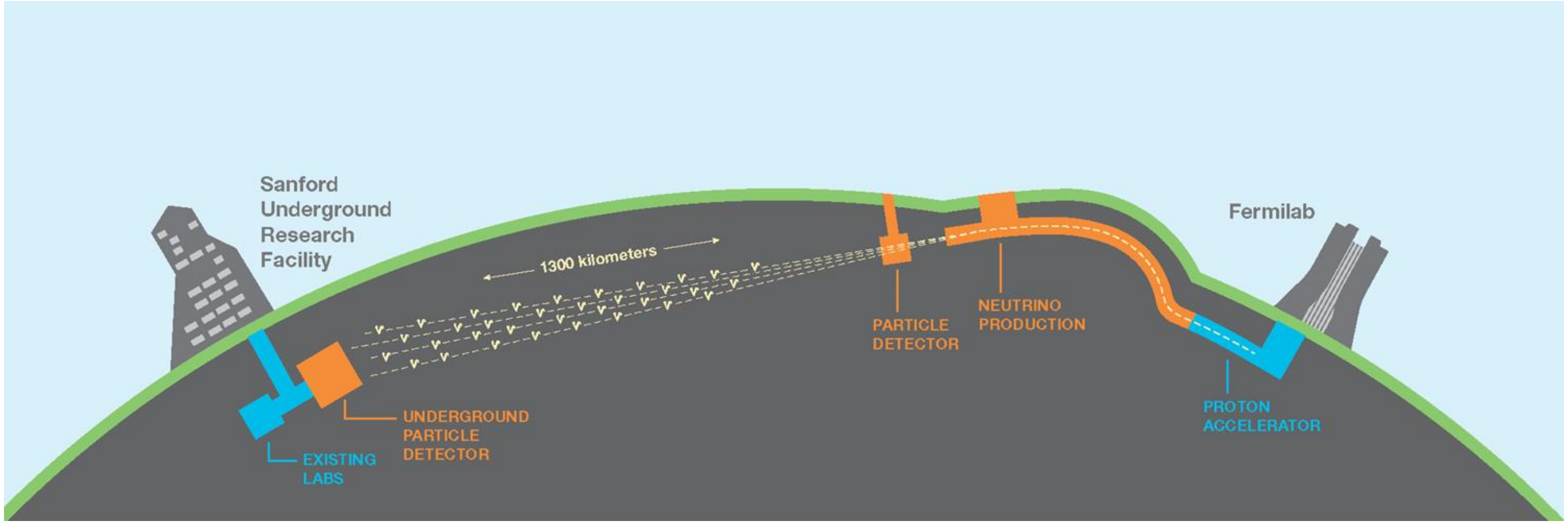
Deep Underground Neutrino Experiment



Kim Siyeon
Chung-Ang University

December 17, 2022

Physics issues of DUNE

원거리 검출기

진동거리 1300 km
지하 1.5 km
극저온 LAr TPC 40 kton

근거리 검출기
페르미랩 내에 하이브리드 범용

L-Ar, G-Ar TPC
SAND(on axis), PRISM(off axis)

양성자 가속과 중성미자 빔

Proton Improvement Plan II (PIP II)
휘도, 초점 Optimization
입자, 반입자의 생성

비표준 모형,
암흑물질 탐색

우주론과 천체물리

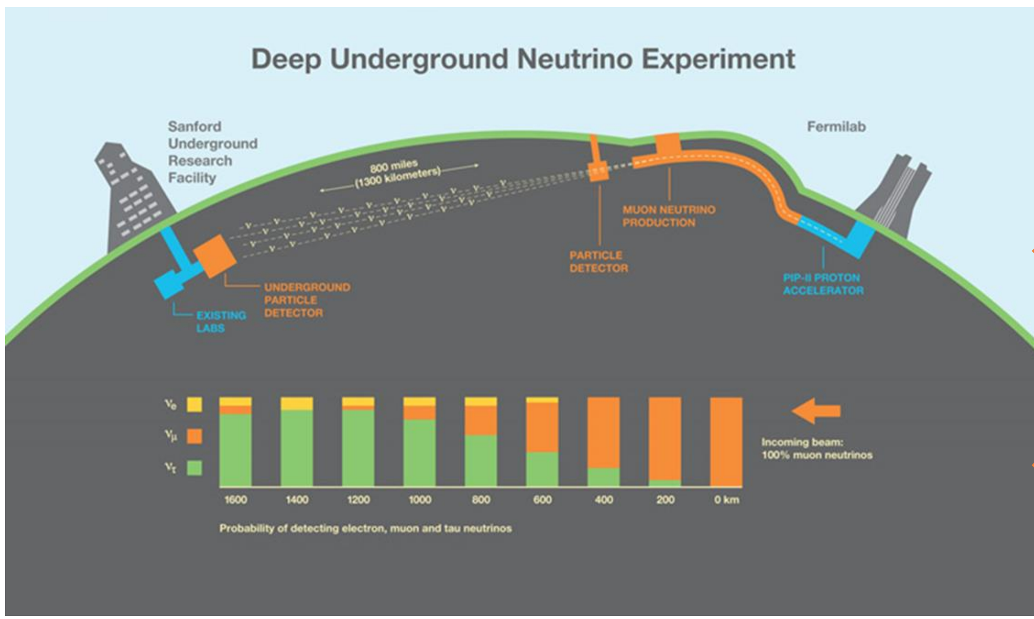
고에너지 중성미자
우주 잔재 중성미자
비활성 중성미자

중성미자 질량과 CP

3세대 중성미자 검증
CP 비대칭 위상
질량의 순서

중성미자 상호작용

QE, DIS, RES,
X-section



빔 라인

진동분석을 위한 개선
(Optimized Beam)

근거리 검출기

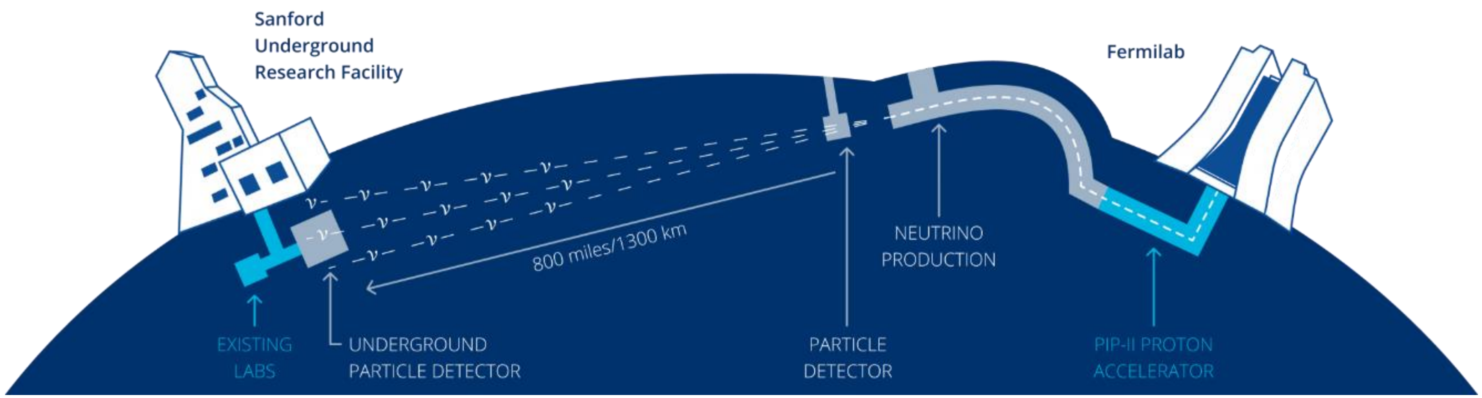
진동 전 중성미자 선속 측정,
오차 개선
중성미자 상호작용 단면적
비표준 상호작용 탐색

원거리 검출기

진동효과의 측정

대기, 태양 중성미자 관측
초신성 폭발 대기,
양성자 붕괴

DUNE 한국 그룹의 활동



DUNE Collaboration

Collaboration Resource Board
Regina Rameika (Fermilab)

Institutional Board
Alfons Weber (Rutherford Lab.)

DUNE Administration
Maxine Hronek(Fermilab)

Fermilab Neutrino Div. Head
Steve Brice (Fermilab)

Computing Coordinator
Heidi Schellman (Fermilab)

DUNE Cospokesperson
Stefan Soldner-Rembold (Manchester U.)
Regina Rameika (Fermilab)

정모세 (UNIST)

가속기와
중성미자 빔 인터페이스

김시연(중앙대)

중성미자 상호작용,
시뮬레이션 / 재구성, 진동분석

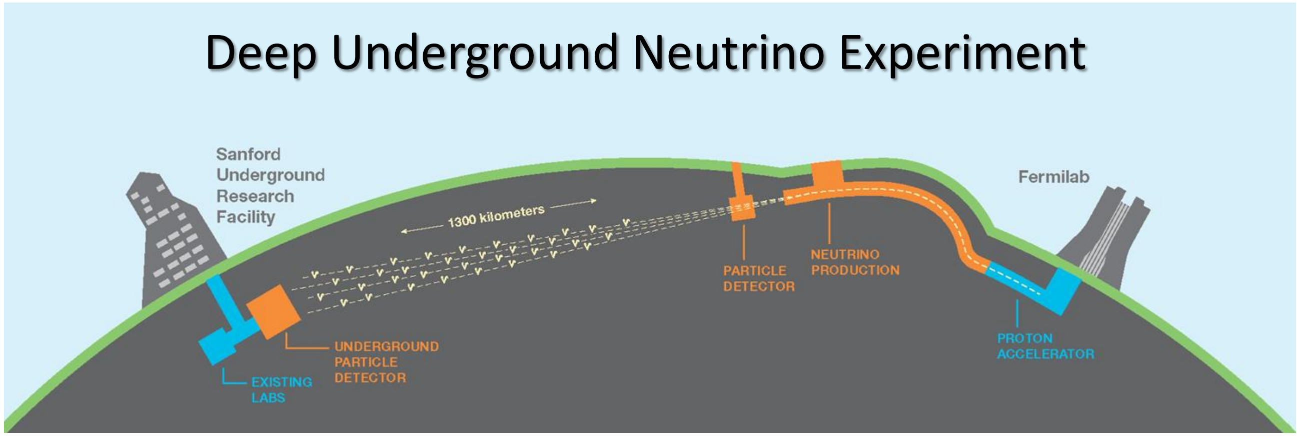
정유선 (중앙대)

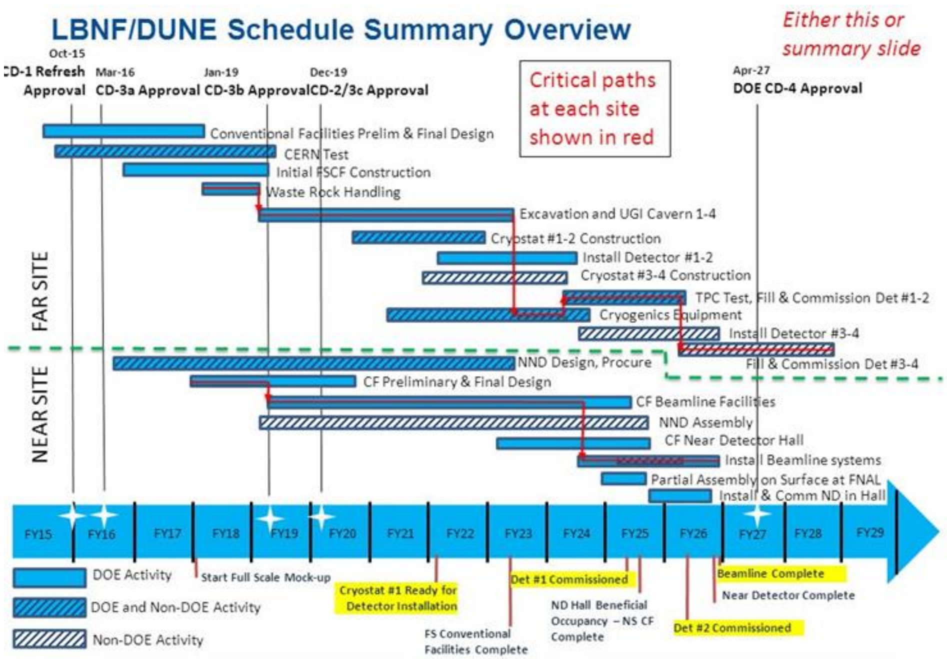
타우중성미자,
고에너지 중성미자

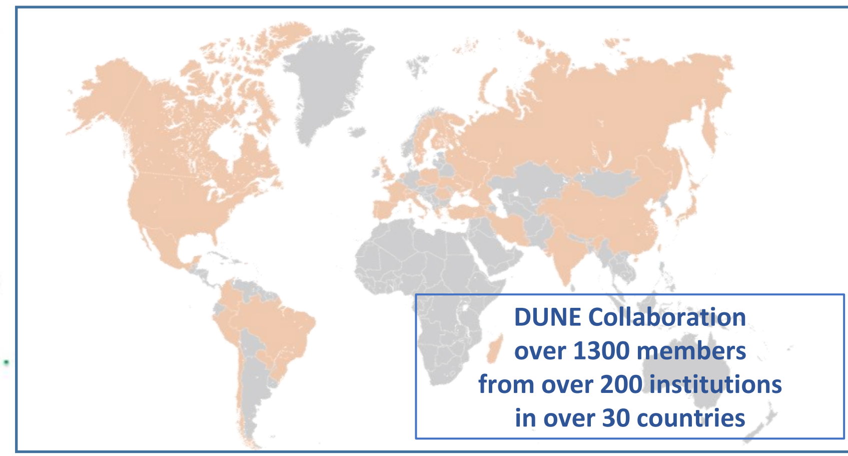
조기현(KISTI) 신서동 (전북대)

암흑물질 탐색,
비표준모형

Deep Underground Neutrino Experiment







Korean members of DUNE Collaboration
(2022년 12월 현재)

권순우(CAU, Ph.D 학생), 김시연(CAU, IR), 신서동(JBNU, IR), 정유선(CAU, Senior), 정모세(CAU, IR), 조기현(CAU, IR)

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

FOR LABORATORY:	**FOR PARTICIPANT:**
Name: Dr. Nigel S. Lockyer	**Name: Dr. Kim Chang Soo**
Title: Director of Fermilab	**Title: President, Chung-Ang University**
Date: November 30, 2018	**Date:** NOV. 30, 2018

전자신문 Conference allshowTV ETEdu English

통신&방송 SW&게임&성장기업 소재&부품 전자&자동차&유통 경제&금융 산업&과학&정책

중앙대, 미 에너지부 산하 가속기 연구기관 '페르미랩'과 공동연구센터 설립

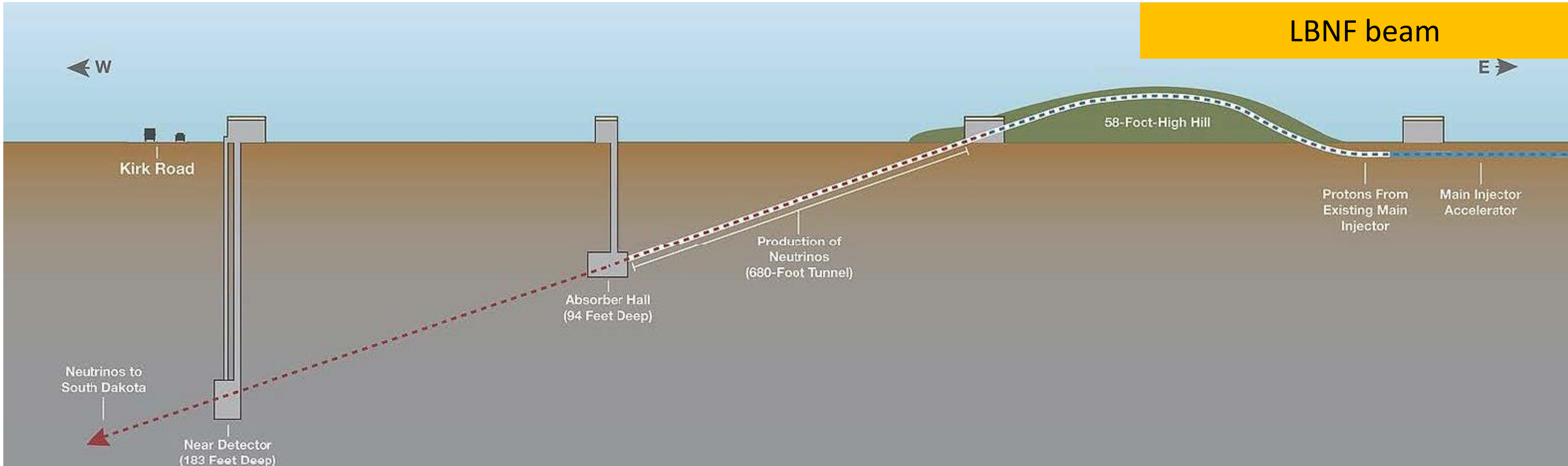
발행일 : 2020.04.07

기사만 쏙

[올쇼TV] IBM-코로나19 사태에 따른 상담 업무 환경의 변화 (4/24 생방송)

<중앙대 전경>

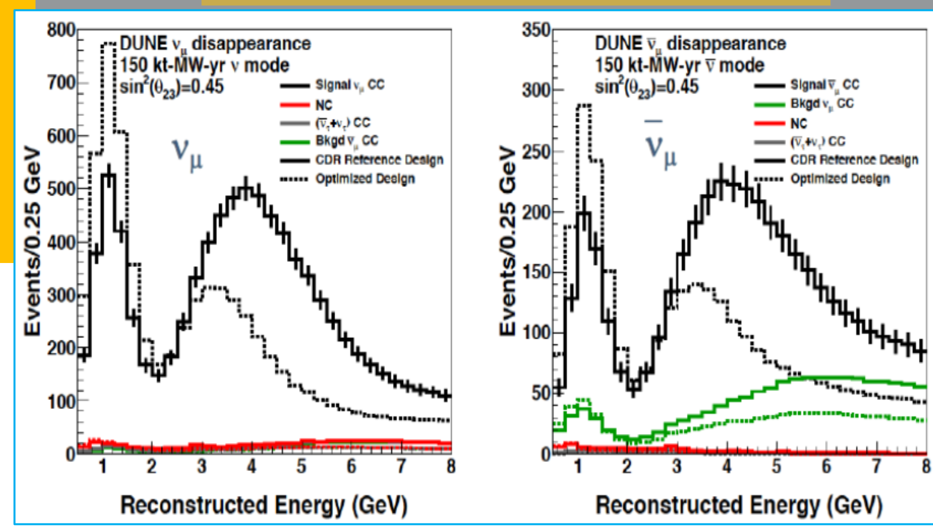
LBNF beam

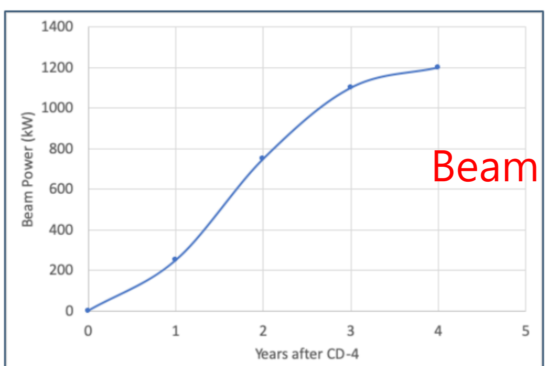


Long-Baseline Neutrino Facility

- Proton Improvement Plan (PIP-II)
- Initial 1.2 MW proton beam to be upgraded to 2.4 MW (proton energy 60-120 GeV)
- Beam optimization s. t. more flux at lower energies for better physics sensitivity
- Neutrino beam available in 2026

Beam Optimization

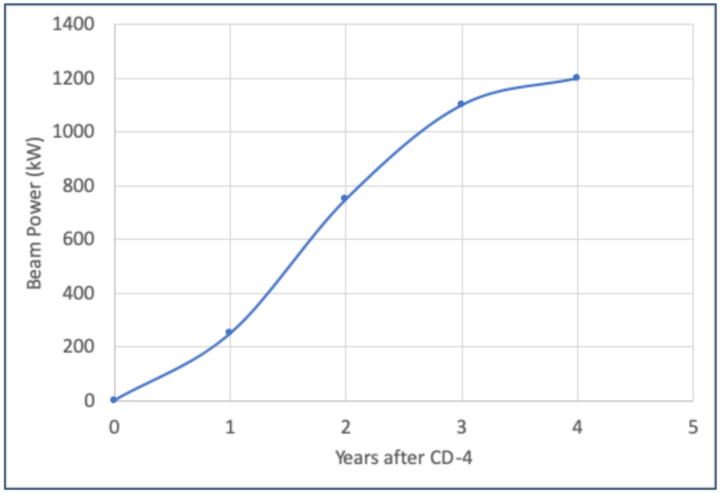




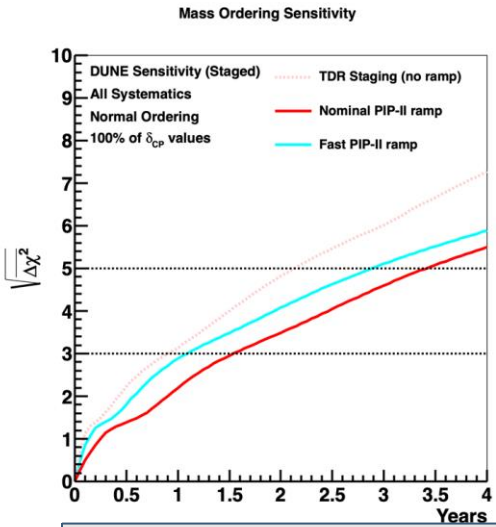
Beam Ramping plan

CHUNG-ANG UNIVERSITY HIGH ENERGY PHYSICS

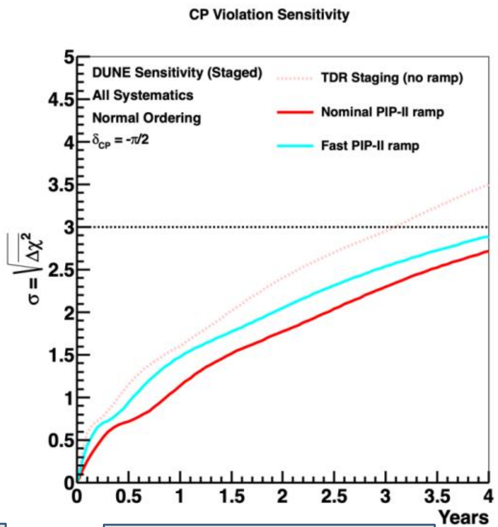
2018: ProtoDUNEs at CERN → 2019: FD TDR → 2020: Excavation starts → ~~2022:~~ 2023: Installation of first module → First physics data: Atm, SN, & solar neutrinos. Proton decay. Calibration → 2026: ND & Neutrino beam available



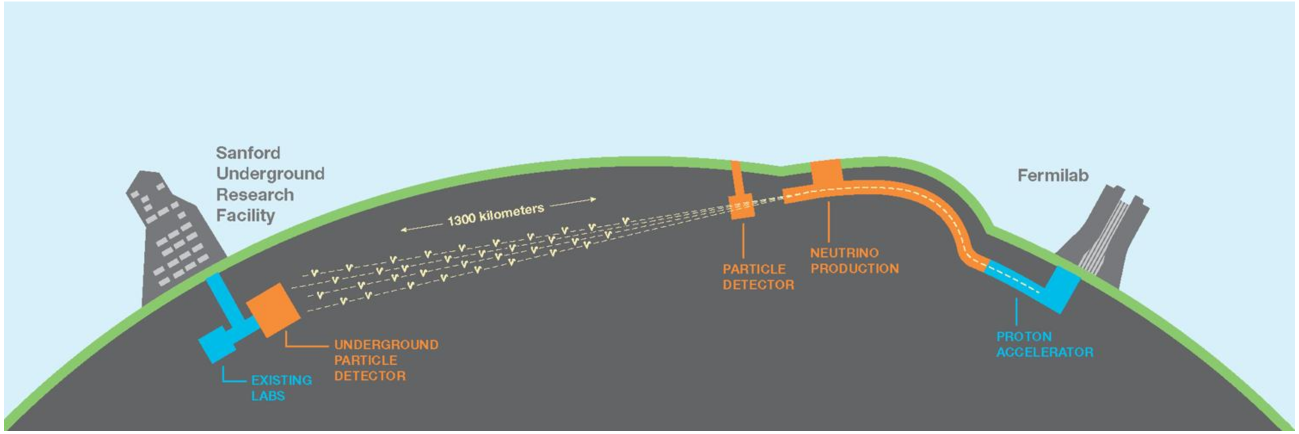
PIP-II
Power Ramp



Mass Ordering
100% δ_{CP} values



CP Violation
$\delta_{CP} = -\pi/2$

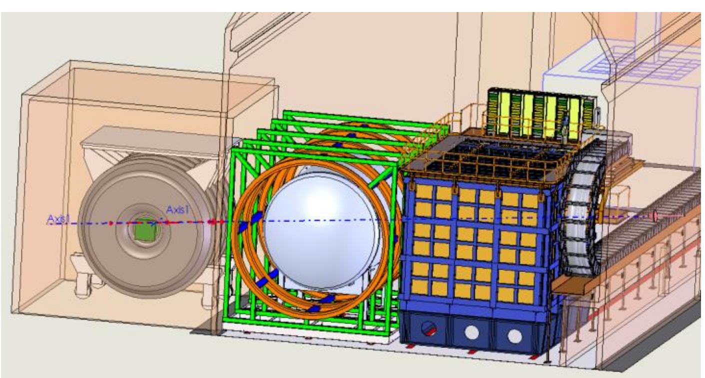


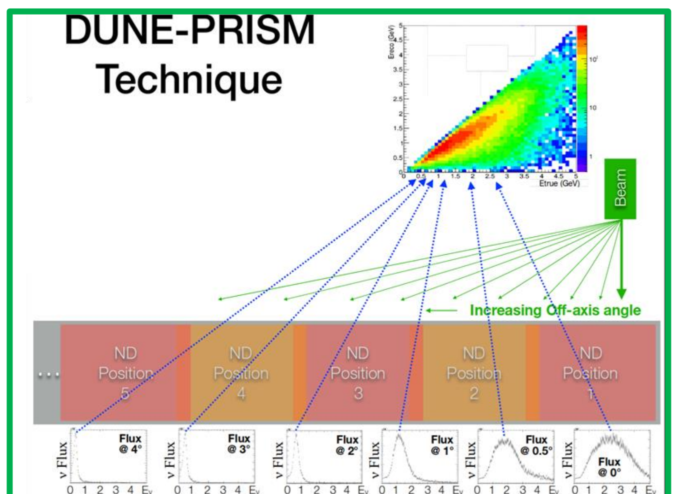
Near Detector

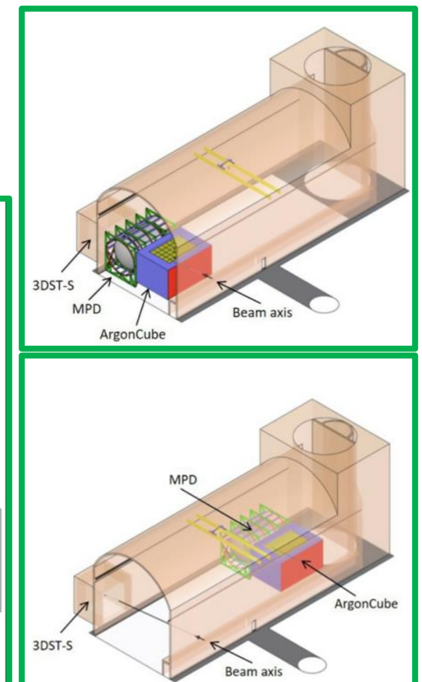
ND Complex (574 m from target hall, 60 m from surface)

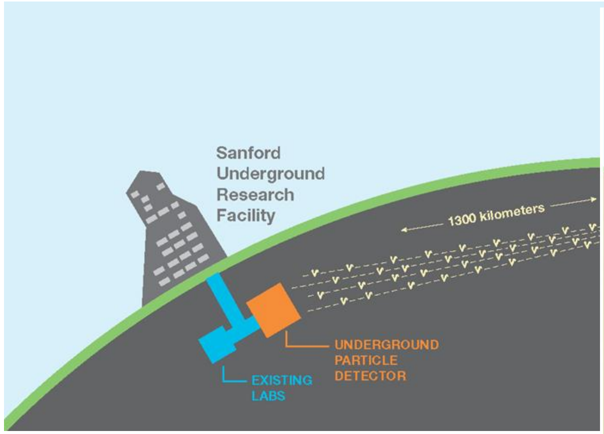
- Liquid Ar Time Projection Chamber
- HP Gas Ar TPC with magnet and ECAL (MPD)
- System for on-Axis Neutrino Detection (SAND)

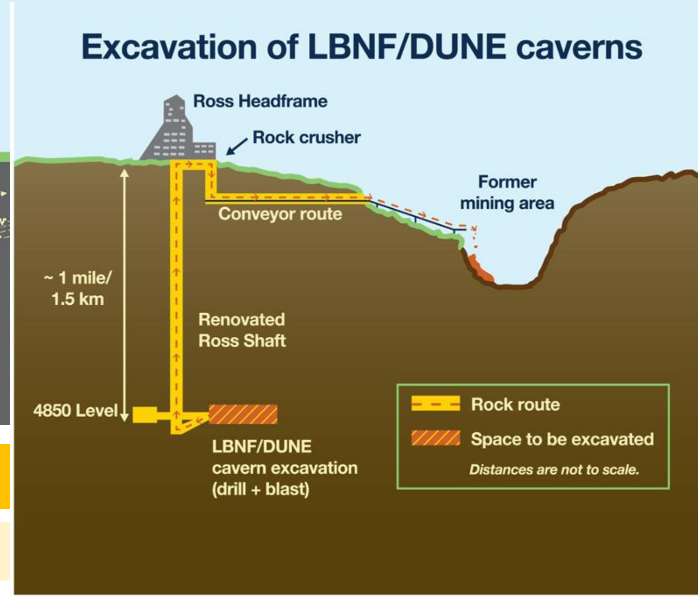
- Prediction of neutrino flux at FD w/o oscillation
- Control of systematics
- Study neutrino interaction with Ar, CH









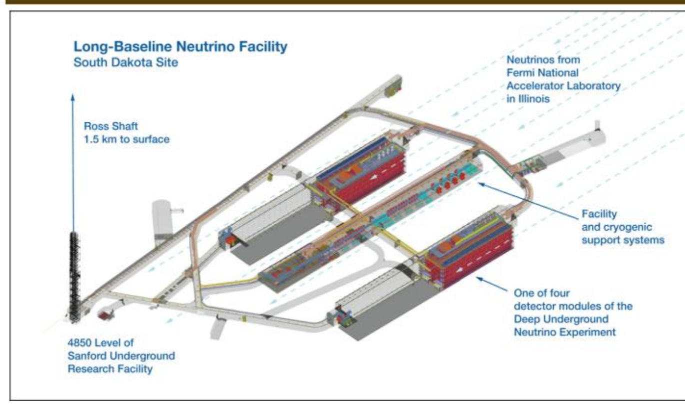


Far Detector

- Measurement of neutrino events (w/ oscillation)

Non-accelerator Physics Program

- Nucleon decay
- Atmospheric neutrinos
- Supernova neutrino bursts
- Lorentz invariance and CPT violation
- Astrophysical Neutrinos, e.g., solar neutrinos, diffuse supernove background, and etc.



- 40-kt Liquid Ar time projection chamber (4 x 10 kt)
- 4850 level (4300 mwe)
- The largest cryogenic instrument ever (89K)
- ProtoDUNE at CERN
- Single-phase and ~~double-phase~~ detectors, 2+1+1 (-> Vertical-Drift LAr TPC) –> HD and VD
- The first module will be single-phase. The installation begins in 2022.
- Technical Design Report available.

2018: ProtoDUNEs at CERN → 2019: FD TDR → 2020: Excavation starts → 2022(?): Installation of first module → First physics data: Atm, SN, & solar neutrinos. Proton decay. Calibration → 2026: ND & Neutrino beam available

DUNE Phase I

- 2 Far Detectors : Horizontal Drift (HD) + Vertical Drift (VD) LAr
- Near Detectors : ND LAr + TMS + SAND + PRISM
- 1.2 MW beam power

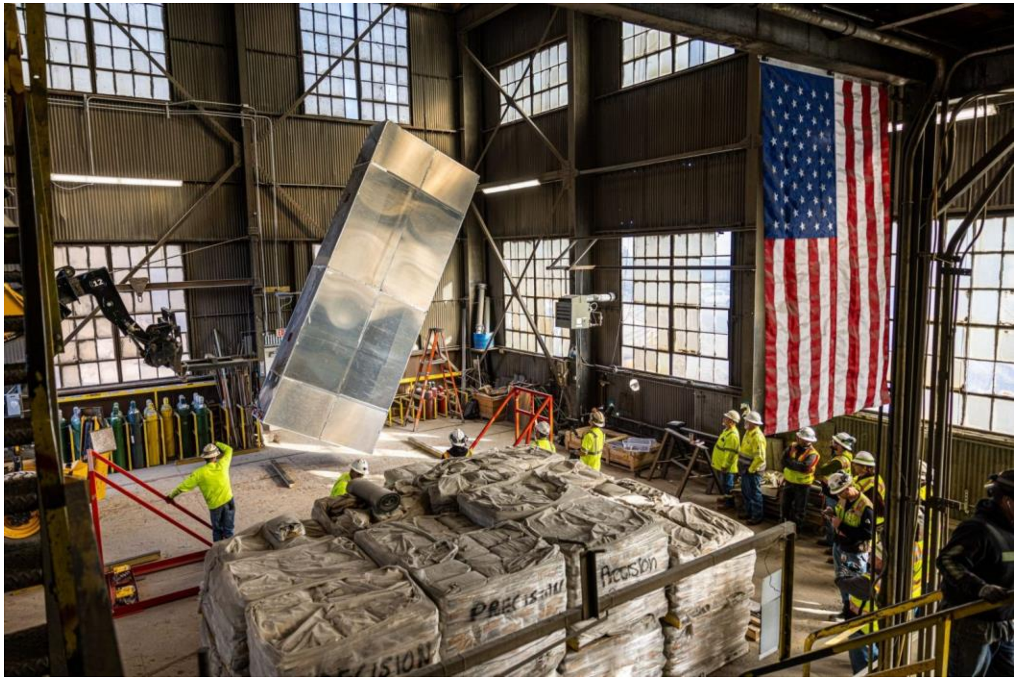
DUNE Phase II

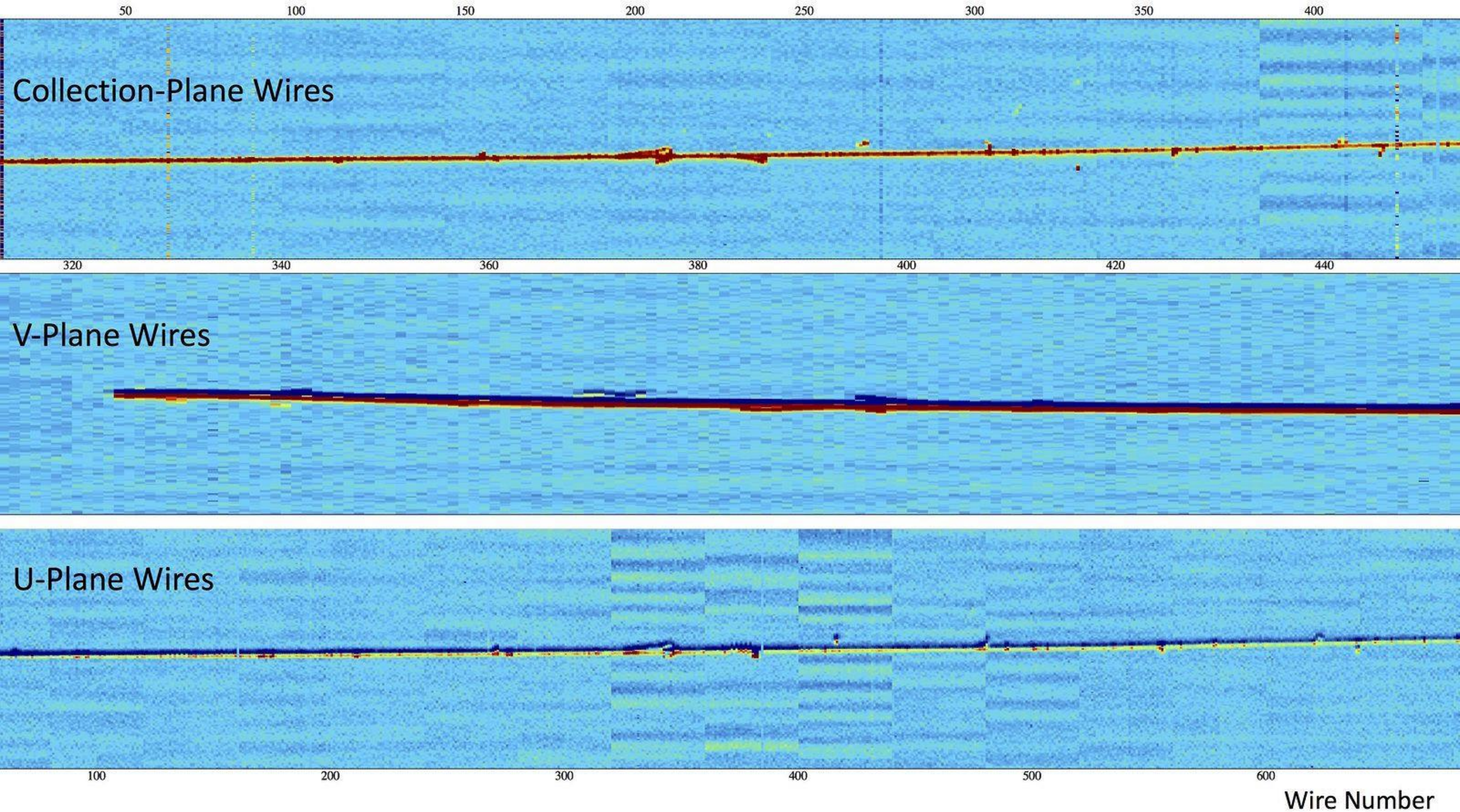
- FD3 + FD4
- ND-Gar replaces TMS.
- 2.4 MW beam power

Staged year
1 (2026) with 20 kt-1.2MW
2 (2027) with 30 kt-1.2 MW
4 (2029) with 40 kt-1.2 MW
7 (2032) with 40 kt-2.4 MW

DUNE Day 1 : When FD1 is filled and turned on, Science begins.

This was a test of the entire logistics chain —
from the UK, to Switzerland, to Illinois, and finally to South Dakota. (December 6, 2022)
In total, 150 APAs will be built for DUNE: 136 from the UK and 14 from the US.




50
100
150
200
250
300
350
400
Collection-Plane Wires
320
340
360
380
400
420
440
V-Plane Wires
U-Plane Wires
100
200
300
400
500
600
Wire Number

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

EP Internal Report 77-8
16 May 1977

THE LIQUID-ARGON TIME PROJECTION CHAMBER: A NEW CONCEPT FOR NEUTRINO DETECTORS

C. Rubbia

2. LIQUID ARGON AS A NEUTRINO TARGET

There are several reasons why pure liquid argon can be considered as an almost ideal target material for the LAPC:

i) it is dense (1.4 g/cm^3);

ii) it does not attach electrons and hence it permits long drift-times;

iii) it has a high electron mobility;

iv) it is cheap, 140-500 dollars/ton, depending on source and quality;

v) it is easy to obtain and to purify -- many of the organic impurities are frozen out from its liquid form;

vi) it is inert and it can be liquefied with liquid nitrogen.

A possible drawback is that some modest cryogenic equipment is required in order to maintain it.

From the physical point of view, liquid argon has properties which make it very similar to the freon CF_3Br of the celebrated Gargamelle experiments:

Korean DUNE Activities

- 2016.05 CAU joined DUNE Collaboration
- 2017 ~ 2018 ProtoDUNE L-Ar TPC Single Phase
  Cold Electronics Module test
- 2019.05 JBNU & UNIST joined
- 2018 ~ 2021 3DST Working Group,
  3DST (3-dim Scintillator Tracker) for SAND/ND
  - Joint consortium with T2K SuperFGD Group
  - Prototype LANL Neutron beam test 2019 & 2020
- 2022 ???
- 2023.01 ~ ProtoDUNE HD Data Analysis
  ProtoDUNE VD Cold Electronics
- ProtoDUNE II: Closing TCO in 2022.11, filling LAr in early 2023, OPS for 2023.06 to 2024.07

최근 중요 실적 및 기여

- 신서동(전북대):
  [Prospects for beyond the Standard Model physics searches at the Deep Underground Neutrino Experiment](), *Eur.Phys.J.C* 81 (2021) 4, 322,
  Boosted dark matter search 집필 기여
- 권순우(중앙대):
  [Deep Underground Neutrino Experiment (DUNE) Near Detector Conceptual Design Report](), *Instruments* 5 (2021) 4, 31,
  Neutron detection from antineutrino events in the 3DST, 분석결과 수록, 집필 기여
- 정기영(중앙대):
  [Muon antineutrino CC 1 neutral pion interaction selection using the invariant mass,]() DUNE-doc-23681-v1,
  Technical note 작성
- 권순우(중앙대):
  [Neutron detection and application with a novel 3D projection scintillator tracker in the future long-baseline neutrino oscillation experiments]() e-Print: 2211.17037 [hep-ex]

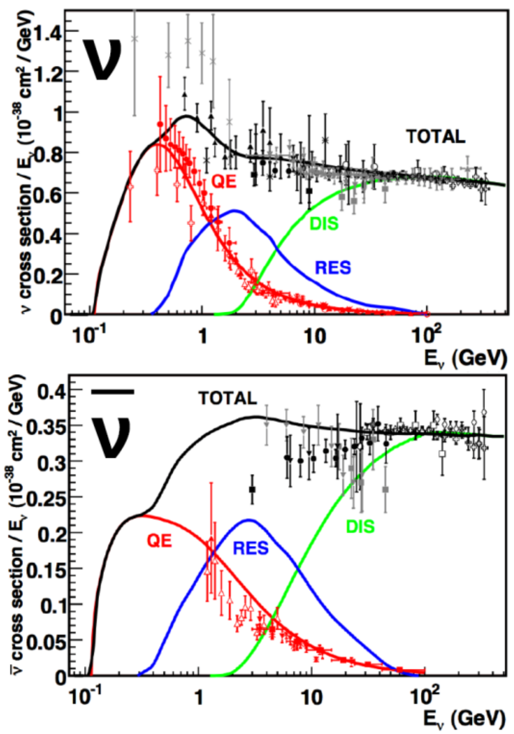
preprint for arXiv

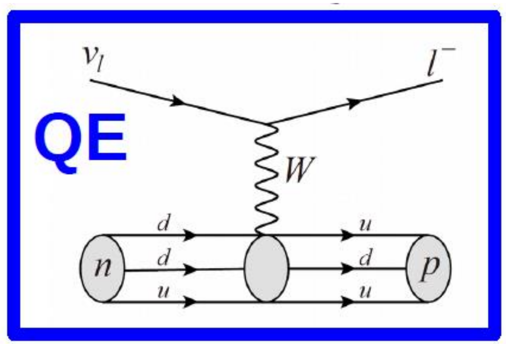
Neutron detection and application with a novel 3D projection scintillator tracker in the future long-baseline neutrino oscillation experiments

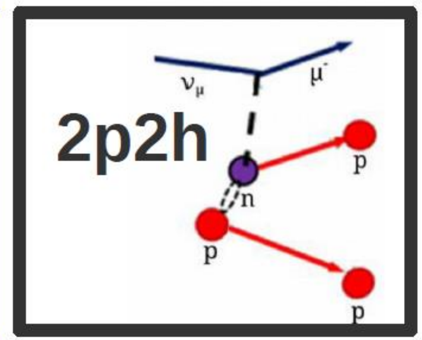
S. Gwon,[1] G. Yang,[2] S. Bolognesi,[3] T. Cai,[4] A.Delbart,[3] A. De Roeck,[5] S. Dolan,[5] G. Eurin,[3] S. Fedotov,[6] G. Fiorentini Aguirre,[7] R. Flight,[4] R. Gran,[8] P. Granger,[3] C. Ha,[1] C.K. Jung,[2] K.Y. Jung,[1] S. Kettell,[9] A. Khotjantsev,[6] M. Kordosky,[10] Y. Kudenko,[6] T. Kutter,[11]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

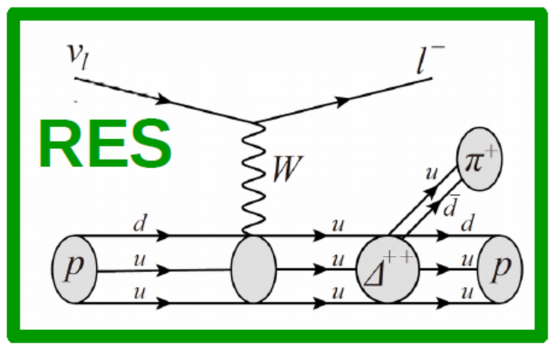
Neutrino Interaction Physics & the DUNE Near Detector

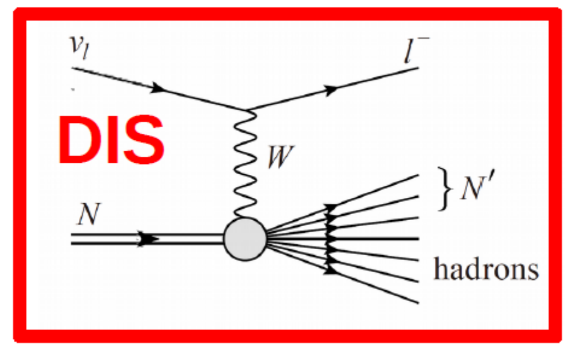
Mateus F. Carneiro on behalf of the DUNE Collaboration











Neutrino Interaction Physics & the DUNE Near Detector

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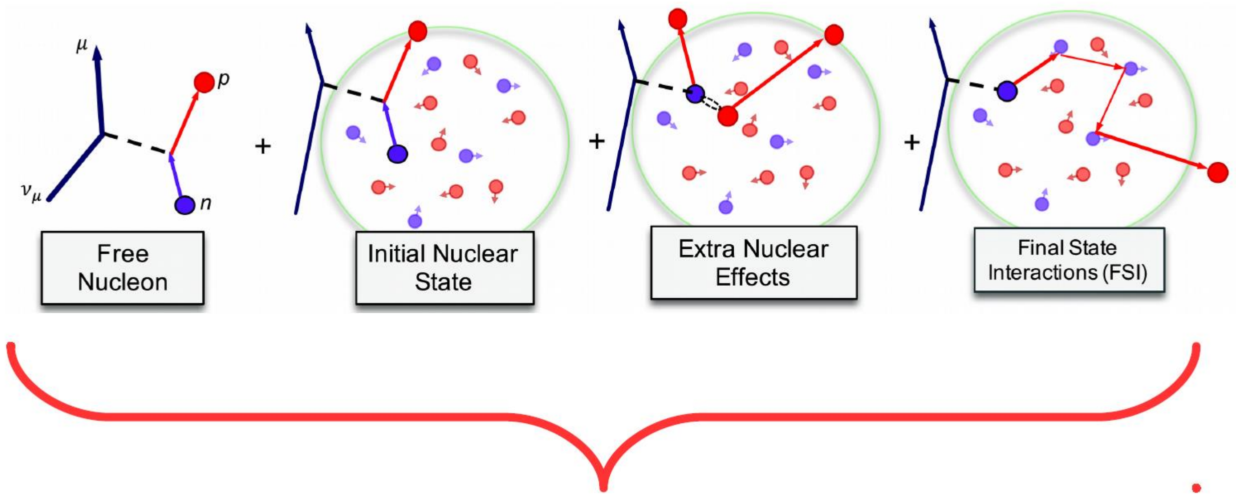

$$R(\vec{\mathbf{x}}) = \Phi(E_\nu) \times \sigma(E_\nu, \vec{\mathbf{x}}) \times \epsilon(\vec{\mathbf{x}}) \times P(\nu_A \to \nu_B)$$

Final state particle content does not isolate initial interaction type!

Pion Multiplicity

Neutrino Interaction Physics & the DUNE Near Detector

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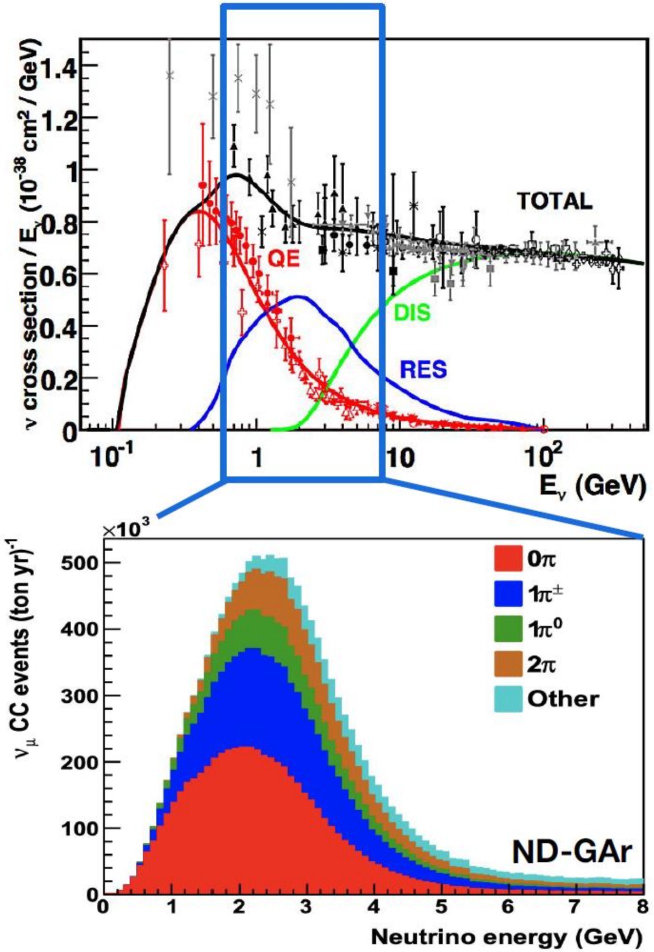
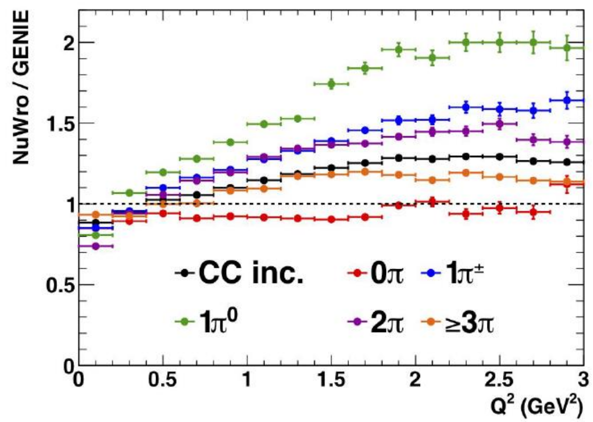


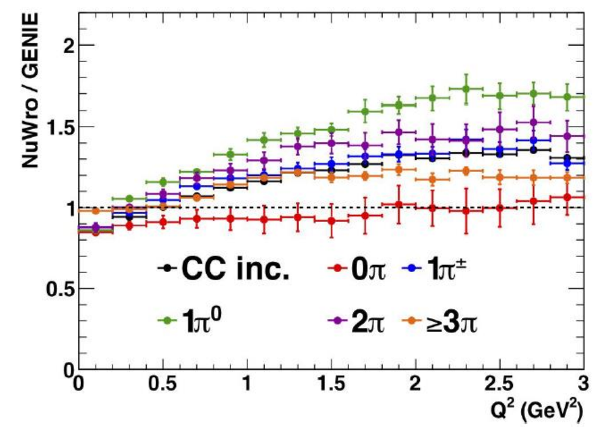
	Interaction Channel		Event Rate	
			ND-LAr	ND-GAr
CC	ν_μ		8.2×10^7	1.64×10^6
		0π	2.9×10^7	5.8×10^5
		$1\pi^\pm$	2.0×10^7	4.1×10^5
		$1\pi^0$	8.1×10^6	1.6×10^5
		2π	1.1×10^7	2.1×10^5
		3π	4.6×10^6	9.3×10^4
		other	9.2×10^6	1.8×10^5
	$\bar{\nu}_\mu$		3.6×10^6	7.1×10^4
	ν_e		1.45×10^6	2.8×10^4
NC			5.3×10^5	5.5×10^5
$\nu + e$			8.3×10^3	1.7×10^2

Events per year (1.1×1021 POT)

True NuWro/GENIE (FHC)



NuWro/GENIE for various reconstructed final states (FHC)



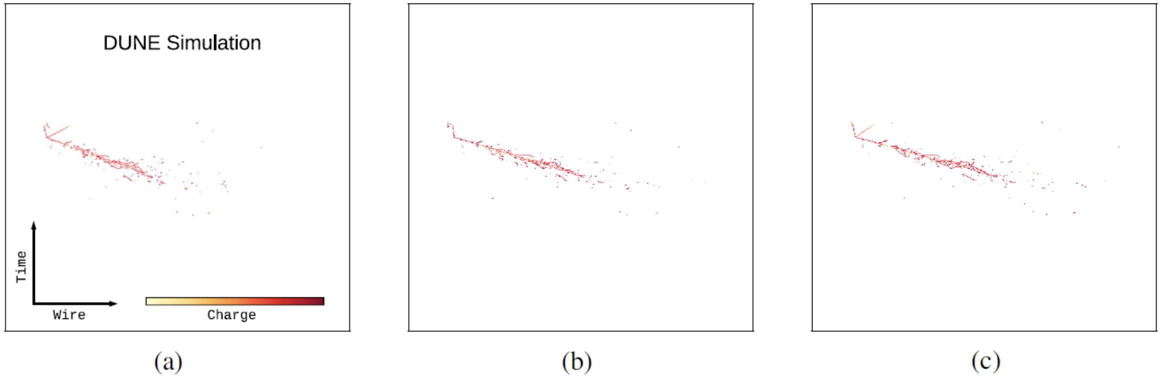
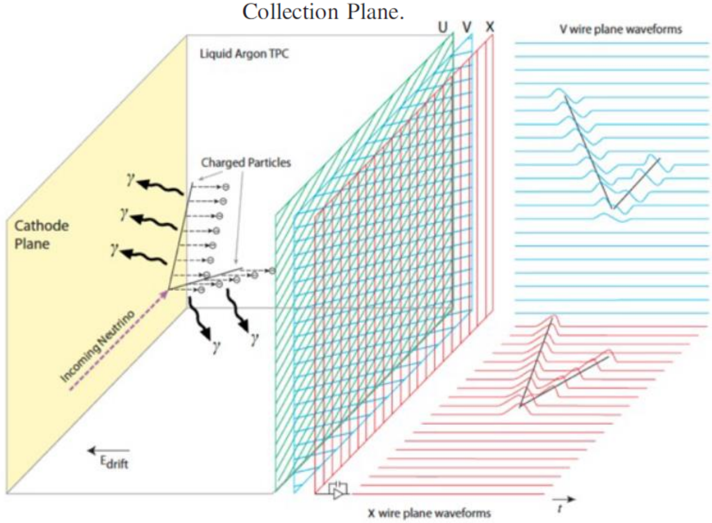
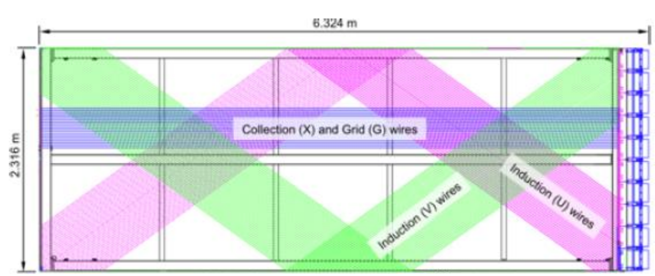
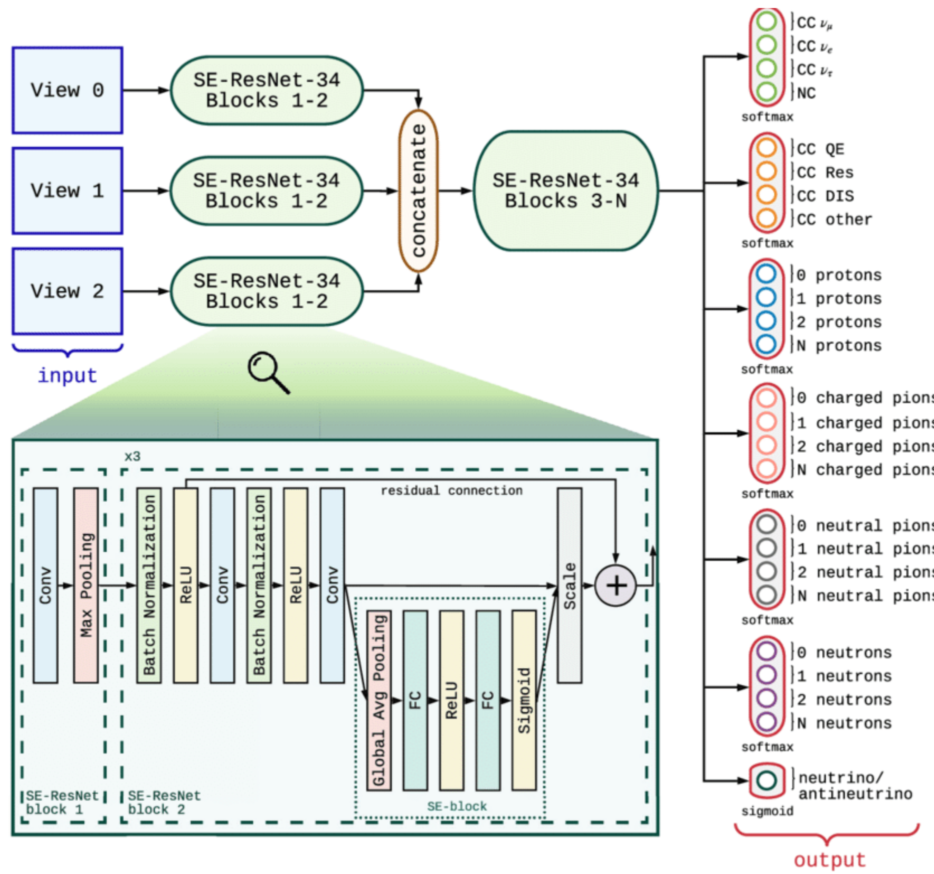


FIG. 2. A 2.2 GeV CC ν_e interaction shown in the three read-out views of the DUNE LArTPCs showing the characteristic electromagnetic shower topology. The horizontal axis shows the wire number of the read-out plane, and the vertical axis shows time. The color scale shows the charge of the energy deposits on the wires. (a) View 0: Induction Plane. (b) View 1: Induction Plane. (c) View 2: Collection Plane.



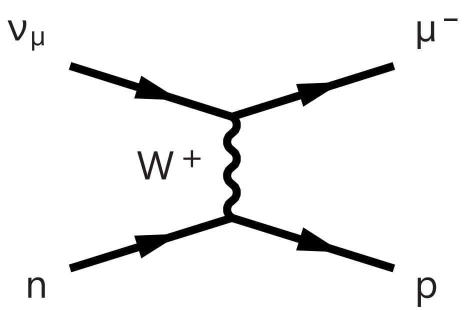


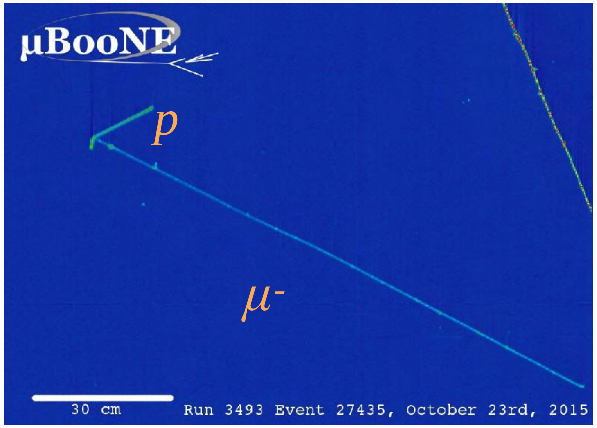


Neutrino Interaction Physics & the DUNE Near Detector

Mateus F. Carneiro on behalf of the DUNE Collaboration

Charged-current quasi-elastic scattering - the “golden channel”





Simple final state - just a muon and a nucleon

Conserve energy and momentum: calculate Q^2 and E_ν just from muon kinematics

Neutrino mode

$$E_\nu^{QE} = \frac{m_p^2 - (m_n - E_b)^2 - m_\mu^2 + 2(m_n - E_b)E_\mu}{2(m_n - E_b - E_\mu + p_\mu \cos\theta_\mu)}$$

(in a nucleus; binding energy E_b = 28 MeV for argon)

Why is this useful?

- Muon has constant dE/dx (minimum-ionizing particle)
- Long, clear track: **easy to measure E_μ and θ_μ**
- $\bar{\nu}$ case - neutron hard to detect (neutral)
- Not affected by **final-state interactions**
  - Nucleons can re-interact in the nucleus.

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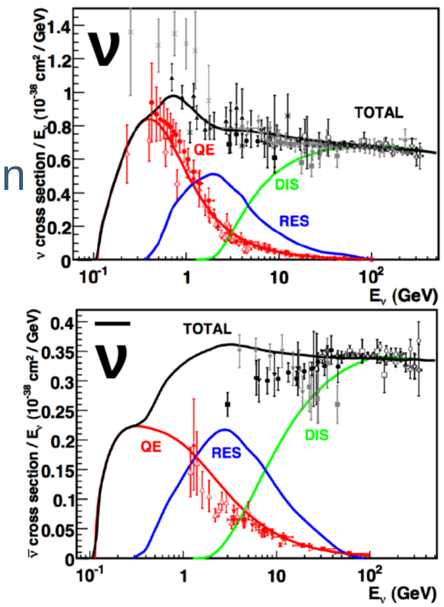
What about anti-muon neutrinos?
What about neutrons?

중성미자 상호작용과 중성자 검출

e-Print: 2211.17037
S. Gwon et al.

- Neutrino-nucleus interaction: nu-Ar, nu-C,H
  COH, QE, RES, DIS
- Neutrons in final states:
  Missing energy in neutrino detection
- Neutron identification:
  - Event-by-event Energy Reconstruction
- 3-dim Scintillator Tracker:
  - DUNE neutrino beam and CH target
  - CCQE-like (cc0pi) event analysis
  - Low-nu fitting for flux constraint
- LANL neutron beam test (3DST & SuperFGD/T2K):
  - Study of secondary neutrons



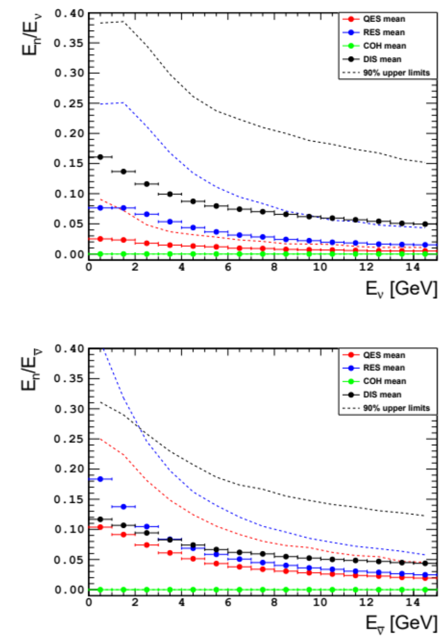
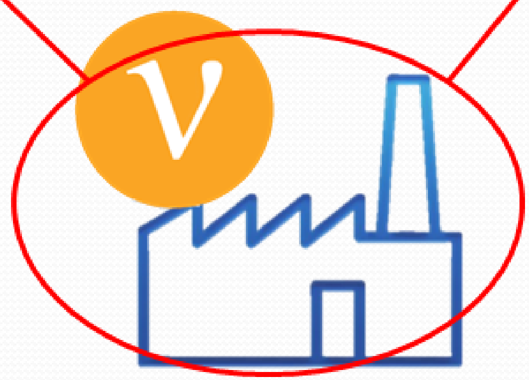


FIG. 1. Average energy fraction delivered to the primary neutrons relative to the neutrino energy(top) and the antineutrino energy(bottom). The average ratios E_n/E_ν are in comparison according to the CC Quasi-elastic (QES), CC resonant (RES), CC coherent (COH) and CC deep-inelastic scattering (DIS) interaction modes.

BSM Physics in Neutrino Experiments

Neutrino-sector BSM

- Beyond 3 neutrino flavors (e.g., sterile neutrinos)
- Non-standard interactions of neutrinos
- ...



Non-neutrino-sector BSM

- (Light) dark matter search
- (Light) mediators or portal scenarios (e.g., dark photon, axion-like particles)
- ...

DUNE Timeline

- Phase I
  - Two far detectors
  - ND-LAr (Movable)
  - TMS (Movable) + SAND
  - 1.2 MW beam power

Leptophilic mediators

Cosmogenic boosted dark matter (BDM)

- Phase II
  - More far detectors
  - ND-GAr (Movable, Replacing TMS)
  - 2.4 MW beam power

Axion-like particles (ALP)

- Proposed off-target mode

Low-mass dark matter (LDM)

Physics Working Groups

Physics Coordination Inés Gil-Botella Chris Marshall	**Long-baseline** Callum Wilkinson Luke Pickering	**High energy** Lisa Koerner Yun-Tse Tsai	**FD sim/reco** Chris Backhouse Dom Brailsford
DUNE Physics Working Groups	**Neutrino Interactions** Cheryl Patrick Mateus Carneiro	**BSM** Justo Martin-Albo Alex Sousa	**ND sim/reco** Linda Cremonesi Mat Muether
Liaisons Dan Cherdack (ND) Tom Junk (computing)	**Low Energy** Clara Cuesta Dan Pershey	**Calibration** David Caratelli Mike Mooney	**protoDUNE analysis** Leigh Whitehead Tingjun Yang

Low-energy = 1-10s MeV-scale physics: supernovae, solar, etc.
This group also works with the backgrounds task force,
as natural radioactivity is an important background for LE physics

High-energy = GeV-scale non-accelerator physics: atmospheric neutrinos, nucleon decay & other signals for which atmospheric neutrinos are a background. Formerly known as the nucleon decay WG.

BSM = other BSM physics, historically more phenomenologically-oriented.
Steriles, NSI, dark matter, BSM searches at the ND.


소화기

Concluding Remark 1

- Long baseline neutrino oscillation DUNE for CPV phase and mass ordering measurements.
- Staged year one is 2026 with neutrino beam, ND, and FD ready.
- Expected to produce a variety of new physics based on different types of interactions and different target materials.

- Korean contributions for protoDUNE, ND/3DST detector, Neutron study for reconstruction of anti muon neutrinos.
- Plan to participate protoDUNE analysis.

- Both global and local activities are waiting for participation of young researchers and students .
- 중앙대 중성미자 연구실
  중성미자 상호작용, Sim/Reco, 데이터 분야 연구원 채용 예정

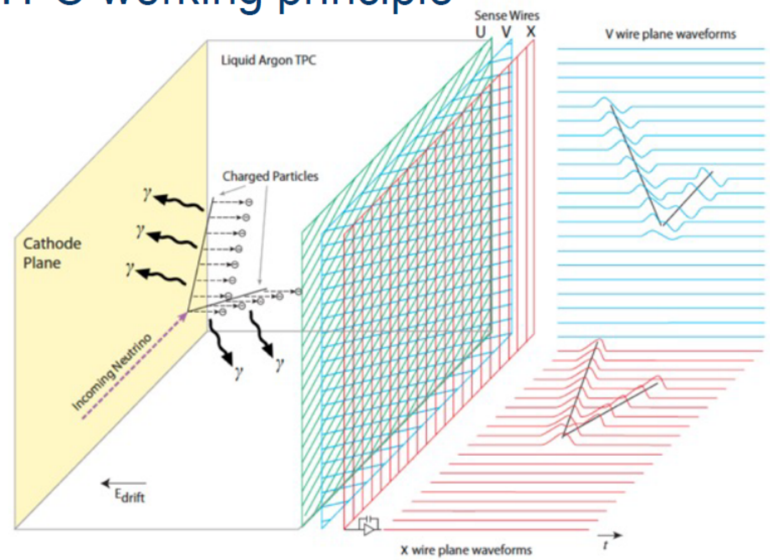
Concluding Remark 2

한국 DUNE 잘 할 수 있습니다.

다른 기관, 연구자들 환영합니다.

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)

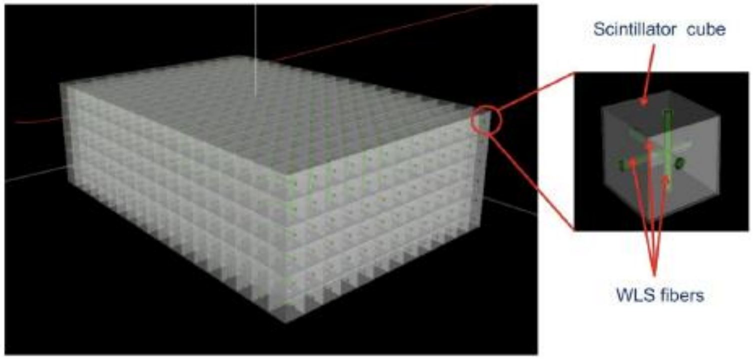
- Technological challenges
  - LAr continuous purification << 0.1 ppt O_2 eq. (>> 3 ms electron lifetime) for long drift
  - Imaging & anode planes
  - Very low noise front end amplifiers to detect ~ fC primary charge deposition
  - Large area photon detectors sensitive to 128 nm wave length
  - HV system 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

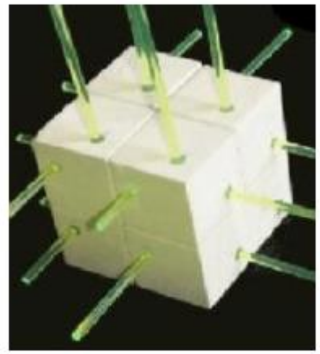
- Plastic scintillator detector with 1 cm x 1 cm x 1cm cubes

1.5 cm x 1.5 cm x 1.5 cm

- Light collected by 3 wavelength shifting fibers
- Each cube etched chemically to keep light entrapped inside the cube
- Read out by MPPC at 3 faces
- 4π coverage, 300 MeV/c proton threshold, 0.5 ns timing for MIP

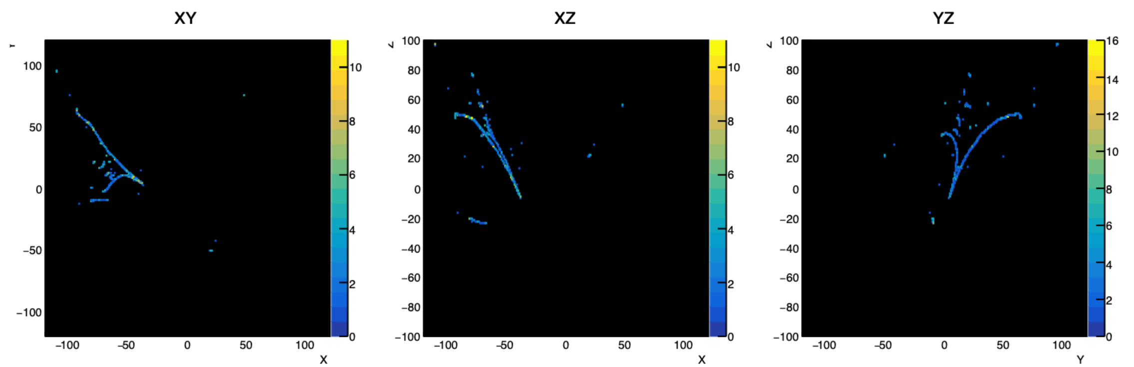
Sunwoo Gwon
for KPS 2020F



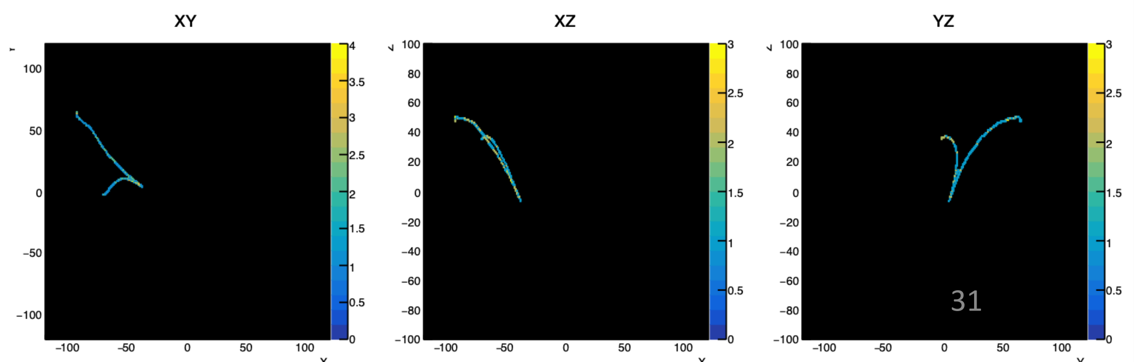


Event Display

contains all neutron, gamma induced hits

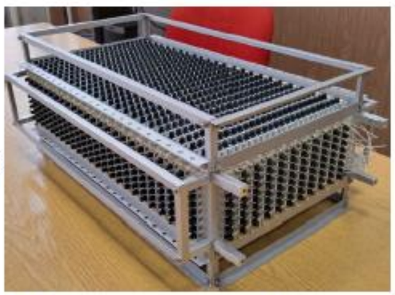


only the cluster



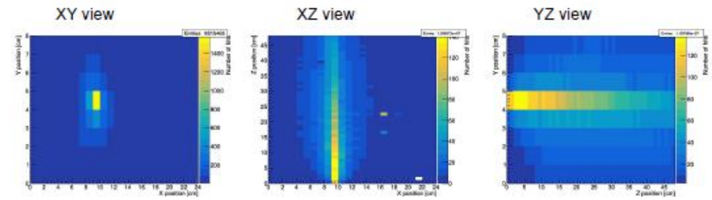
Los Alamos Neutron Beam test

- SuperFGD 24x8x48 (2019, 2020)
- 3DST prototype 8x8x32 (2020)

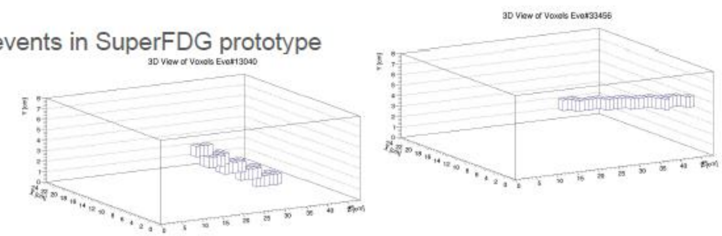


Neutron beam data

- Neutron beam observed in SuperFDG prototype detector



- Neutron events in SuperFDG prototype detector



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Joint T2K-DUNE 3D Scintillator R&D Group Institutions

CERN

Louisiana State University, USA

University of Pittsburgh, USA

Stony Brook University, USA

ETH Zurich, Switzerland

University of Pennsylvania, USA

High Energy Accelerator Research Organization (KEK), Japan

South Dakota School of Mines and Technology, USA

University of Geneva, Switzerland

Imperial college, UK

University of Rochester, USA

University of Tokyo, Japan

Chung-Ang University, South Korea

CHUNG-ANG UNIVERSITY HIGH ENERGY PHYSICS