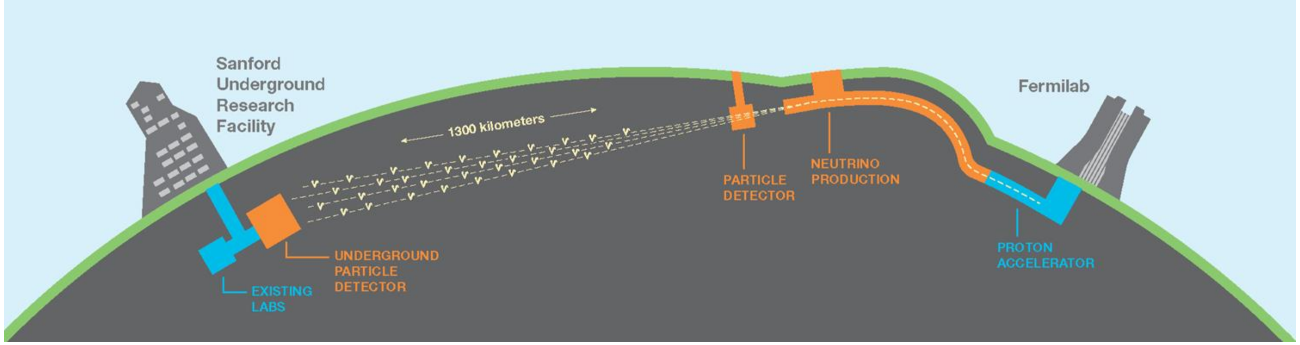
Deep Underground Neutrino Experiment



Kim Siyeon
Chung-Ang University

Nov 18, 2022

Celebrating the Inauguration of
Korean Society of High Energy Physics

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

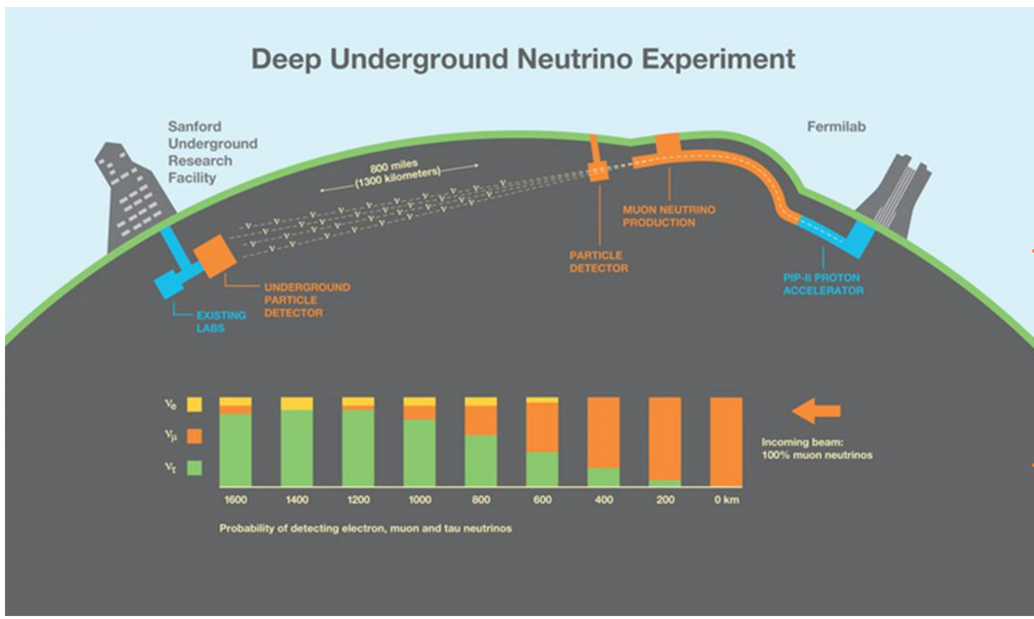
고에너지 중성미자
우주 잔재 중성미자
비활성 중성미자

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

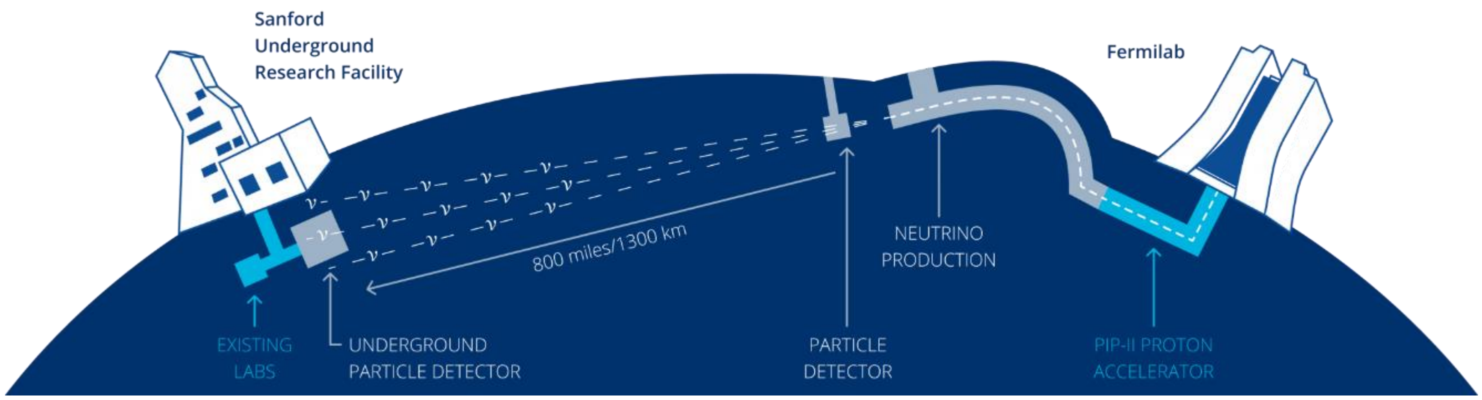
진동 전 중성미자 선속 측정,
오차 개선
중성미자 상호작용 단면적
비표준 상호작용 탐색

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,
에너지 재구성, 진동분석

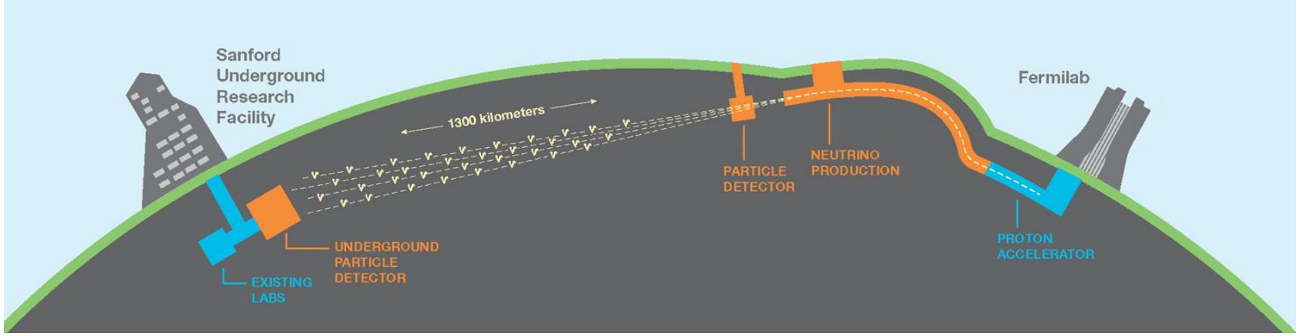
정유선 (중앙대)

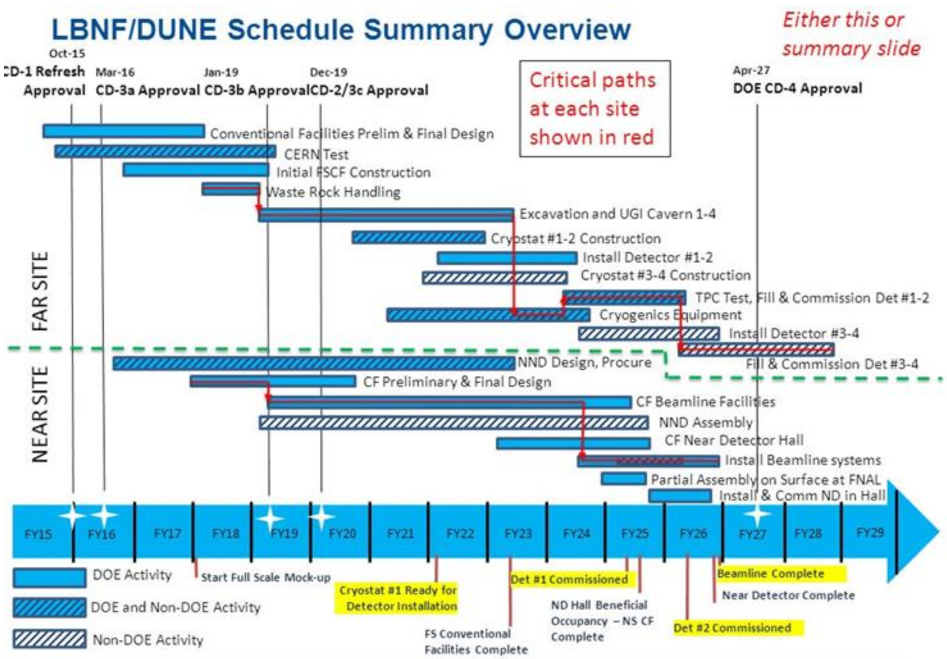
타우중성미자,
고에너지 중성미자

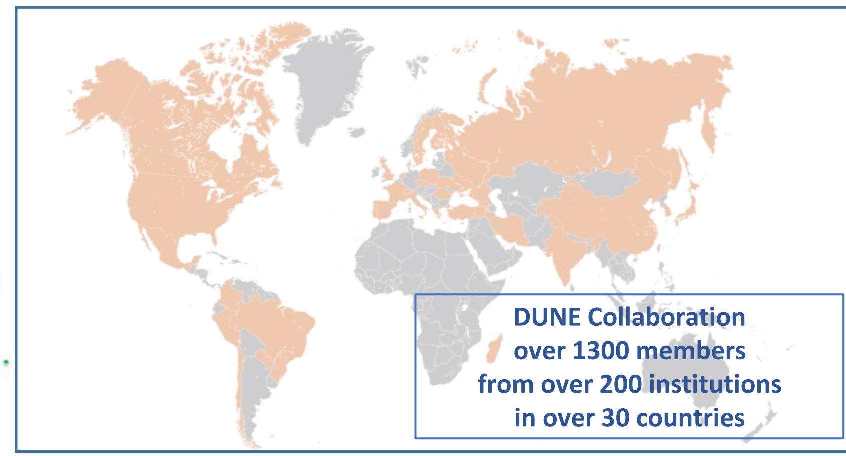
조기현(KISTI) 신서동 (전북대)

암흑물질 탐색,
비표준모형

Deep Underground Neutrino Experiment



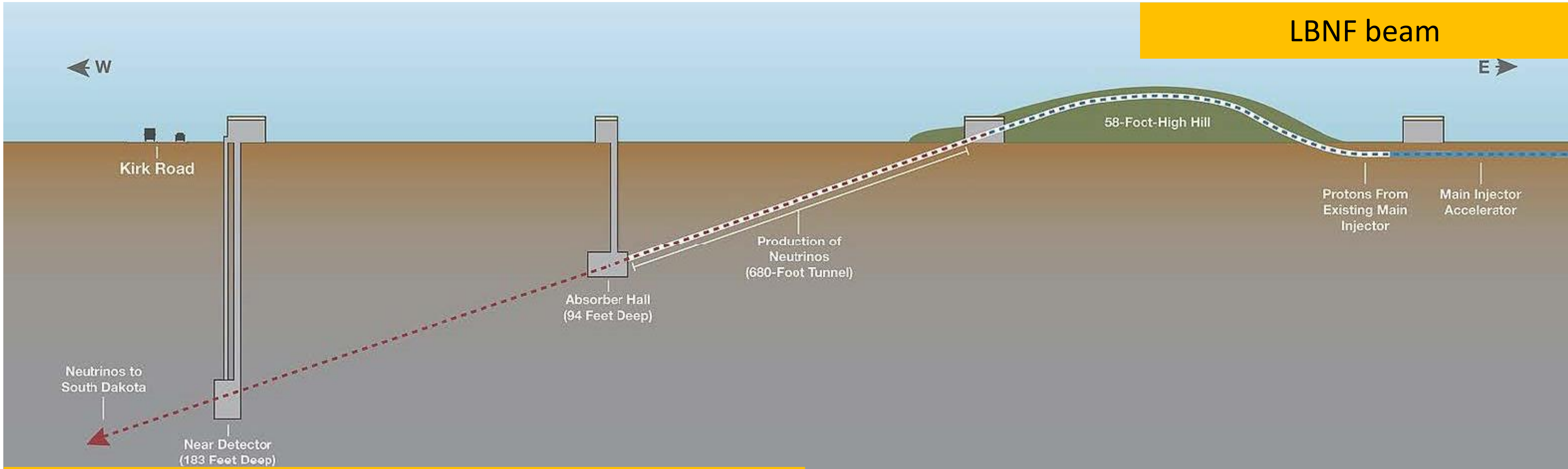




Korean members of DUNE Collaboration
(2022년 10월 현재)

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

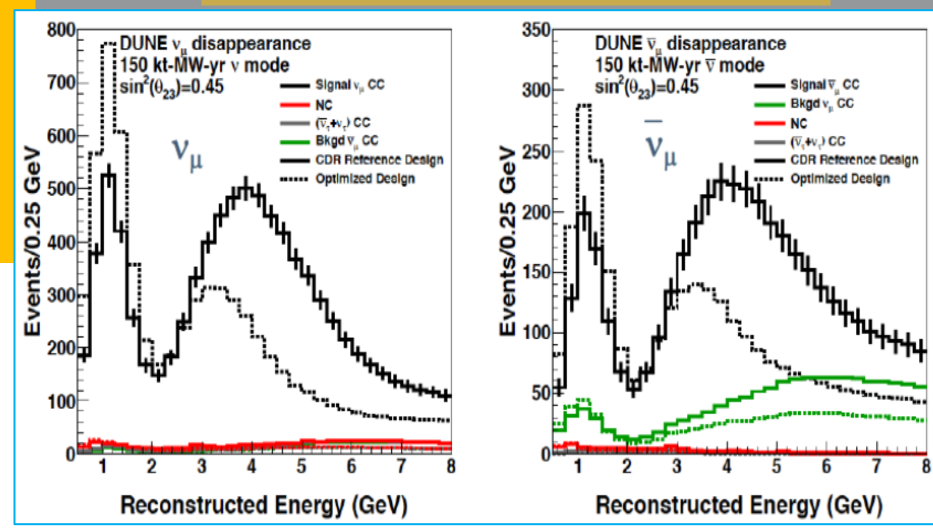
LBNF beam

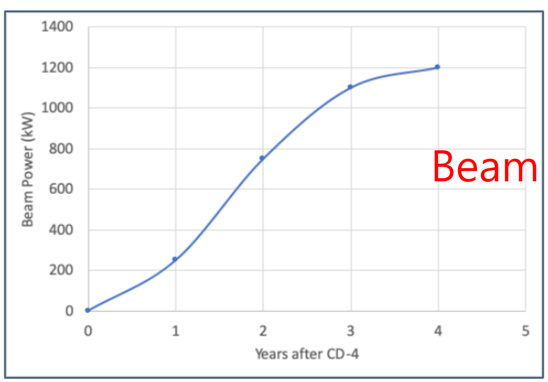


Long-Baseline Neutrino Facility

- 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

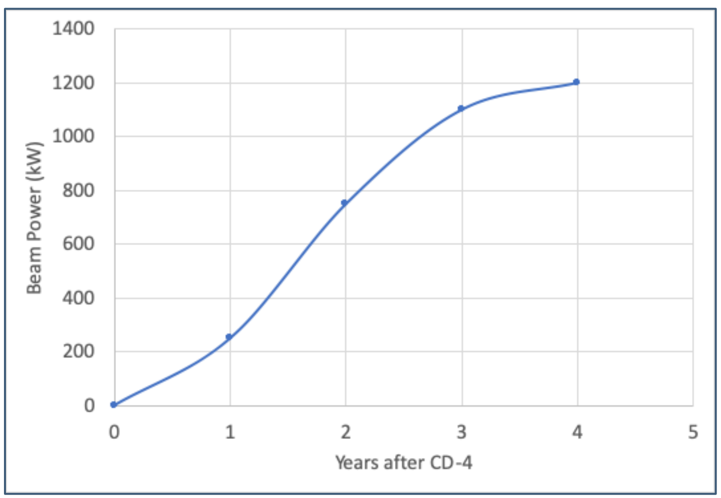
Beam Optimization



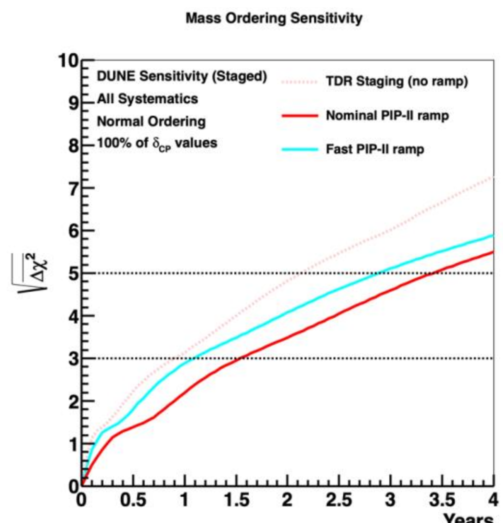


Beam Ramping plan

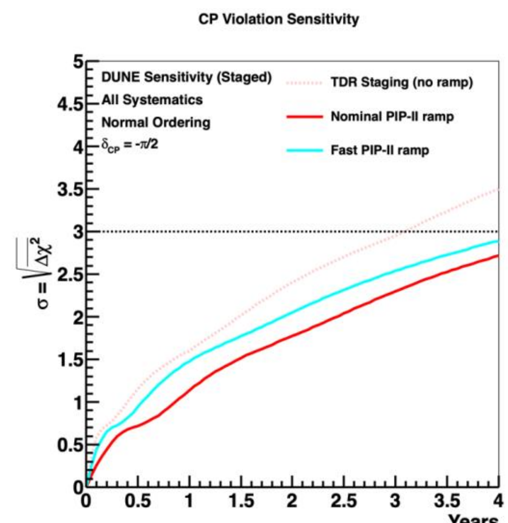
2018: ProtoDUNEs at CERN → 2019: FD TDR → 2020: Excavation starts → ~~2022:~~ 2023: Installation of first module → First physics data: Atm, SN, & solar neutrinos. Proton decay. Calibration → 2026: ND & Neutrino beam available



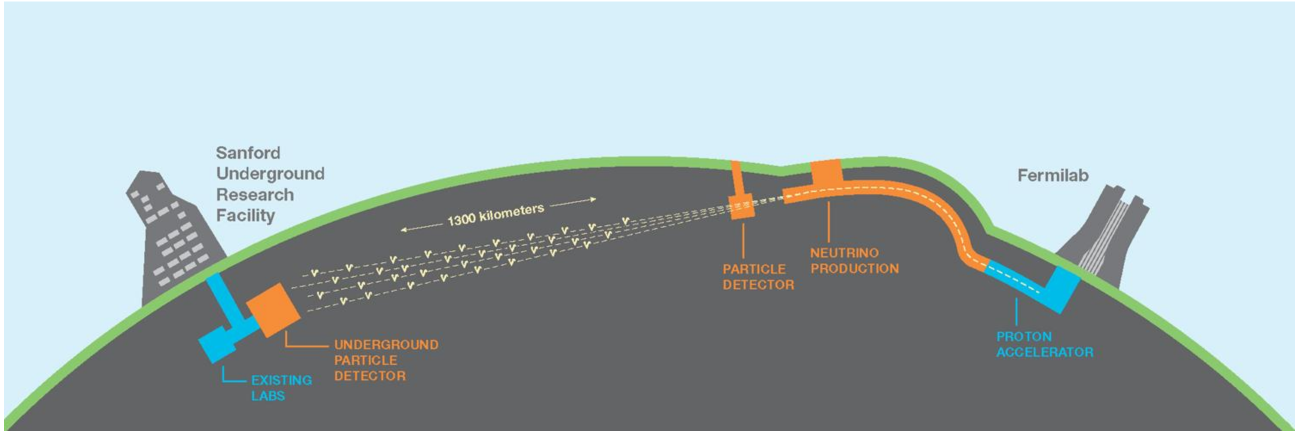
PIP-II
Power Ramp



Mass Ordering
100% δ_{CP} values



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

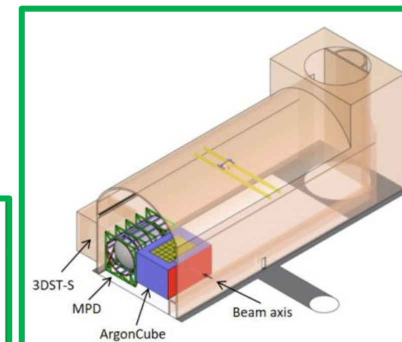


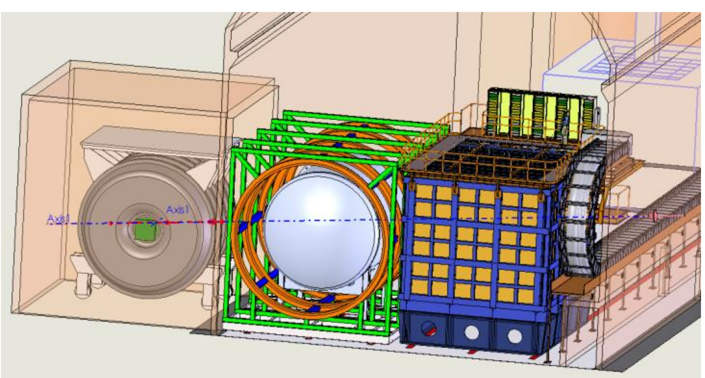
Near Detector

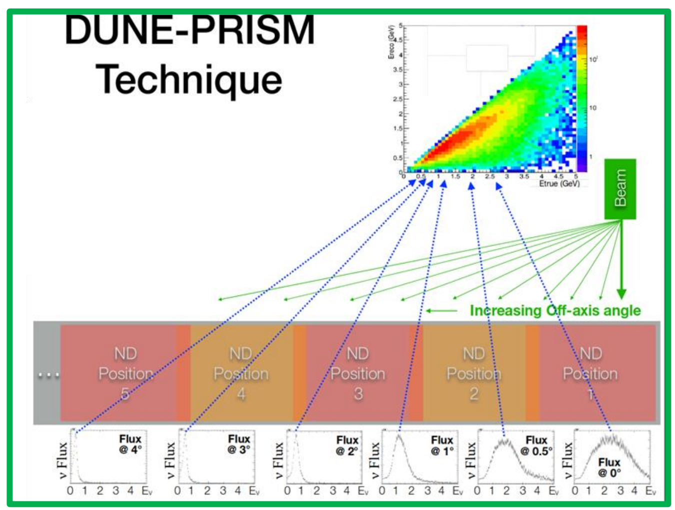
ND Complex (574 m from target hall, 60 m from surface)

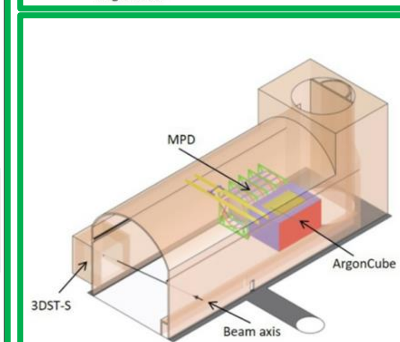
- Liquid Ar Time Projection Chamber
- HP Gas Ar TPC with magnet and ECAL (MPD)
- System for on-Axis Neutrino Detection (SAND)

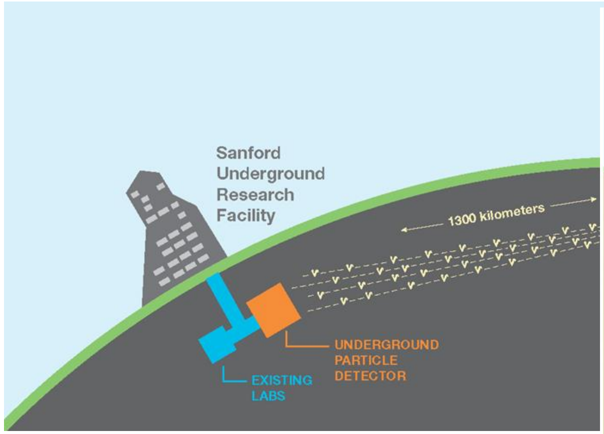
- Prediction of neutrino flux at FD w/o oscillation
- Control of systematics
- Study neutrino interaction with Ar, CH

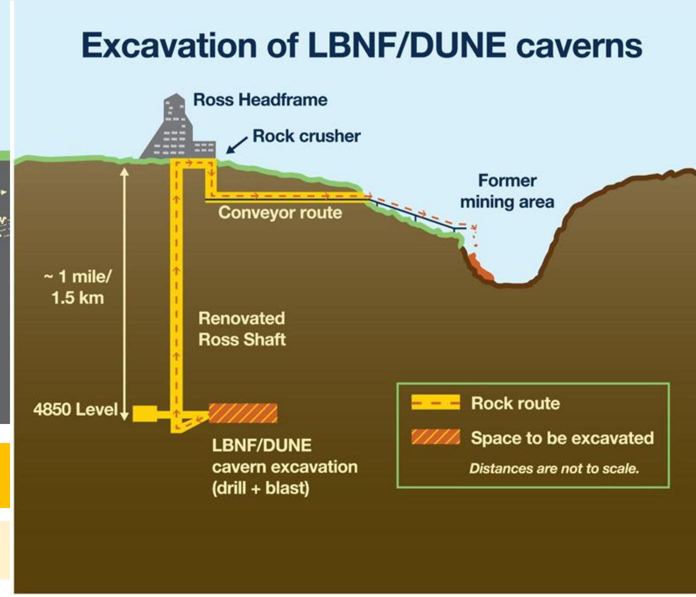








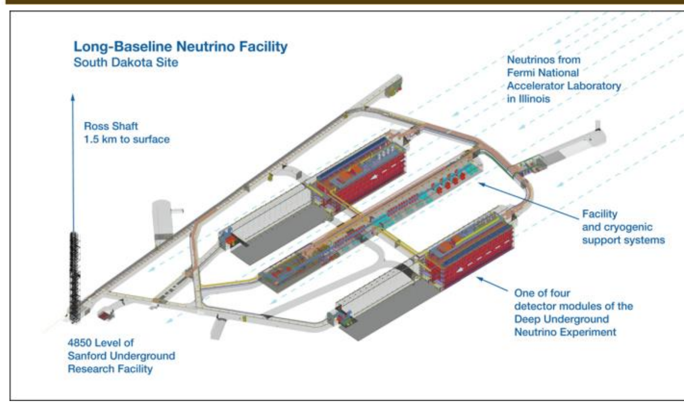




Far Detector
- Measurement of neutrino events (w/ oscillation)

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.

Korean DUNE Activities

- 2016.05 CAU joined DUNE Collaboration
- 2017 ~ 2018 ProtoDUNE L-Ar TPC Single Phase Cold Electronics Module test
- 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

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>


소화기

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 Submitted to APC in DUNE

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]

중성미자 상호작용과 중성자 검출

- 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

preprint for arXiv

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

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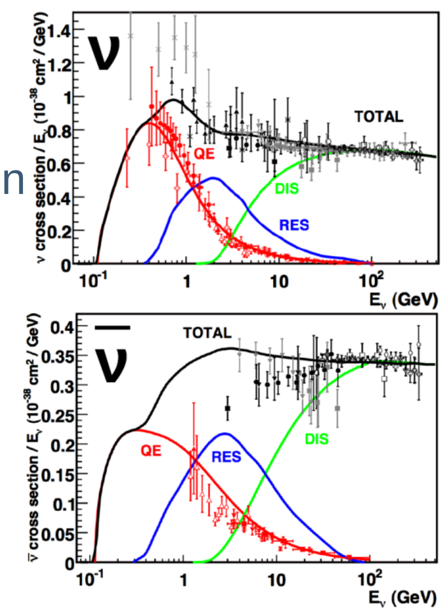


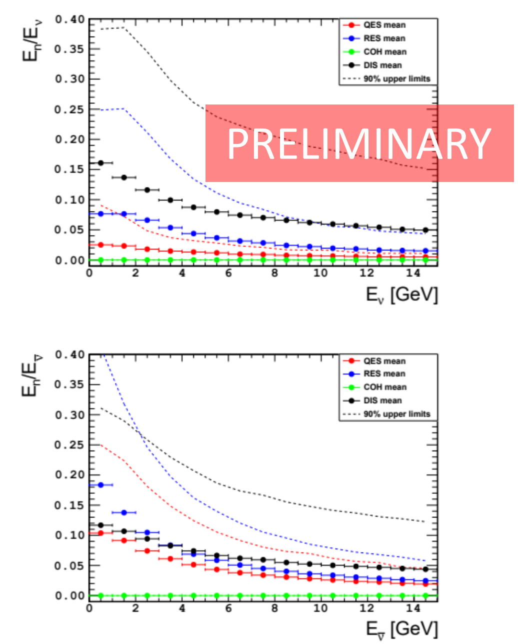
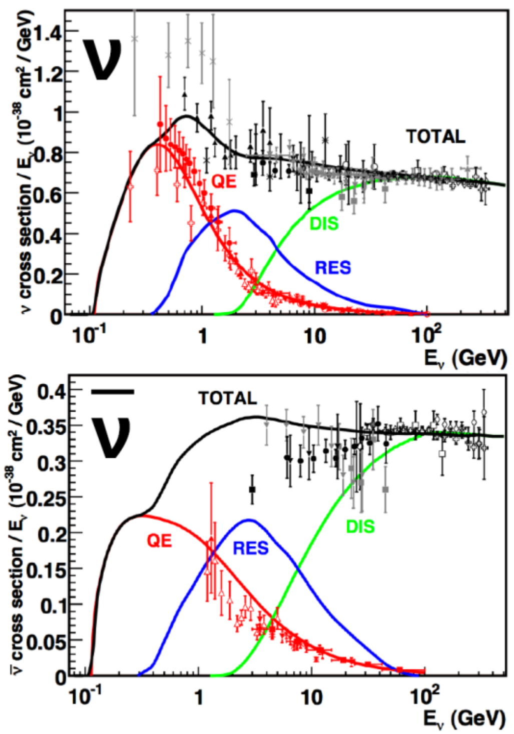
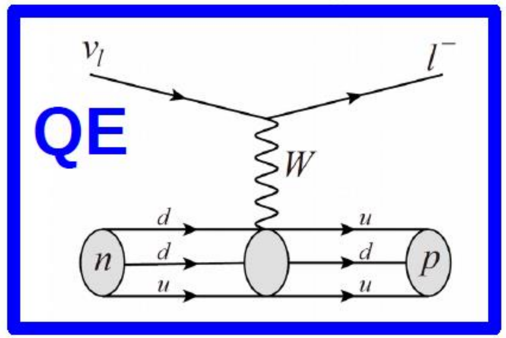
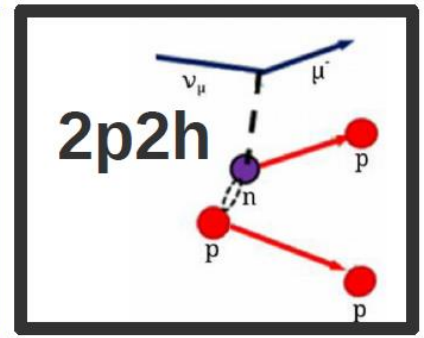
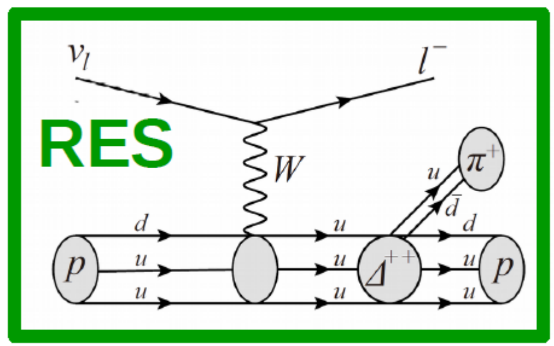


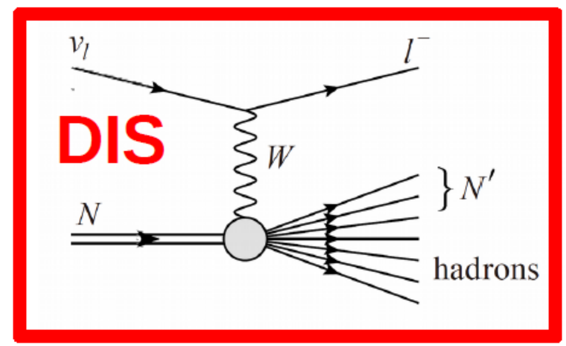
FIG. 1. Average energy fraction delivered to the primary neutrons relative to the neutrino energy(top) and the antineutrino energy(bottom). The average ratios E_n/E_ν are in comparison according to the CC Quasi-elastic (QES), CC resonant (RES), CC coherent (COH) and CC deep-inelastic scattering (DIS)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

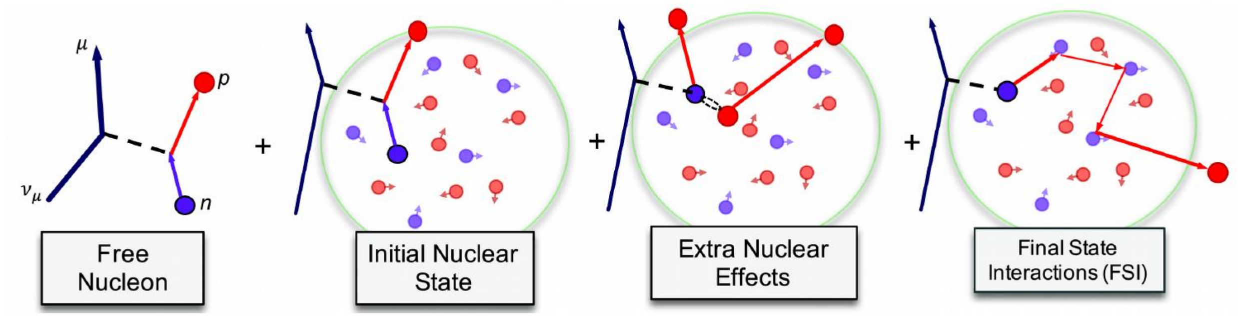

ν
TOTAL
QE
DIS
RES
ν cross section / E_ν (10^{-38} cm² / GeV)
E_ν (GeV)
TOTAL
QE
RES
DIS
$\bar{\nu}$ cross section / E_ν (10^{-38} cm² / GeV)
E_ν (GeV)


QE
ν_l
l^-
W
n
p


2p2h
ν_μ
μ^-
p
n
p
p


RES
ν_l
l^-
W
π^+
p
Δ^{++}
p


DIS
ν_l
l^-
W
N'
N
hadrons

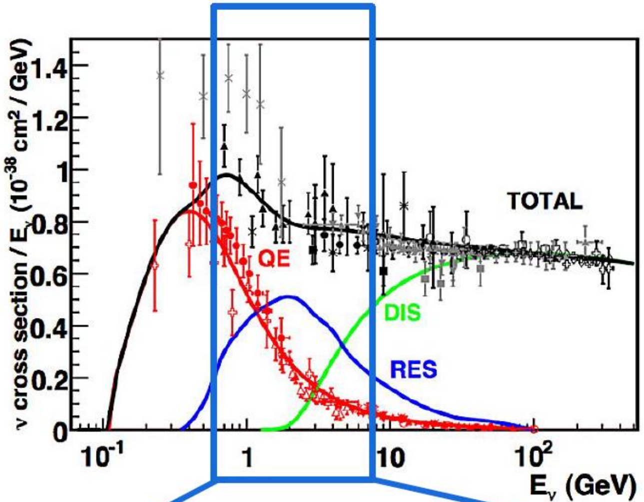


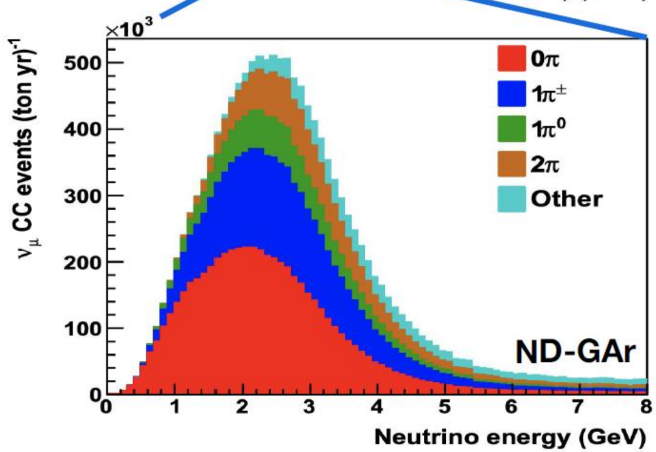
$$R(\vec{\mathbf{x}}) = \Phi(E_\nu) \times \sigma(E_\nu, \vec{\mathbf{x}}) \times \epsilon(\vec{\mathbf{x}}) \times P(\nu_A \to \nu_B)$$

Final state particle content does not isolate initial interaction type!

Neutrino Interaction Physics & the DUNE Near Detector

Mateus F. Carneiro on behalf of the DUNE Collaboration

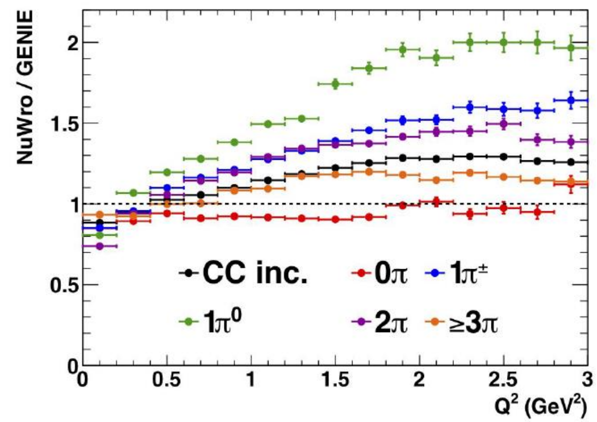




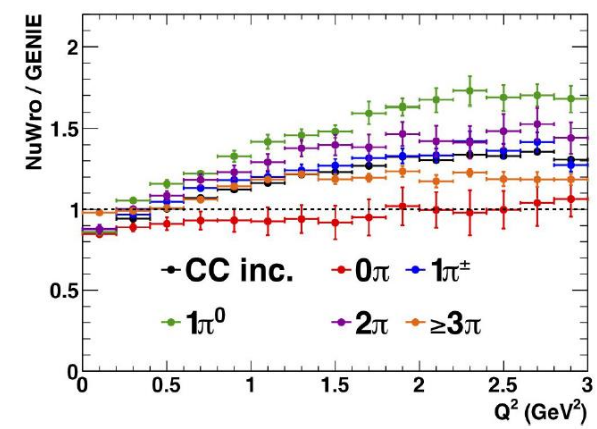
			Interaction Channel		Event Rate	
					ND-LAr	ND-GAr
CC	ν_μ				8.2×10^7	1.64×10^6
		0π			2.9×10^7	5.8×10^5
		$1\pi^\pm$			2.0×10^7	4.1×10^5
		$1\pi^0$			8.1×10^6	1.6×10^5
		2π			1.1×10^7	2.1×10^5
		3π			4.6×10^6	9.3×10^4
		other			9.2×10^6	1.8×10^5
	$\bar{\nu}_\mu$				3.6×10^6	7.1×10^4
	ν_e				1.45×10^6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



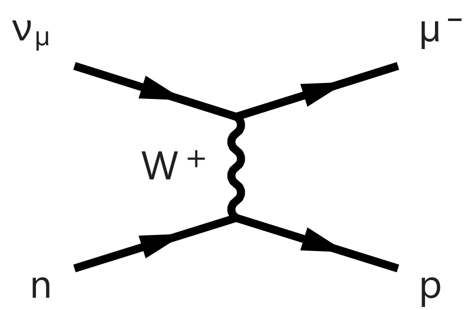
NuWro/GENIE for various reconstructed final states (FHC)

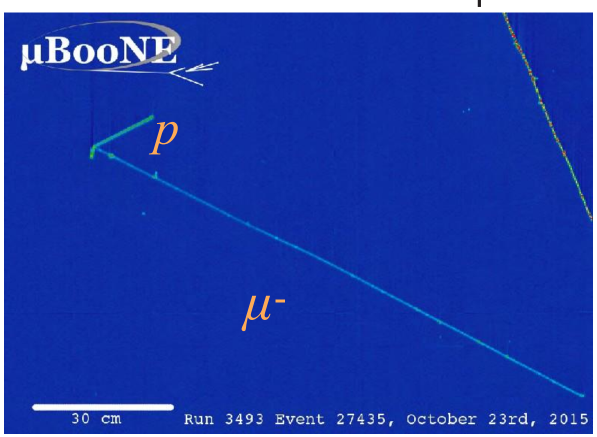


Neutrino Interaction Physics & the DUNE Near Detector

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?

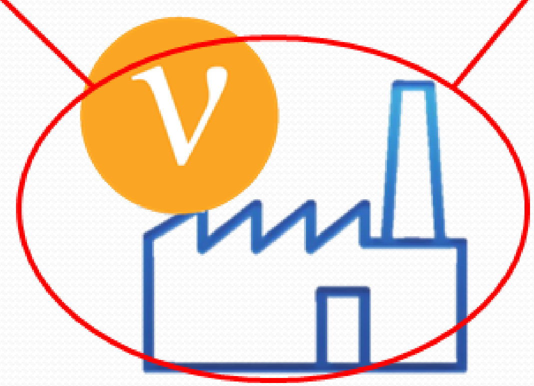
- Muon has constant dE/dx (minimum-ionizing particle)
- Long, clear track: **easy to measure E_μ and θ_μ**
- $\bar{\nu}$ case - neutron hard to detect (neutral)
- Not affected by **final-state interactions**
  - Nucleons can re-interact in the nucleus.

What about anti-muon neutrinos?
What about neutrons?

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

Leptophilic mediators

Cosmogenic boosted dark matter (BDM)

Axion-like particles (ALP)

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.

Concluding Remarks

- 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.

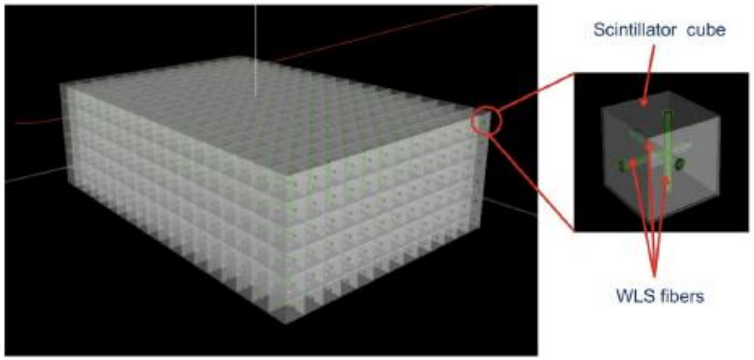
- Korean contributions for protoDUNE, ND/3DST detector, Neutron study for reconstruction of anti muon neutrinos.
- Plan to participate protoDUNE analysis.

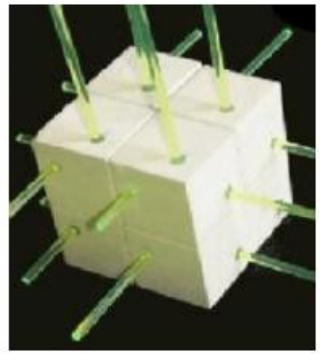
- Both global and local activities are waiting for participation of young researchers and students .
- 중앙대 중성미자 연구실
  중성미자 상호작용, Sim/Reco, 데이터 분야 연구원 채용 예정

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

1.5 cm x 1.5 cm x 1.5 cm

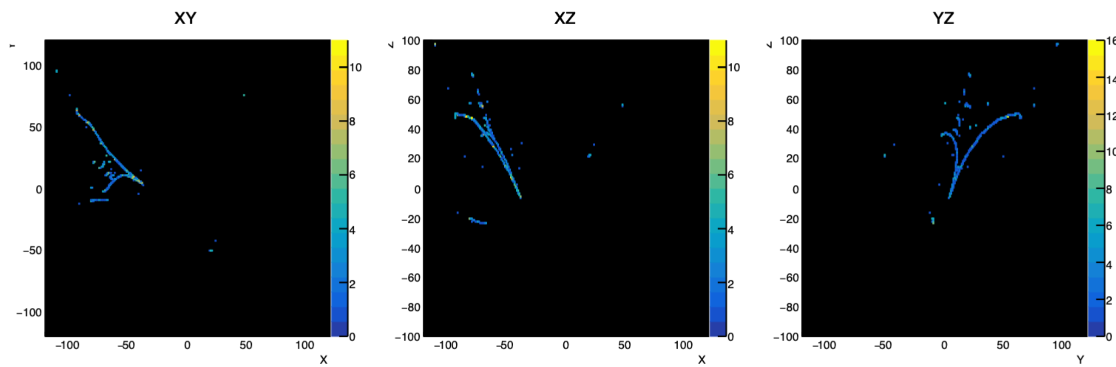
Sunwoo Gwon
for KPS 2020F



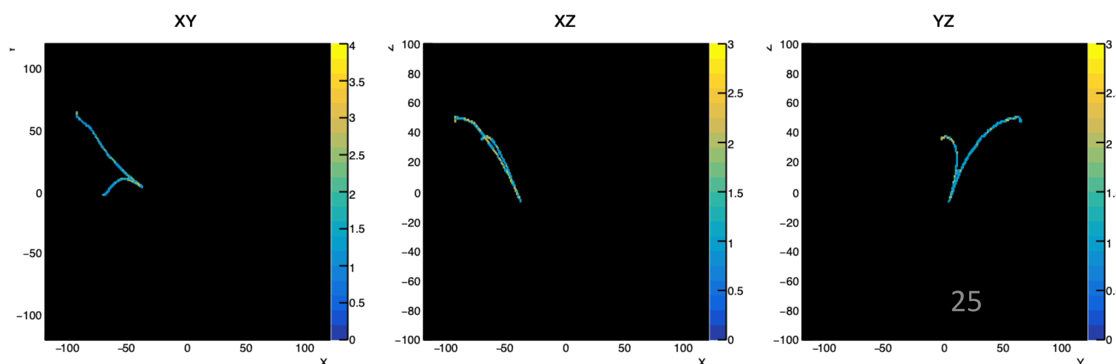


Event Display

contains all neutron, gamma induced hits

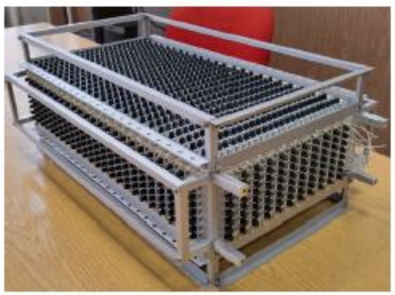


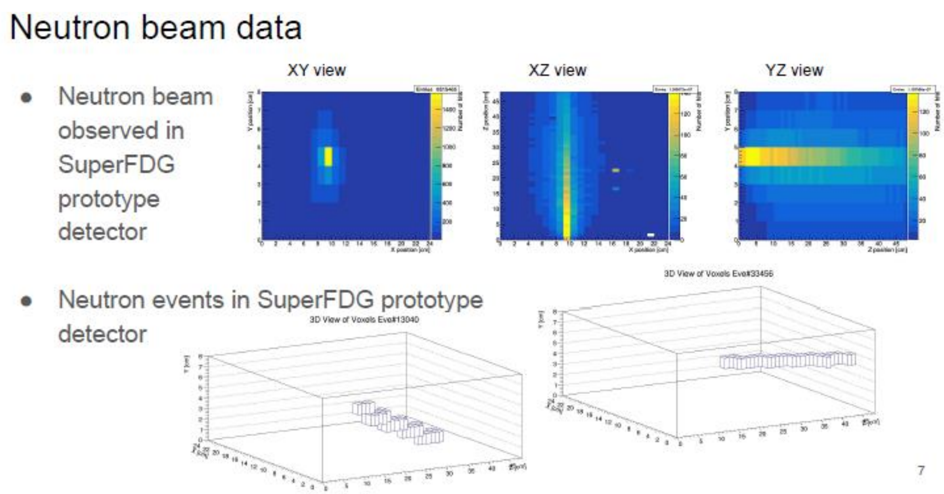
only the cluster



Los Alamos Neutron Beam test

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





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

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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