE
    with A. De Roeck et al. JHEP11(2020)043
  - Kim Siyeon (CAU, 2024)
    > Probing Large Extra Dimensions at DUNE Using Beam Tunes
    > with Suhyeon Kim, Mehedi Masud, Juseong Park, JHEP 11(2024) 141
  - Mehedi Masud (CAU, 2025)
    > Sterile sector impacting the correlations and degeneracies among mixing parameters at the DUNE
    > with S. Parveen et al. JHEP 01(2025) 139

Korean Contributions

- Near Detector > System for on-Axis Neutrino Detection > 3-Dimensional Scintillator Tracker
  : Collaboration with Stony Brook NN Group

- ProtoDUNE & Far Detector Cold Electronics
  : Collaboration with BNL Electronics Detector Group

- Wire-Cell Reconstruction & AI/ML
  : Collaboration with BNL Electronics Detector Group

Korean Contributions

2017



Formal members:

Kim Siyeon(김시연)

Chang Hwan Jang(장창환) , Youngju Ko(고영주)

Candidates:

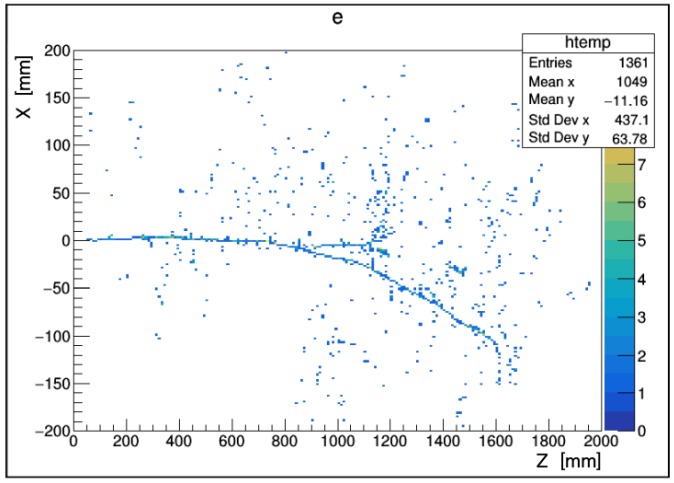
Sunwoo Gwon(권순우), Yeonwoo Jeong(정연우)

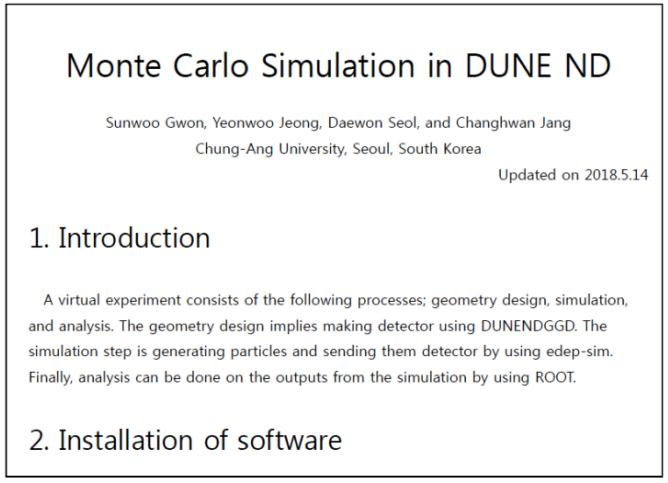
Daewon Seol(설대원)

Collaboration with BNL to test Cold Electronics

Tested more than 1800 ADC chips in cold condition at BNL, Jan-Feb 2018

- **For DUNE internal note, "MC simmulation in DUNE ND" under supervision of Dr. Jose Palomino**





Monte Carlo Simulation in DUNE ND

Sunwoo Gwon, Yeonwoo Jeong, Daewon Seol, and Changhwan Jang

Chung-Ang University, Seoul, South Korea

Updated on 2018.5.14

1. Introduction

A virtual experiment consists of the following processes; geometry design, simulation, and analysis. The geometry design implies making detector using DUNENDGGD. The simulation step is generating particles and sending them detector by using edep-sim. Finally, analysis can be done on the outputs from the simulation by using ROOT.

2. Installation of software

Korean Contributions

- ND > SAND > 3DST

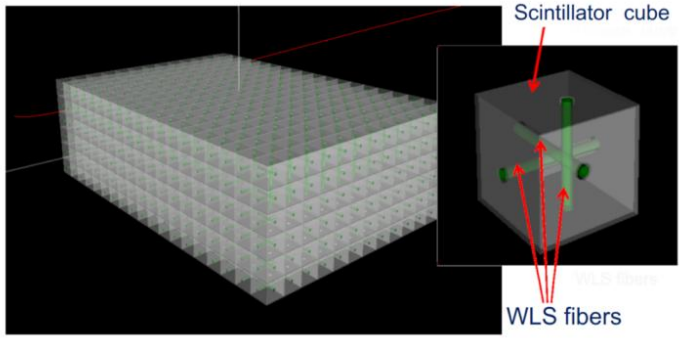


FIG. 1. The concept of the 3D-projection scintillator tracker.

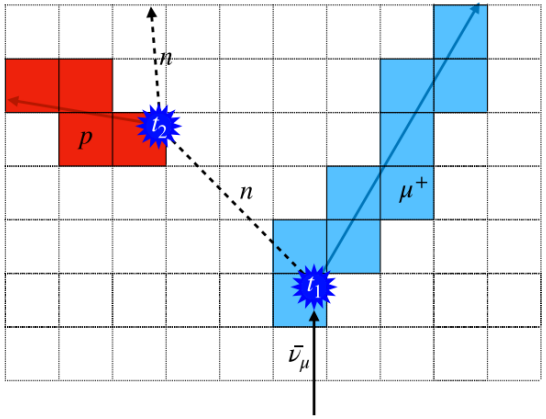


FIG. 3. Time-of-flight and lever arm. A neutron-induced cluster in the 3DST is identified by the first cluster after the $\bar{\nu}_\mu$ interaction.

PHYSICAL REVIEW D **107,** 032012 (2023)

Neutron detection and application with a novel 3D-projection scintillator tracker in the future long-baseline neutrino oscillation experiments

S. Gwon,[1] P. Granger,[2] G. Yang,[3,4,*] S. Bolognesi,[2] T. Cai,[5] M. Danilov,[6] A. Delbart,[2] A. De Roeck,[7] S. Dolan,[7] G. Eurin,[2] R. F. Razakamiandra,[8] S. Fedotov,[9] G. Fiorentini Aguirre,[10] R. Flight,[5] R. Gran,[11] C. Ha,[1] C. K. Jung,[12] K. Y. Jung,[1] S. Kettell,[13] M. Khabibullin,[9] A. Khotjantsev,[9] M. Kordosky,[14] Y. Kudenko,[9,15,16] T. Kutter,[17] J. Maneira,[18] S. Manly,[5] D. A. Martinez Caicedo,[10] C. Mauger,[19] K. McFarland,[5] C. McGrew,[12] A. Mefodev,[9] O. Mineev,[9] D. Naples,[20] A. Olivier,[5] V. Paolone,[20] S. Prasad,[17] C. Riccio,[12] J. Rodriguez Rondon,[10] D. Sgalaberna,[21] A. Sitraka,[10] K. Siyeon,[1] N. Skrobova,[6] H. Su,[20] S. Suvorov,[9] A. Teklu,[12] M. Tzanov,[17] E. Valencia,[14] K. Wood,[12] E. Worcester,[13] and N. Yershov[9]

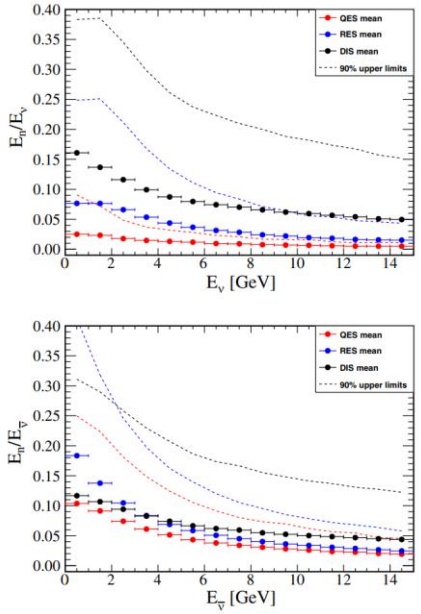


FIG. 2. Average energy fraction transferred to the primary neutrons relative to the neutrino energy (top) and the antineutrino energy (bottom). The average ratios are calculated for CCQE, CCRES, and CCDIS interaction modes. The dashed lines show for each channel the energy fractions below 90% of the distribution.

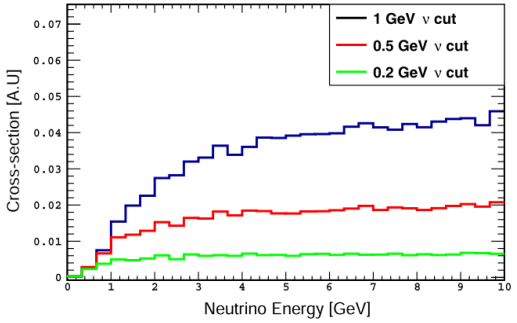
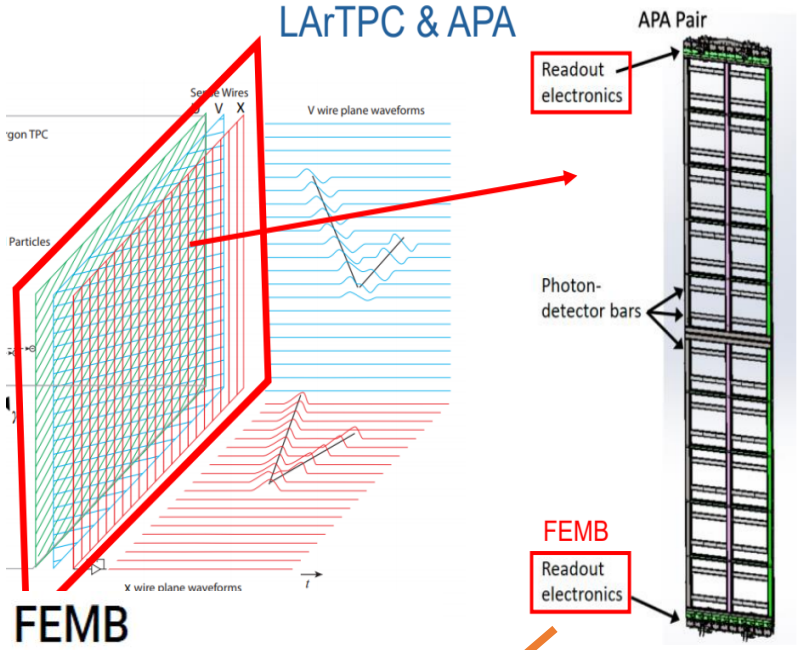


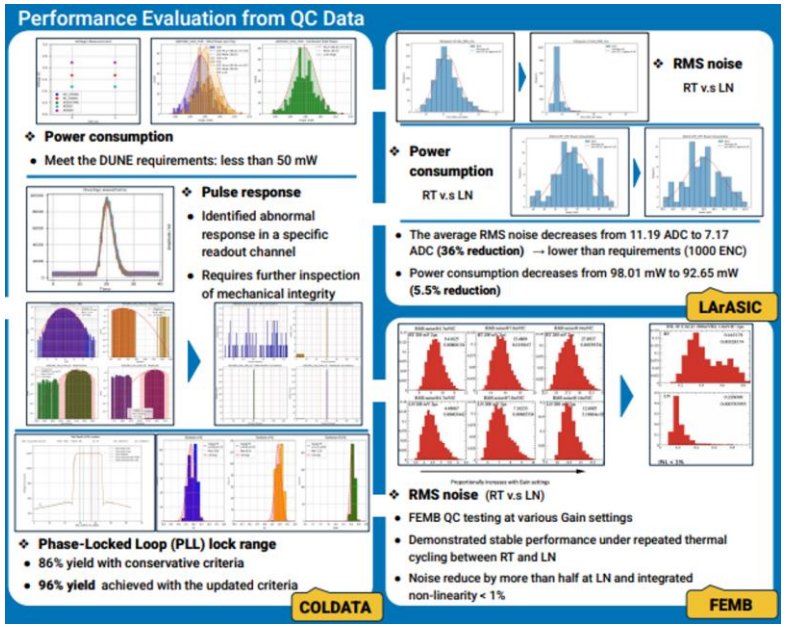
FIG. 26. Cross section shape as a function of E_ν with various ν selections. The lower-ν results in a flatter cross section.

Cryogenic Readout Electronics

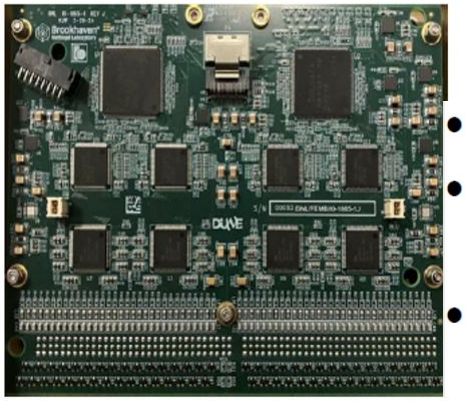
K-DUNE Activities

LArTPC U, V, X wires → Cold Electronics → Warm Electronics → DAQ → Data Processing → Event Selection → Reconstruction → Physics Analysis





❖ FEMB



- COLDATA configures and controls 4 COLDADCs and 4 LArASICs
- LArASIC provides front-end amplification
  - Four adjustable gain levels: 4.7, 7.8, 14, 25 mV/fC
- Front-End Motherboard (FEMB) integrates **All ASICs** :
  - 8 x LArASIC, 8 x ColdADC, 2 x COLDATA

2025-11-18, 중앙대 남호경, Masud 외
Internal Report DUNE-doc-35313.

Korean Contributions

Visiting BNL for Collaboration with EDG
for cold electronics Readout system

YYYY.MM	교수	대학원생 .연구원	학부생	총인원	
2017.07-08	김시연	장창환		2	
2018.01-02		장창환	권순우, 정연우, 설대원	4	
2019.01-02		권순우, 정연우		2	
2021.01-02		권순우	정기영	2*	
2021.07-08		권순우, 정기영		2*	
2023.02	김시연			1	으로 방문하여 활동
2023.02-03		권순우, 정기영	박유진	3	
2024.01-02		권순우, 김수현, Emar Masaku	박주성, 고경의	5	
2025.01-02	Kim Siyeon	Masud, Fiza, 김수현, 남호경, 박주성, 권순우		7	
2026. 02		김선홍, 남호경, 박주성	박유진	4	



DUNE Software Development

K-DUNE Activities

Event Generation → Simulation → Data Processing → Event Selection → Reconstruction → Physics Analysis

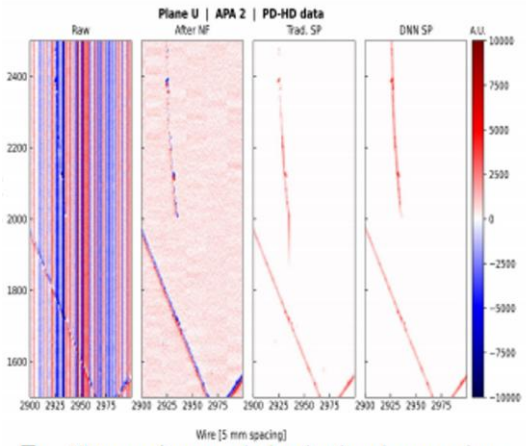
Liquid Argon Software: Simulation and reconstruction packages for LArTPC detectors

- **Event generation:** Genie, CORSIKA, CRY, SingleGen module
- **Simulation:** GEANT4, FLUKA
- **Reconstruction:** **Wire-Cell**, Pandora

Wire-Cell Toolkit

Part 1:	Part 2:	Part 3:
Simulation	3D imaging	3D vertexing
Noise Filtering	Clustering	Particle Identification
Signal Processing	Charge-Light Matching	3D Pattern Recognition
	Neutrino Event Selection	

MicroBooNE → SBND, ProtoDUNE-HD, ProtoDUNE-VD, DUNE FD



2D waveform evolution in signal processing

Raw data > noise filtering > traditional signal processing > DNN signal processing

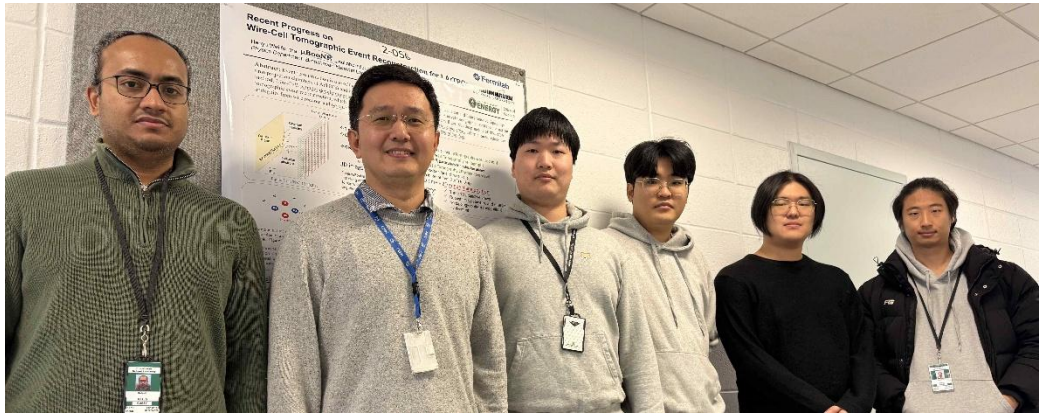
Wire Cell (Leader Xin Qian at BNL)
- Fully validated with MicroBooNE

K-DUNE Activities
- Extension to ProtoDUNE
- Extension to DUNE FD
- Upgrade to DNN Wire Cell
- Test of Quantum ML

- Currently working on ProtoDUNE
- Stronger team with more CAU, Seoul Tech, and Jeju University.

Korean Contributions











CAU Plans

- ProtoDUNE data analysis for physics target (Wire Cell)
- ND-Lar 2x2 Data Analysis (TRED)
- Readout FEMB Test
- Participation in FD contruction.

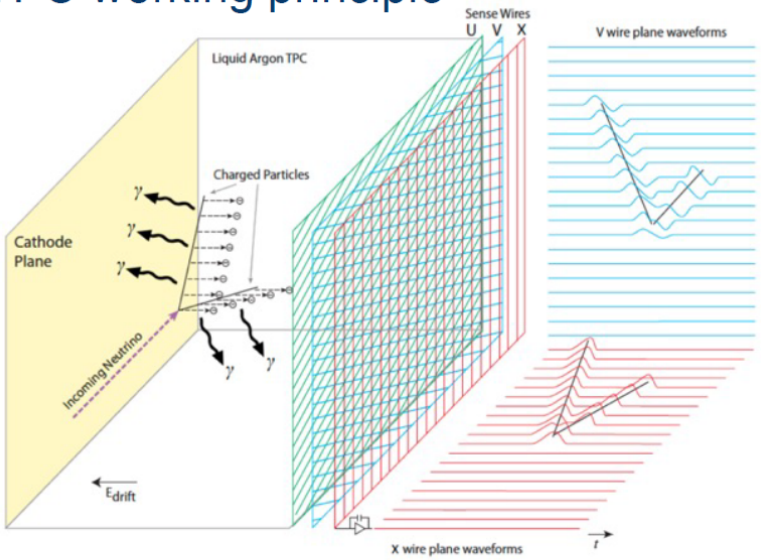
- CE test site in Korea
- FD3 Photon Detection system





The Single-Phase LAr-TPC

TPC working principle



- Ionization electrons [~5 fC/cm] drift to the anode in pure LAr & uniform E-field (~500 V/cm)
  - Few mm pitch and ~MHz sampling frequency
  - 3D via multiple 2D view (wire# vs drift time)
  - high imaging capabilities → kinematic reconstruction with mm-scale spatial resolution
  - Intrinsically excellent Calorimetry and Particle Identification (dE/dx) capability
- Prompt scintillation light (@128 nm)
  - T = 0, trigger, calorimetry

LAr as radiation detection medium

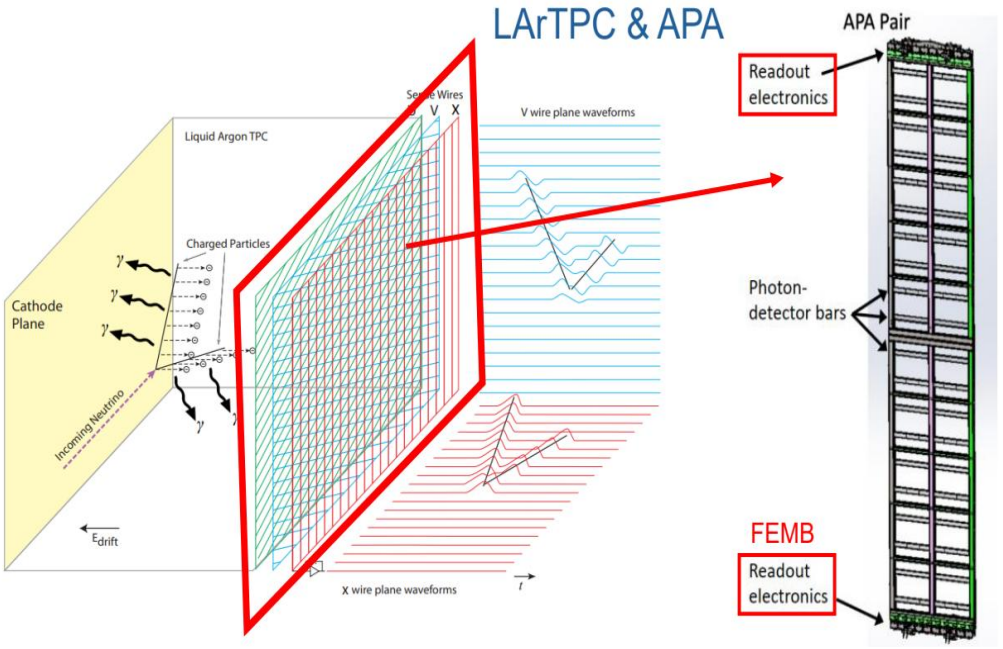
- Dense: 40% more than water
- Abundant primary ionization: 42 000 e^-/MeV
- High electron lifetime if purified → long drifts
- High light yield: 40k γ/MeV
- Easily available: ~1% of the atmosphere
- Cheap: $2/L ($3000/L for Xe, $500/L for Ne)

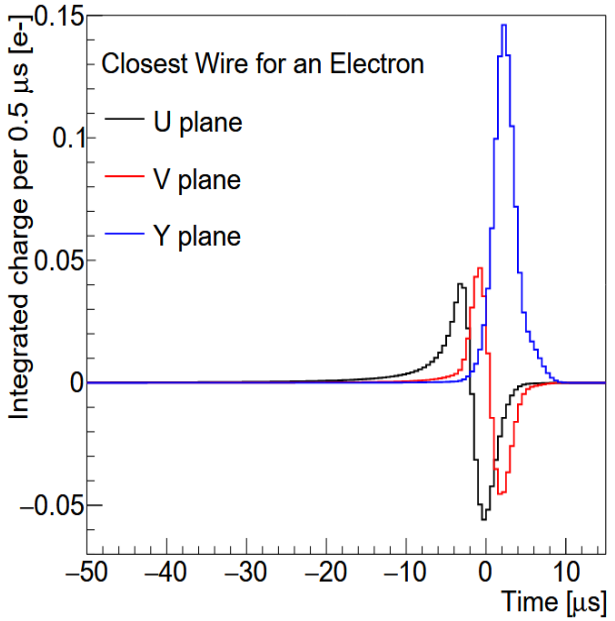
- Technological challenges
  - LAr continuous purification << 0.1 ppt O_2 eq. (>> 3 ms electron lifetime) for long drift
  - Imaging & anode planes
  - Very low noise front end amplifiers to detect ~ fC primary charge deposition
  - Large area photon detectors sensitive to 128 nm wave length
  - HV system to provide uniform/stable E-field in large drift volume
- Pioneered by ICARUS and adopted in present and next generation neutrino ezperiment (μBoone, SBND, DUNE)
  - DUNE: scaling to multi-kt size

From Detection to Analysis

LArTPC U, V, X wires → Cold Electronics → Warm Electronics → DAQ → Data Processing → Event Selection → Reconstruction → Physics Analysis

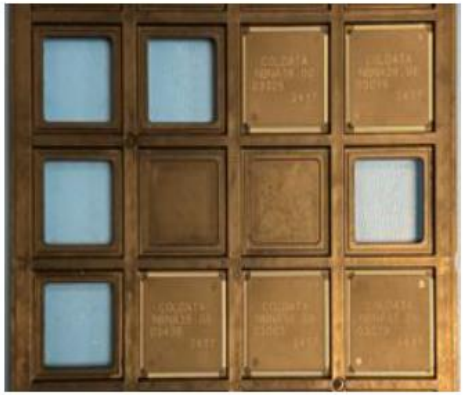
Event Generation → Simulation → Data Processing → Event Selection → Reconstruction → Physics Analysis



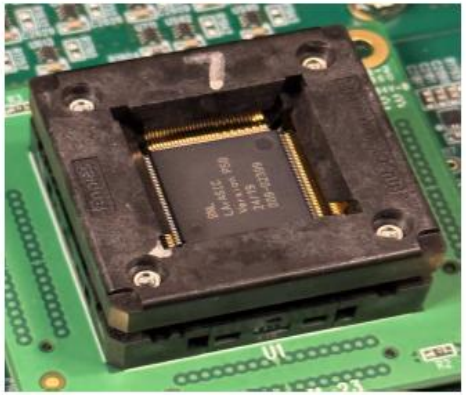


Cold Electronics Readout

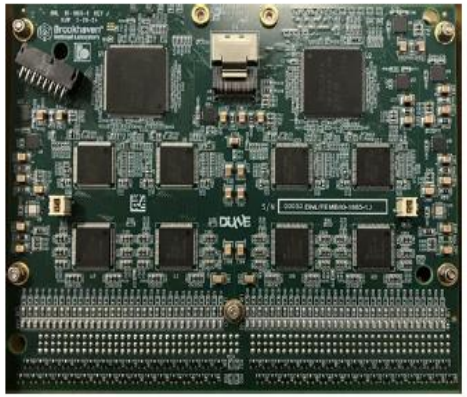
❖ COLDATA



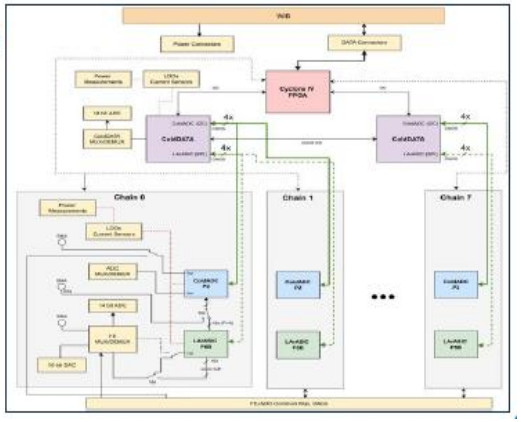
❖ LArASIC

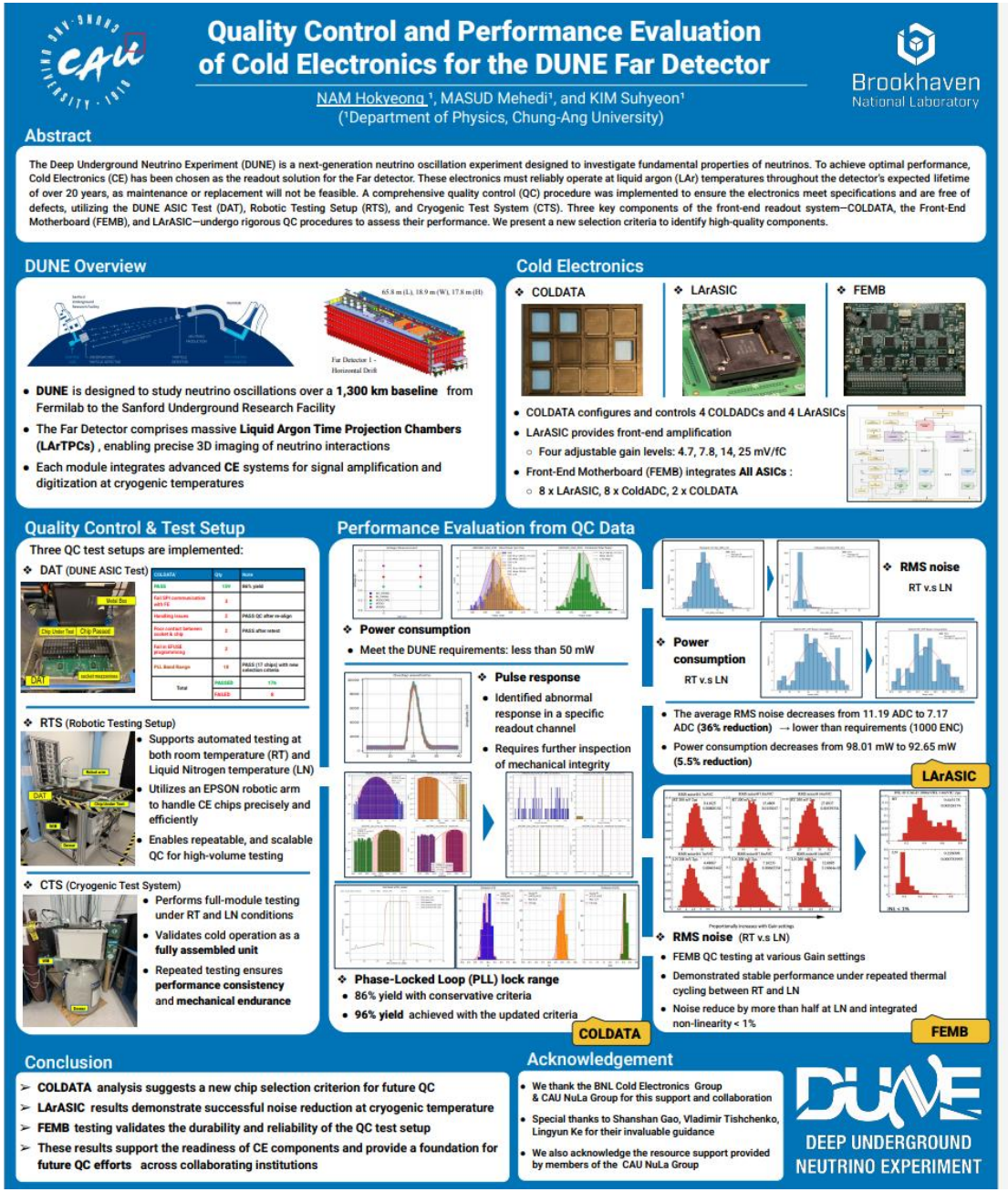


❖ FEMB



- COLDATA configures and controls 4 COLDADCs and 4 LArASICs
- LArASIC provides front-end amplification
  - Four adjustable gain levels: 4.7, 7.8, 14, 25 mV/fC
- Front-End Motherboard (FEMB) integrates **All ASICs** :
  - 8 x LArASIC, 8 x ColdADC, 2 x COLDATA





- CAU NULA

Finalizing an internal report on performance evaluation

Cold Electronics Working Group making a paper for publication

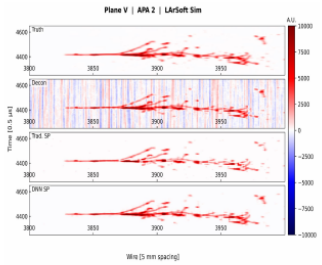
Wire-Cell and DUNE/ProtoDUNE Analysis

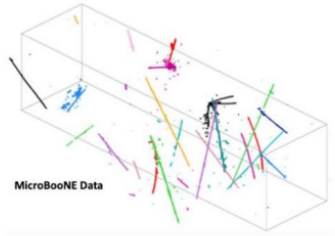
NAM Hokyeong[1], PARK Yujin[1], PARK Juseong[1], KIM Sunhong[1], SIYEON Kim[1]
([1]Department of Physics, Chung-Ang University)

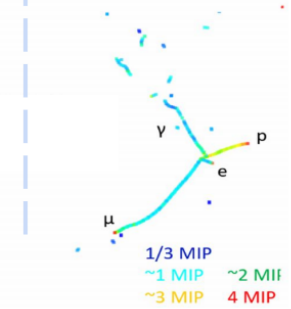
Brookhaven National Laboratory

Wire-Cell Toolkit

Part 1:	Part 2:	Part 3:
Simulation	3D imaging	3D vertexing
Noise Filtering	Clustering	Particle Identification
Signal Processing	Charge-Light Matching	3D Pattern Recognition
	Neutrino Event Selection	







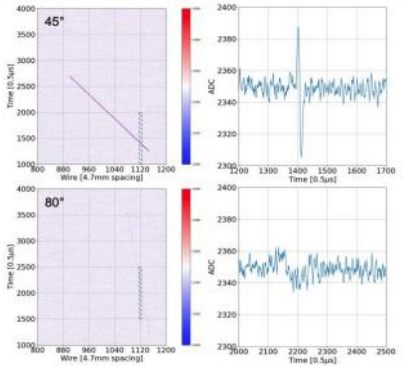
MicroBooNE → SBND, ProtoDUNE-HD, ProtoDUNE-VD, DUNE FD

Liquid Argon Software:

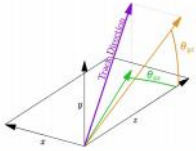
Simulation and reconstruction packages for LArTPC detectors

- **Event generation: Genie, CORSIKA, CRY, SingleGen module**
- **Simulation: GEANT4, FLUKA**
- **Reconstruction: Wire-Cell, Pandora**

DNN Signal Processing Motivation

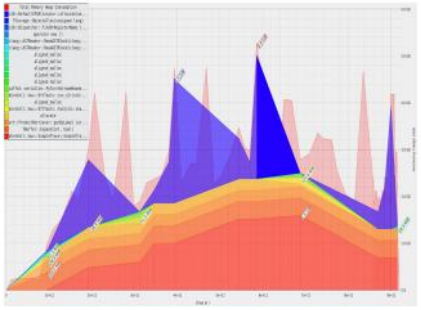


- Object with large θ_xz angles
  → **Prolonged topology**
- Object with small θ_xz angles
  → Isochronous topology
- Prolonged topologies lead:
  - Poor S/N ratio in induction wire planes
  - Disconnected objects in reco.
    & issues in 3D imaging and clustering



X axis - electric field direction
Y axis - vertical upward
Z axis - beam direction
arXiv: 2007.06722

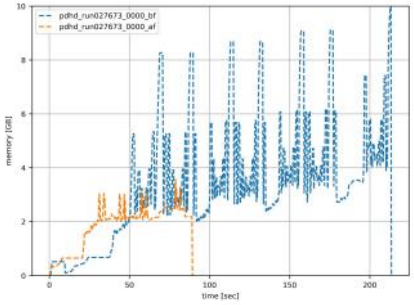
Memory Usage Optimization



- Memory profiling using Valgrind Massif tool
- The cause of excessive memory usage
  - ML inference peak (blue)
  - duplication of data saving pipeline (red)

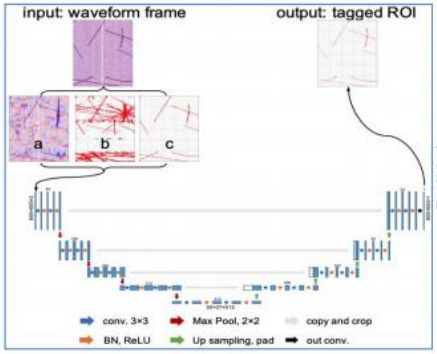
Strategy

1. Lightweight *MobileNetV3* architecture as backbone
   → less number of parameters
2. Dedicated filter for duplicated pipeline
   → Keep only the necessary data

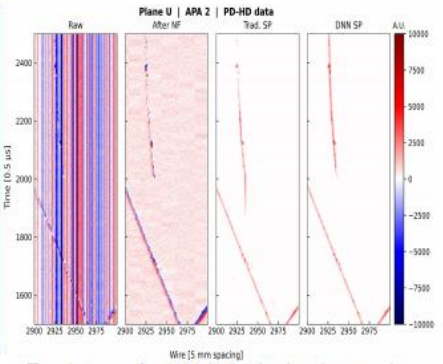


- DUNE computing environment recommends keeping memory usage below 4 GB
  → DNN SP was not applicable yet
- After the optimization, the memory usage is reduced from 10.0 GB to 3.6 GB
- Through an additional memory optimization (chunking for ML inference), the memory usage can be further reduced

DNN Signal Processing Results

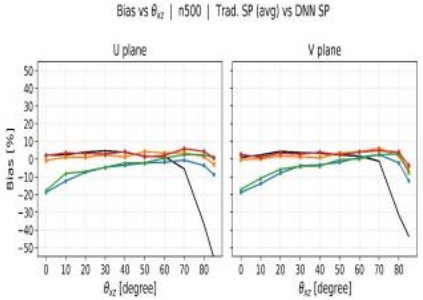


❑ DNN-based ROI finding

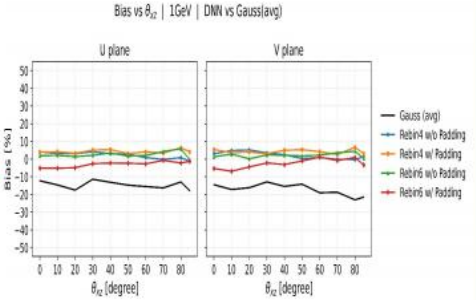


❑ 2D waveform evolution in signal processing

- Input features for ML training: loose low frequency filter - noise, multi-plane coincidence
- U-Net like architecture: encoder - decoder
- DNN-based signal processing (DNN SP) demonstrated
  - better charge reconstruction performance in prolonged topology
  - capability to truncate "tear drop"
- Performance evaluation showed the DNN SP could be a better option specifically in prolonged topology



❑ Single track evaluation



❑ Single shower evaluation

Conclusion

- Wire-Cell Toolkit has been actively developed for LArTPC experiments
- DNN SP showed better charge reconstruction performance
- Memory optimization made it possible to use the DNN SP in the actual DUNE workflow
- DNN SP becomes more important as cosmic backgrounds are prolonged in ProtoDUNE-VD