Future Neutrino Experiments; DUNE & Hyper–K

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Outline

- Introduction
- DUNE and Hyper – K, the next generation ν experiments
- Physics Potential
- Status and Schedule of the experiments
- Conclusions

In the Past Quarter Century

- Observation of The Top Quark
- Higgs-like Scalar Boson Discovery

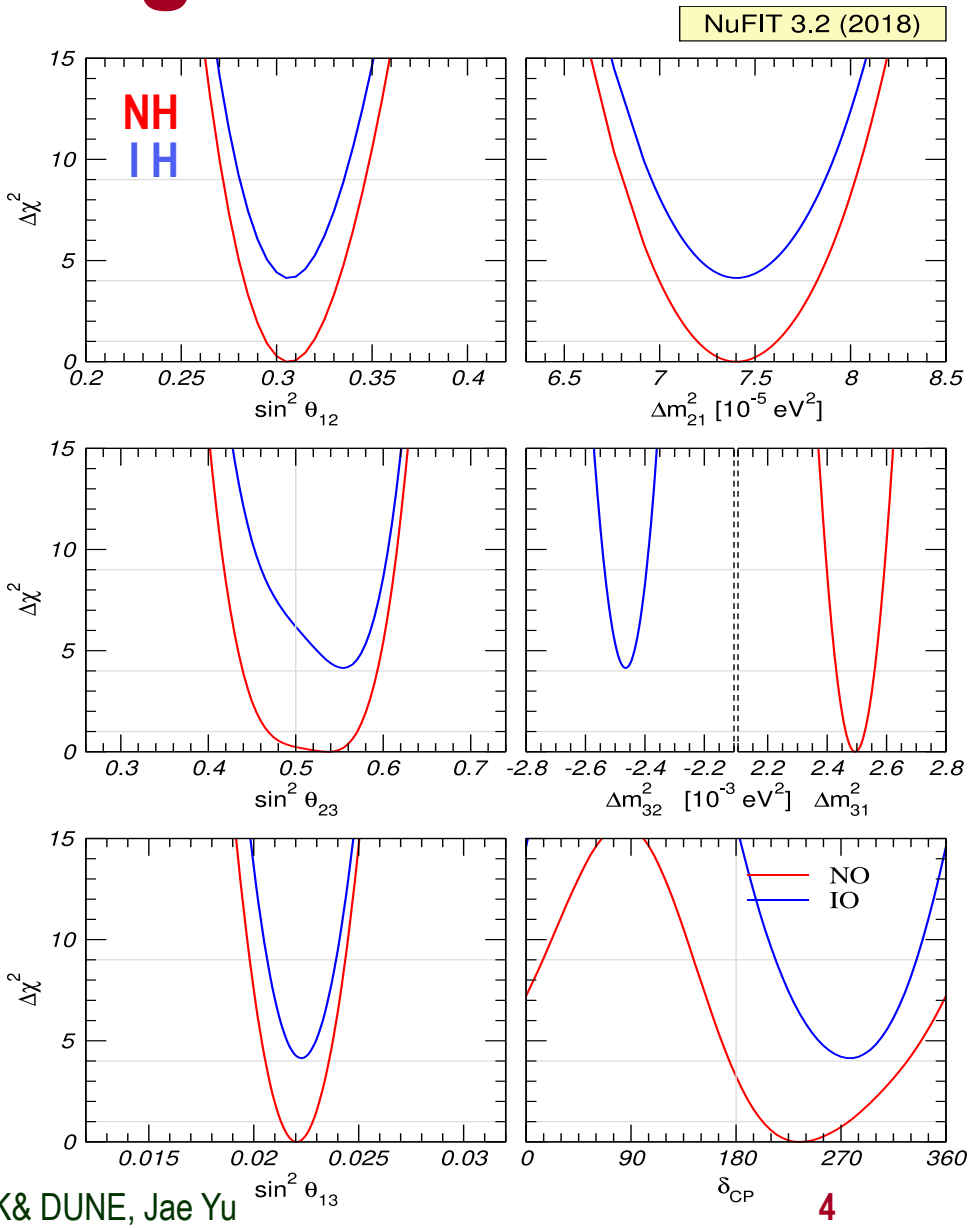
- Neutrino oscillation discovery

Physics Motivation

- The neutrino sector in the Standard Model needs a fix, so
  - Precision measurements of the oscillation parameters
    - Mixing angles and mass hierarchy
  - Studying the CPV and precisely measuring the CP phase
    - Do neutrinos and anti-neutrinos oscillate the same way?
- These could lead to a new symmetry
- The question of the grand unification
  - Energy scale of the unification and nucleon decay
- Understanding neutrinos of astrophysical origin
  - Supernova, relic neutrinos, dark matter, etc
- These require high statistics samples
  - Large volume and highly capable (near and far!) detectors
  - High intensity neutrino beam facility with a long baseline

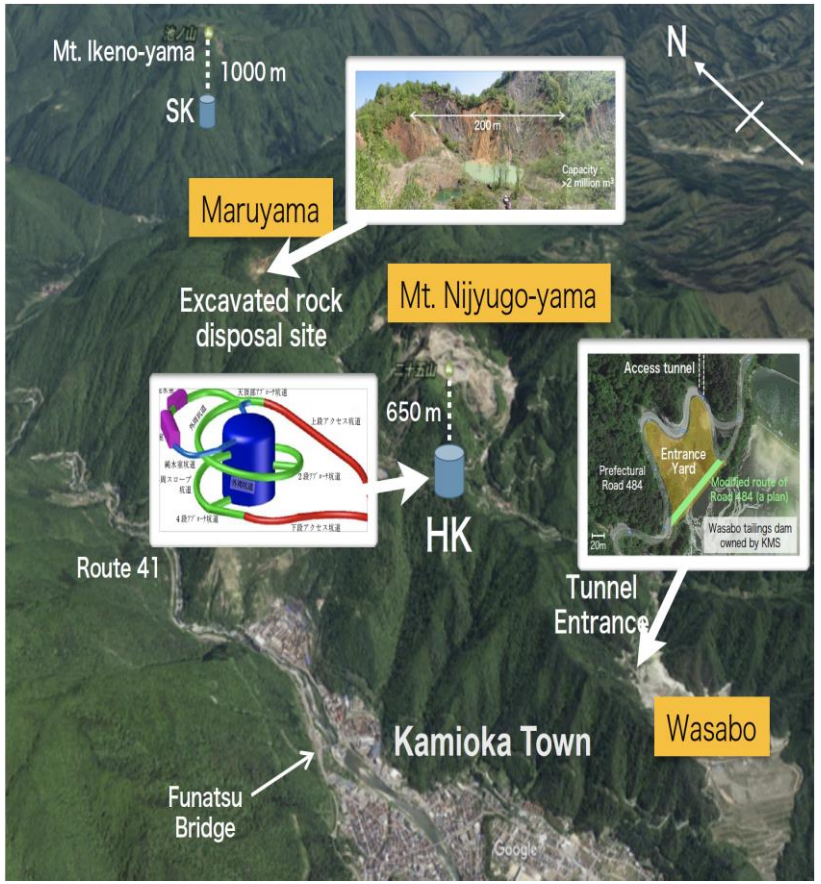
Current Understanding of ν Oscillation

- θ_{23} & ΔM^2_{23} measurements
  - Atm. ν: SK, IceCube, Km^{3}NET, etc
  - Long Baseline: K2K, MINOS, Opera, NOvA, etc
- θ_{12} & ΔM^2_{12} measurements
  - Solar ν: SNO, SK, Borexino, etc
  - Reactor: KamLAND
- θ_{13} measurements
  - Long Baseline: MINOS, T2K, NOvA, etc
  - Reactor: Daya Bay, RENO, Double Chooz

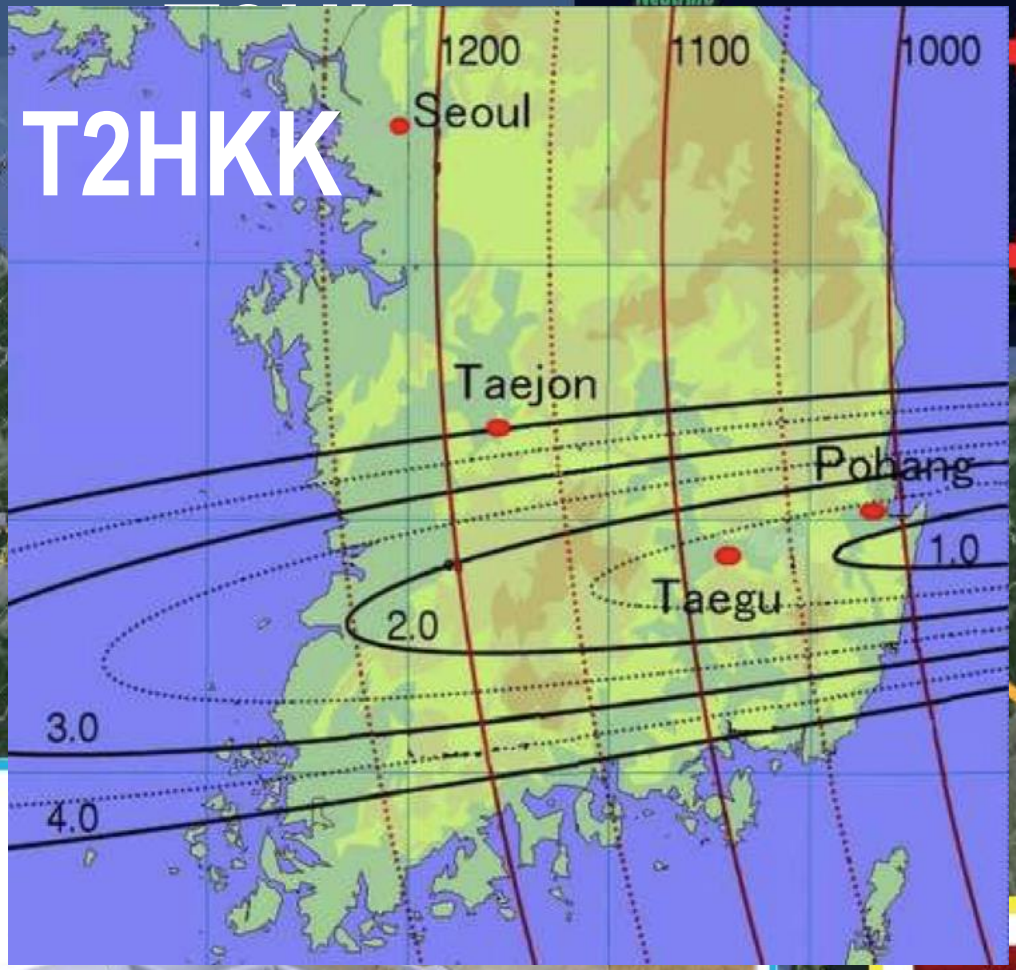


The Next Generation ν Experiment – I

- With the 2013 strategic planning of the community in the three regions, the efforts of building two large scale neutrino experiments progressed in earnest
- The Hyper Kamiokande, T2HK and T2HKK
  - Joint efforts of the teams from all three regions at Kamioka
  - Water Cerenkov ➔ Proven technology!
  - ~300 members, 74 institutions from 14 countries in the proto-collaboration
  - Supported JPY 10M from MEXT this year for fundamental studies
  - Recently released the design report
    - arXiv:1805.04163



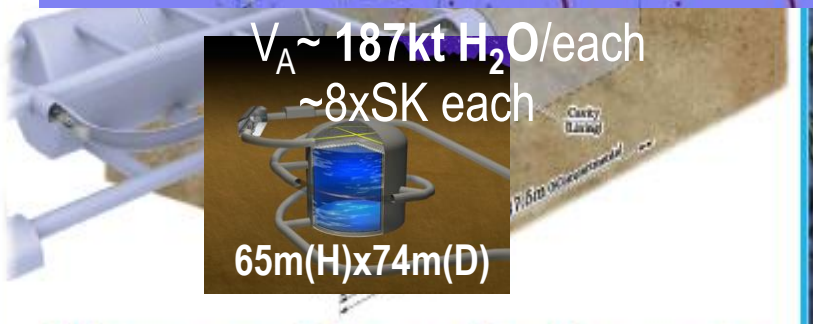
T2HKK



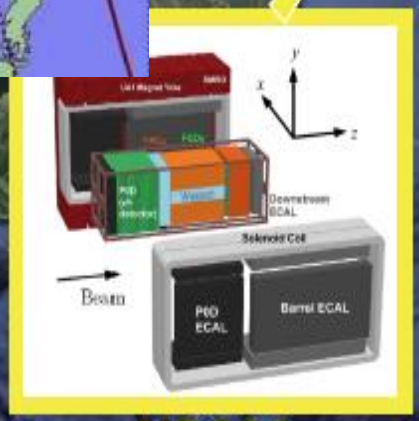
Neutrino Facility at J-PARC

2.5° off-axis narrowband ν beam
P_{Beam}~1.3MW,

TOKAI



Hyper-Kamiokande



ND280 Near Detectors

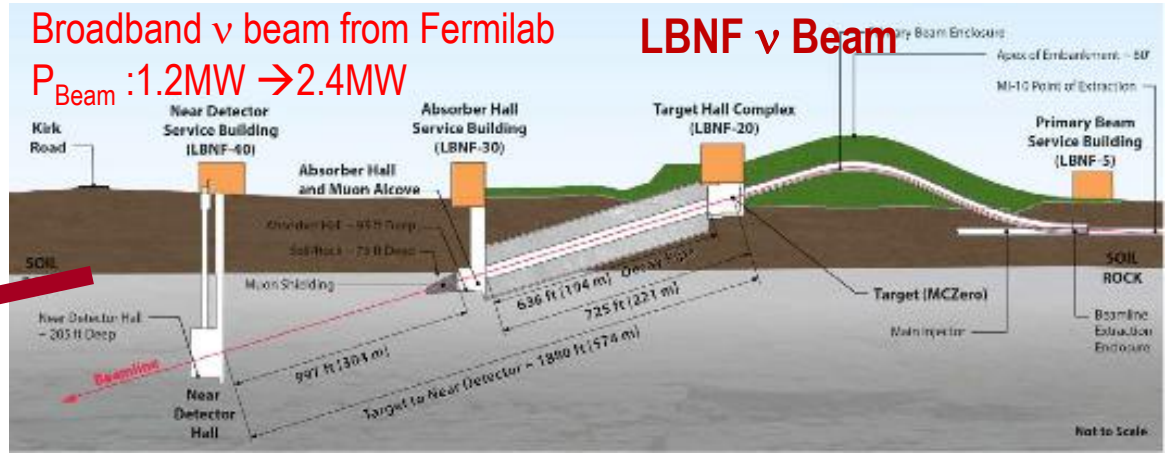
The Next Generation ν Experiment – II

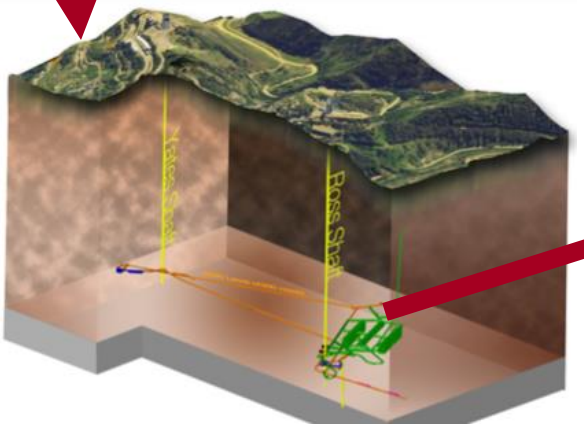
- The Deep Underground Neutrino Experiment (DUNE)
  - Joint efforts of teams from all three regions – Americas, Europe and Asia – hosted by Fermilab in the US
  - 1132 members, 179 institutions from 32 countries
  - LAr TPC ➔ Employ two technologies (SP/DP) within one experiment, systematic x-check
  - LBNF (Long Baseline Neutrino Facility) far site facility construction approved by US DOE in Sept. 2016 ➔Ground breaking at the far site July 2017

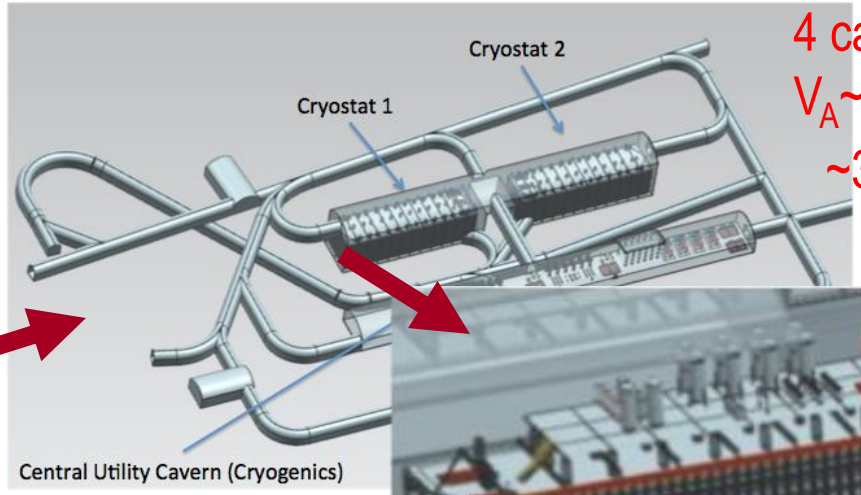
Anatomy of DUNE Experiment

Broadband ν beam from Fermilab

P_{Beam} :1.2MW →2.4MW



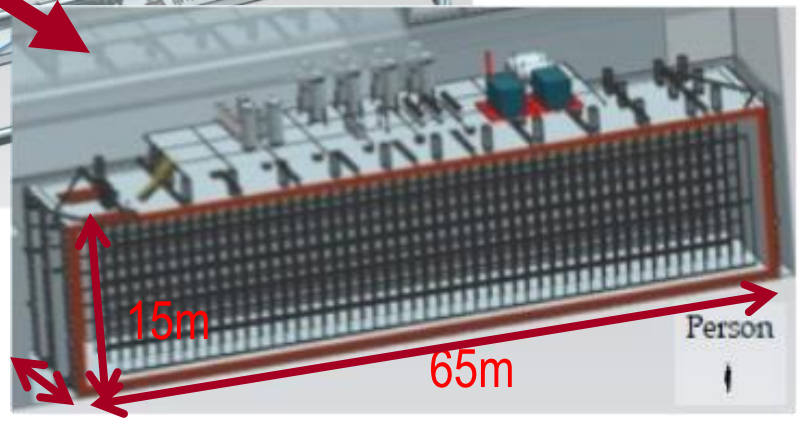




4 caverns w/ fiducial

V_A~ **10kt LAr** each

~30xICARUS

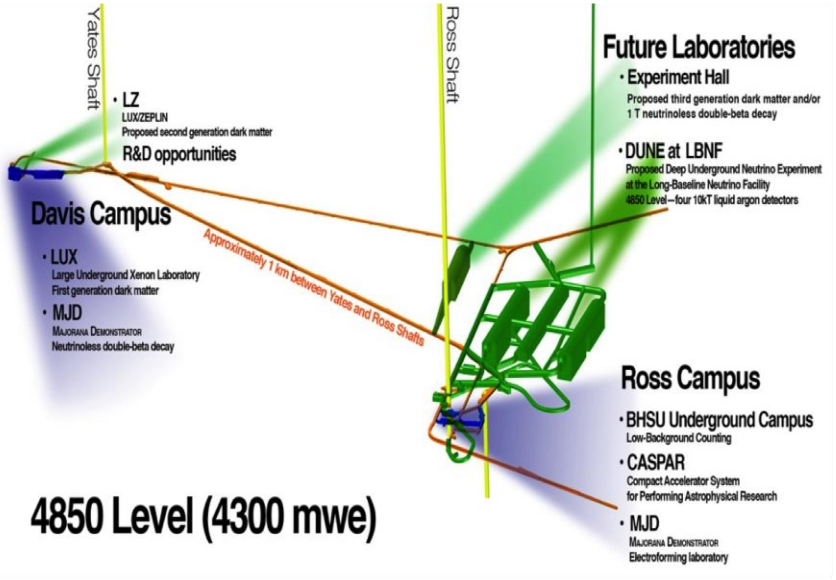


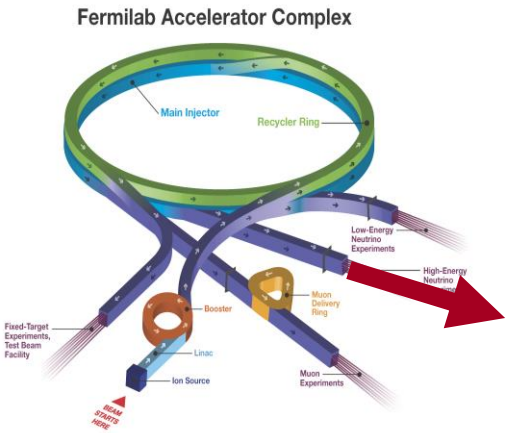
LBNF Far Detector Site, SURF

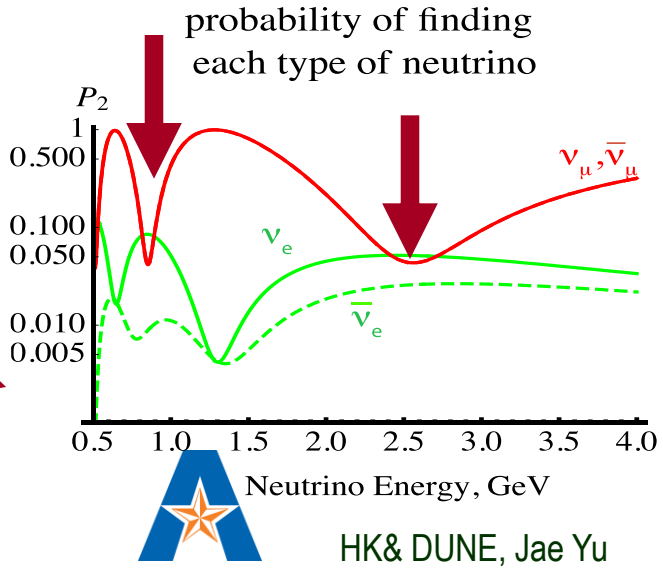
1500m underground

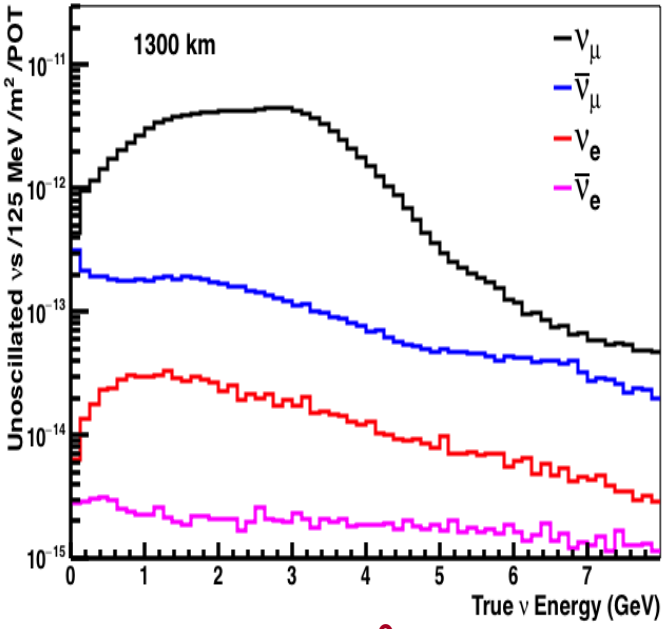
Long Baseline Neutrino Facility (LBNF)

- LBNF Consists of two elements
  - Far detector site: Sanford Underground Research Facility (SURF) in South Dakota
  - Neutrino Beam Line at Fermilab
    - E_p=60 – 120 GeV
    - 1.2MW upgradable to 2,4MW
    - Horn focused beam optimized for CPV studies ➔ Provides access to two oscillation maxima





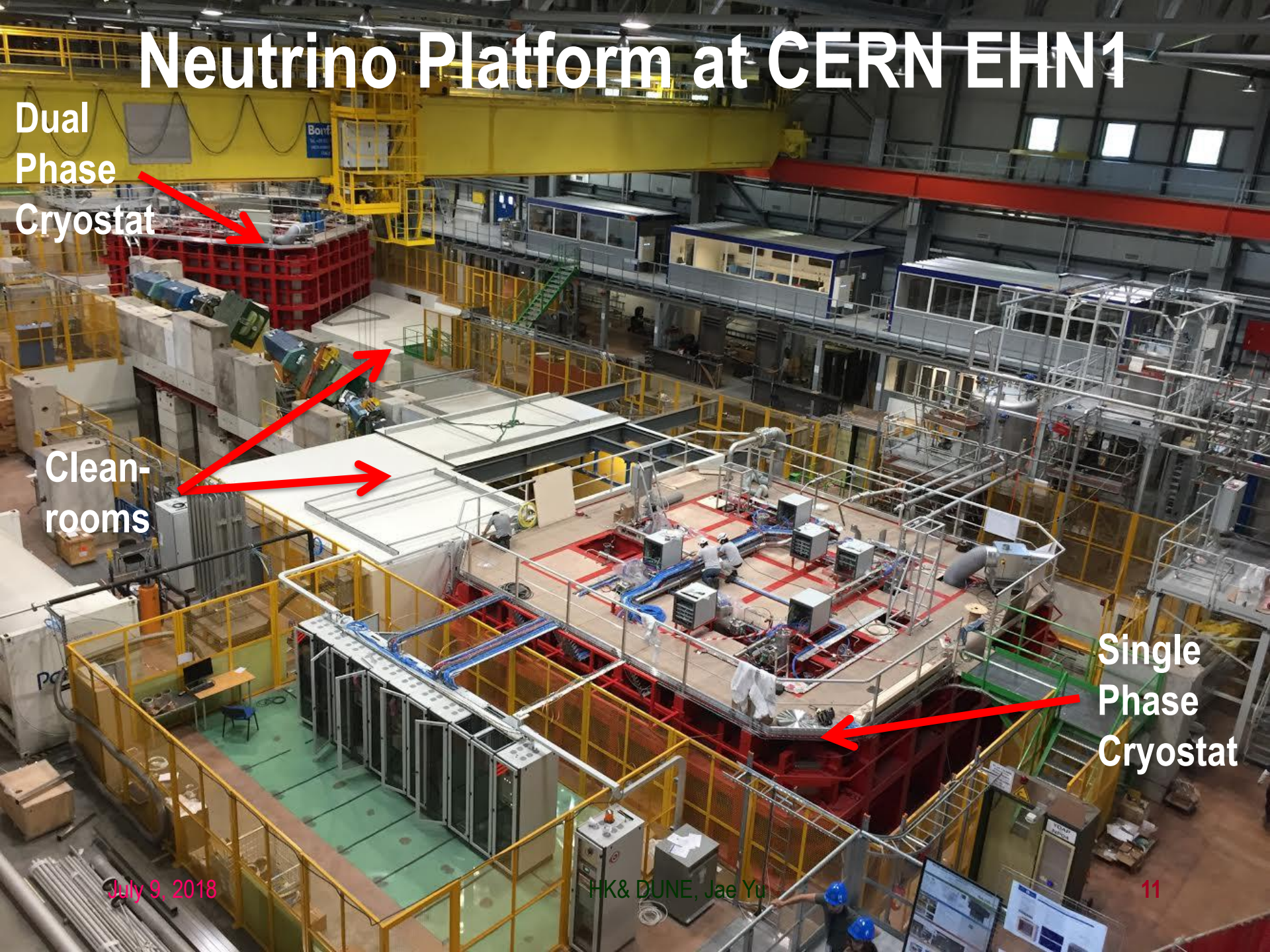




NG ν Experiments – Financial Supports

- Hyper – K supported with 10M JPY
- DUNE funding support highlights
  - US DOE
    - LBNF – SURF facility cavern excavation fully approved
    - LBNF ν Beam facility to be approved shortly
      - Accelerator improvement plan strongly supported!
    - Detector construction for prototyping in progress
  - CERN
    - Constructed Neutrino Platform in North area extension
    - Built 2 ProtoDUNE cryostats & currently committed to build one DUNE Cryostat (1st meeting with the GTT last week!)
    - Playing leadership role in installation of the prototypes
  - UK has agreed in sept. 2017 to award $88M project grant for DUNE

Neutrino Platform at CERN EHN1

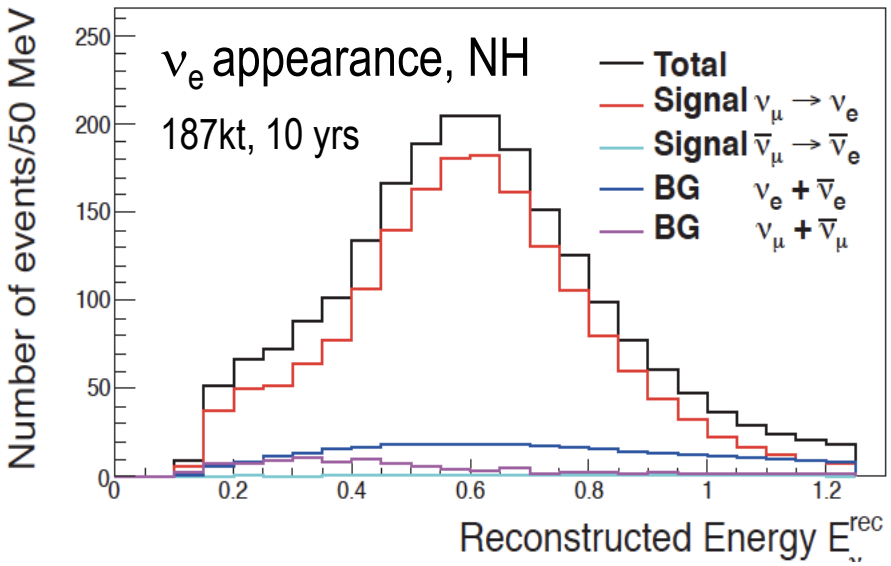


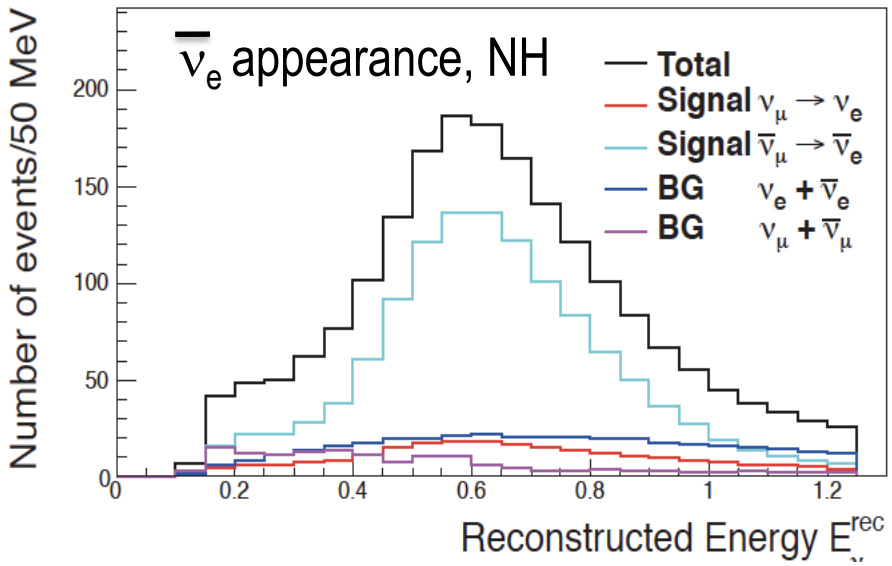
DUNE and Hyper-K Facility

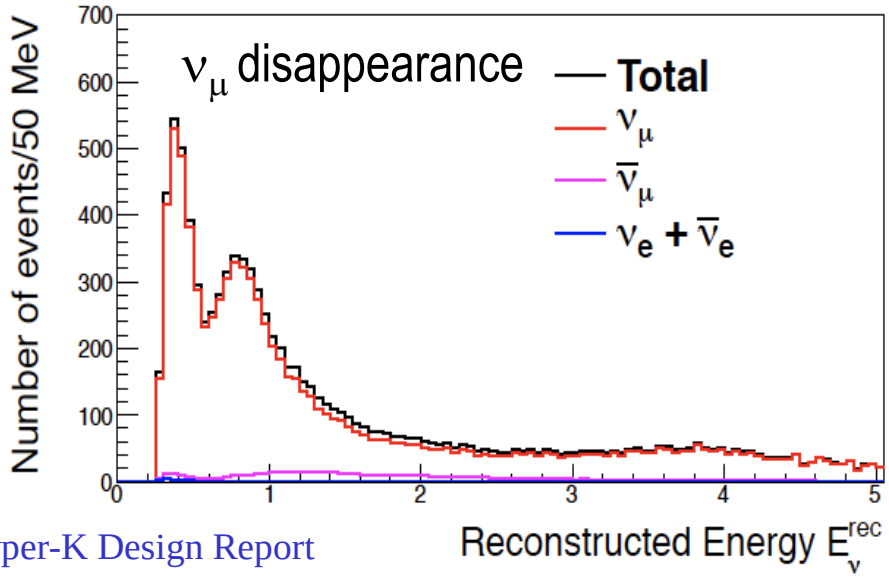
	DUNE	HK/T2HK	T2HKK
FD Technology & Fiducial Mass	LArTPC (2+1+1) x10kt	Water Cerenkov (1+1) x187kt	Water Cerenkov 187kt (Kamioka) + 187kt (Korea)
Proton Beam power	1.2MW → 2.4MW	1.3MW	
Proton Energy (GeV)	60 – 120	30	
Baseline (km)	1300	297	1100
FD Depth (m)	1500	650	1120
ND from ν target (m)	575	280	

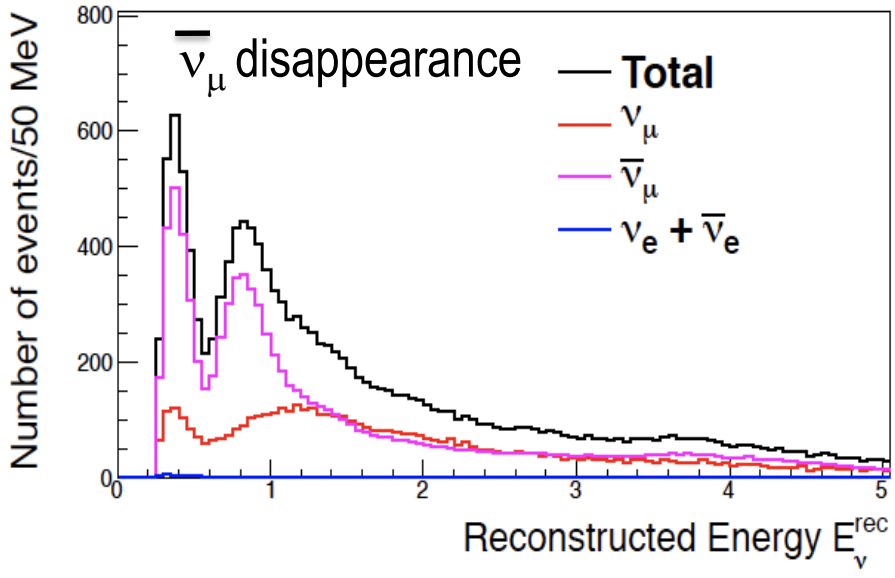
Hyper-K Design Report arXiv:1805.04163
DUNE Conceptual Design Report (CDR) arXiv:1512.06148

T2HK Oscillation Expectation









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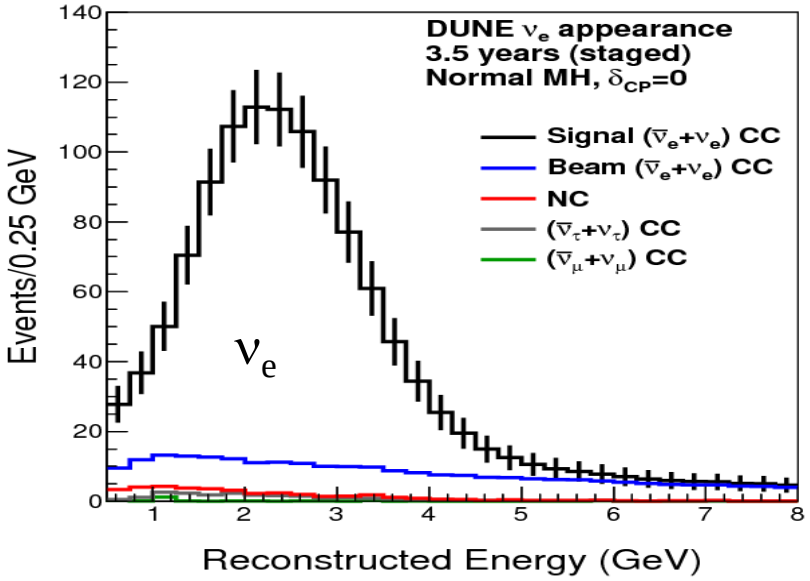
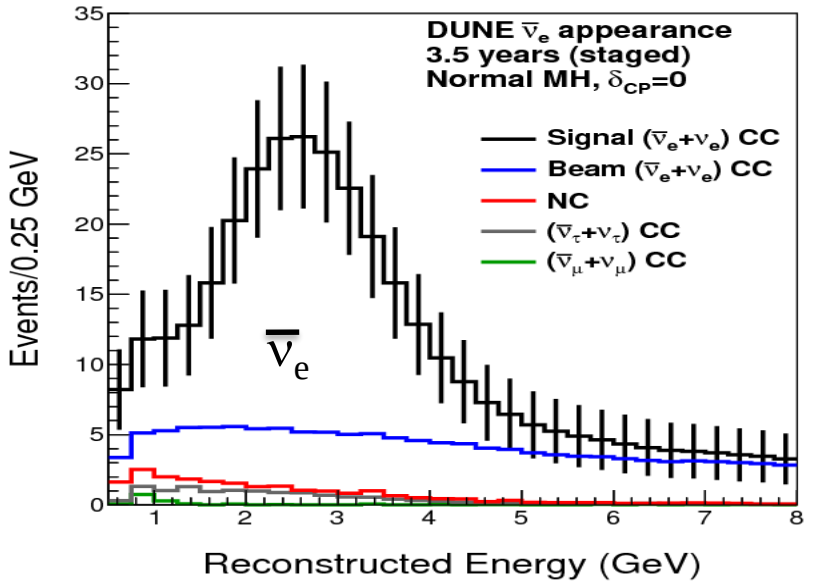
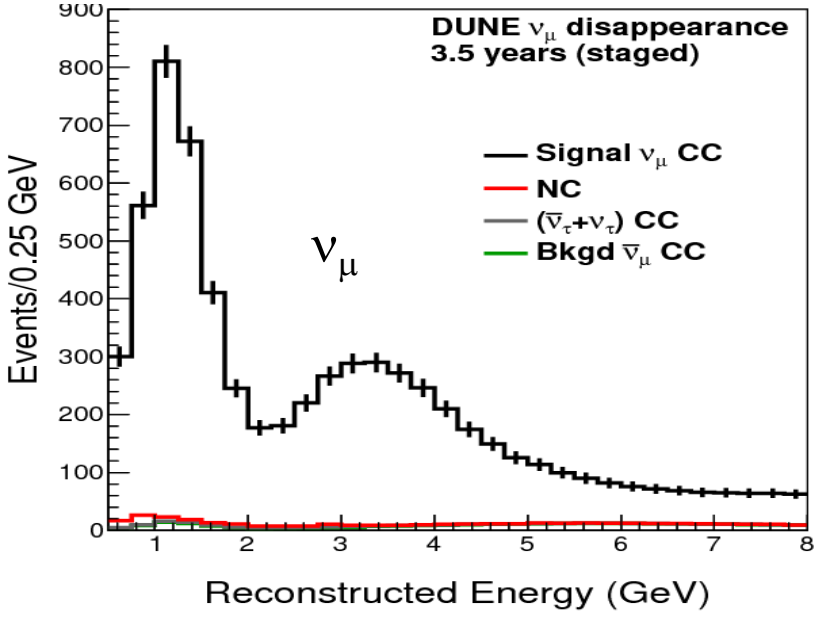
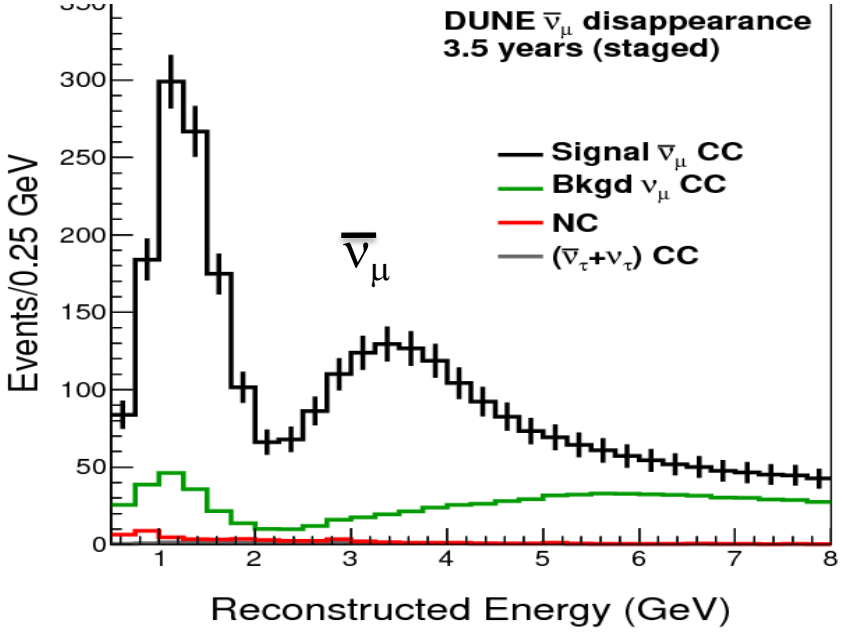
DUNE Oscillation Expectation



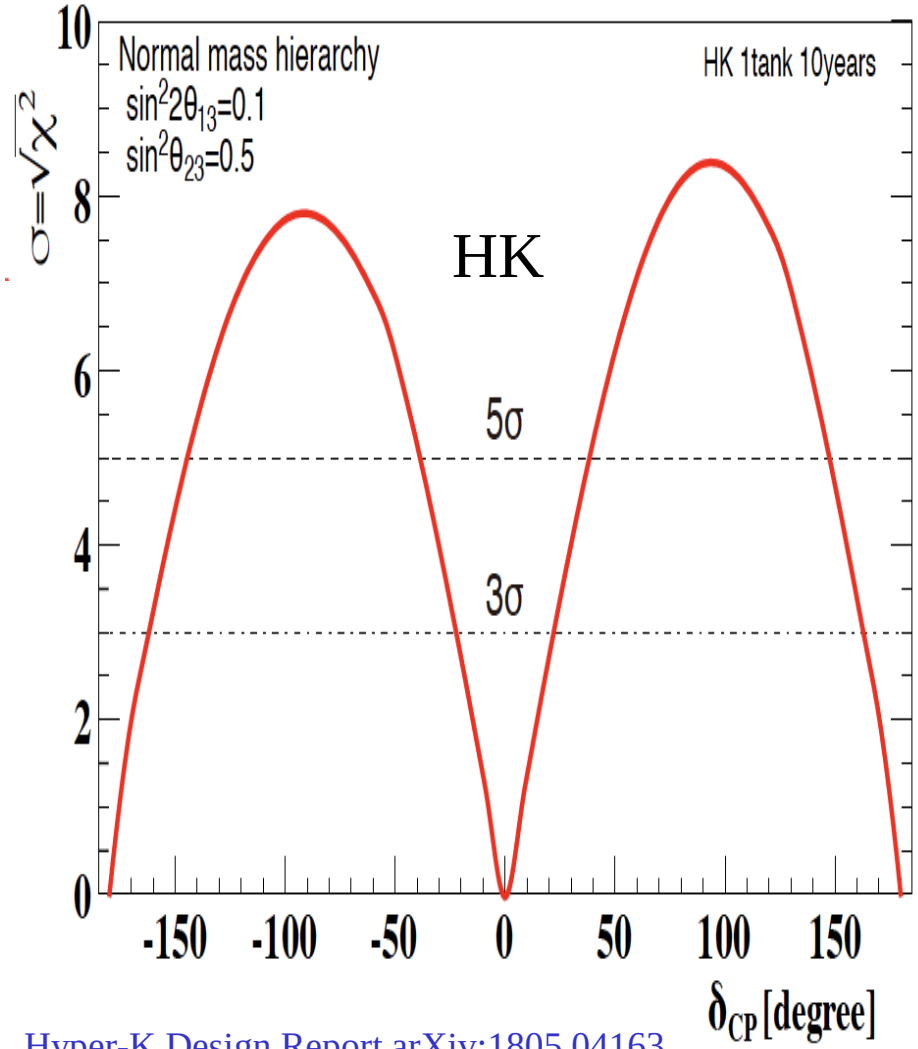


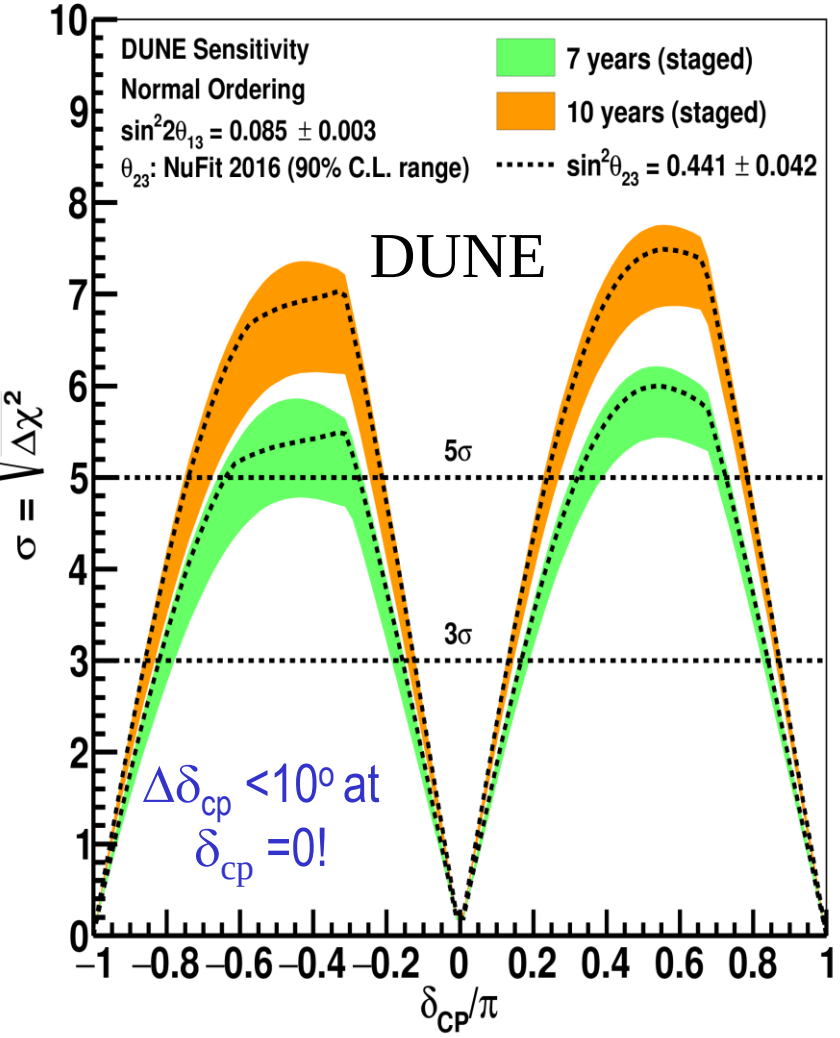




DUNE Conceptual Design Report (CDR) arXiv:1512.06148

Physics Reach, CPV





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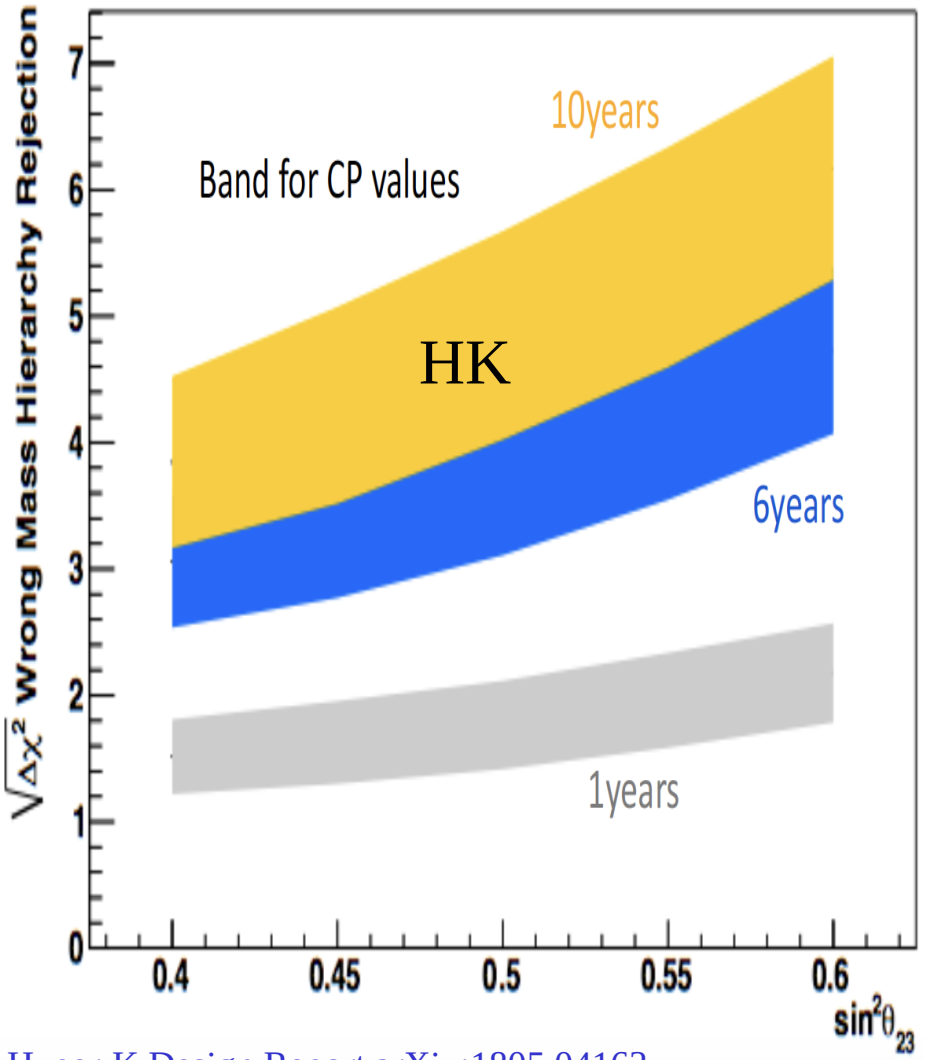
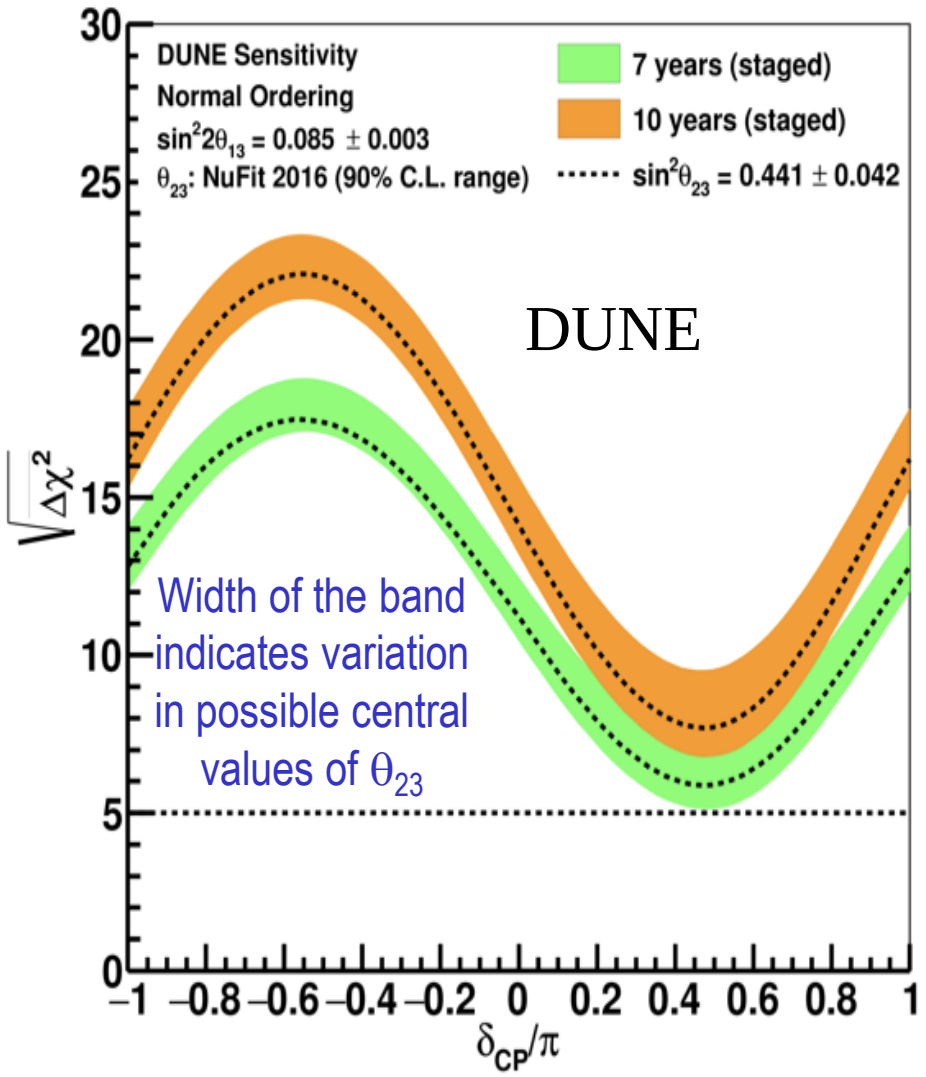
Width of the band indicates variation in possible central values of θ_{23}

Physics Reach, Mass Hierarchy





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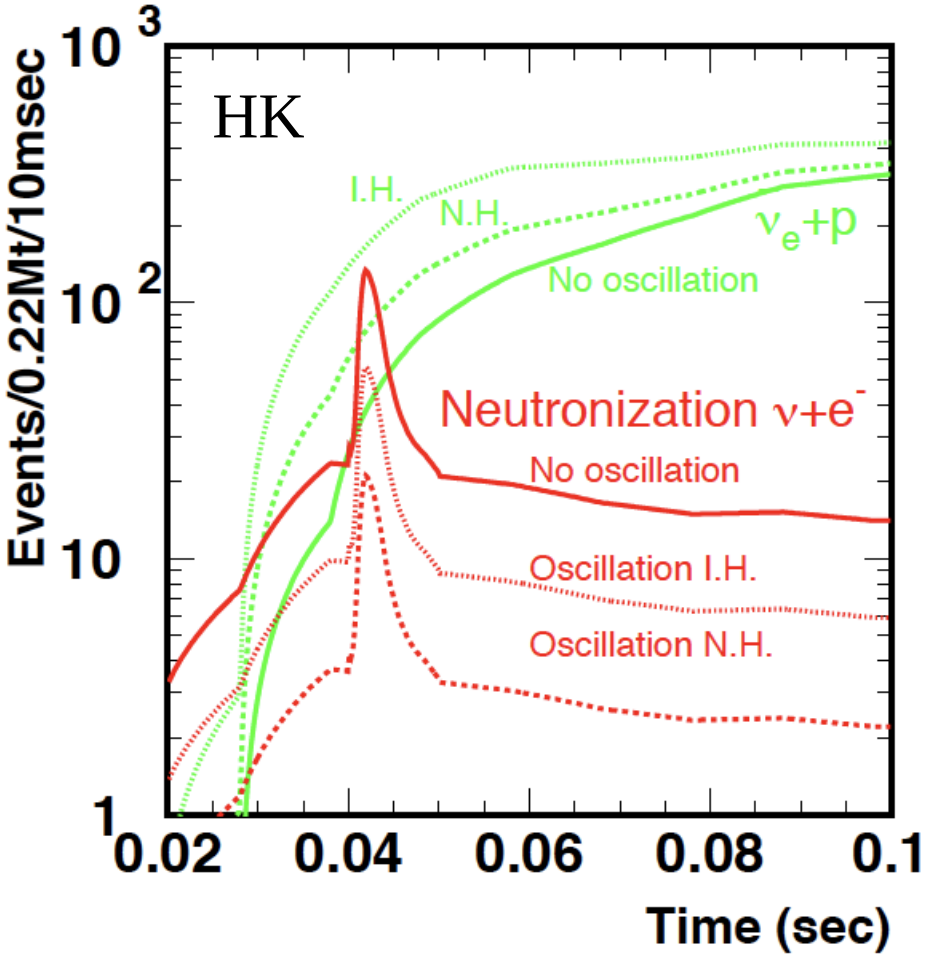
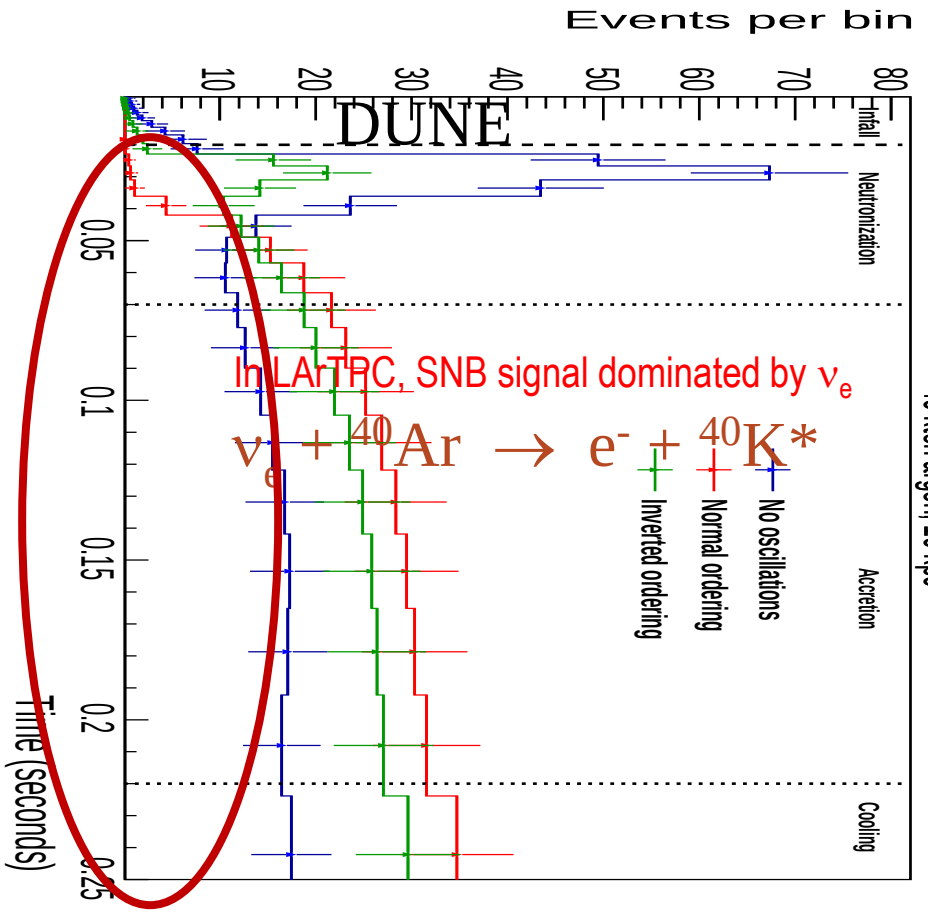
SNB Neutrinos

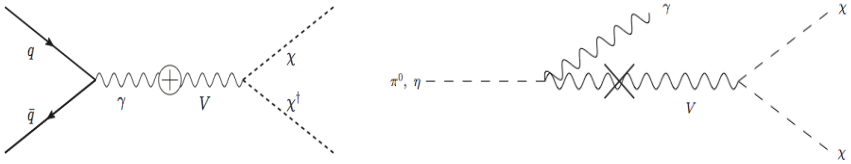




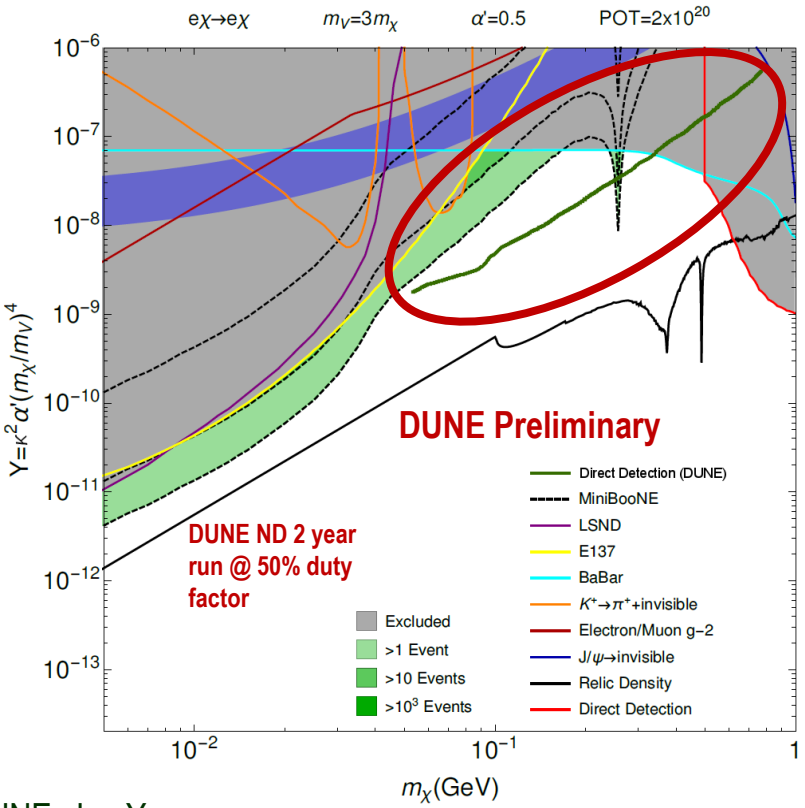
Observation of early time development yields sensitivity to neutrino mass ordering and details of SNB model.

BSM Physics at a ν Experiment?

- The high beam power, large detector mass + highly capable detectors make other BSM Physics viable
  - Low mass Dark Matter
  - Boosted Dark Matter
  - Sterile neutrinos
  - Non-standard Interactions, Non-Unitarity Mixing, CPT violation
  - Neutrino Trident
  - Large Extra Dimensions
- Promote close collaborations between phenomenology community and experimentalists



Battell *et al.*, PRD80, 095024

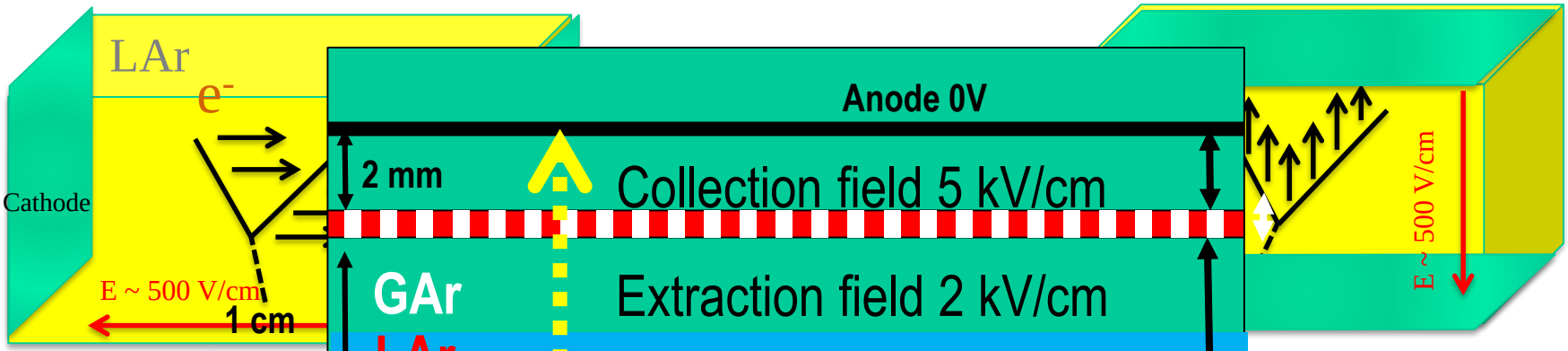


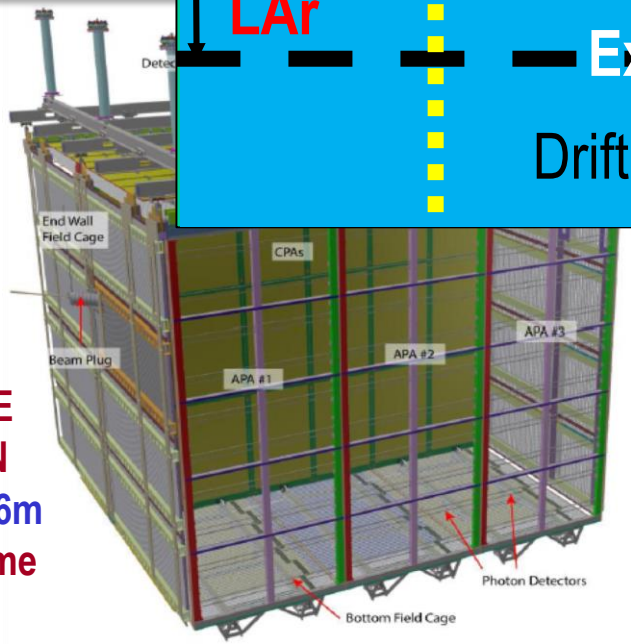
DUNE Single & Dual Phase Prototypes

Enabled by CERN Neutrino Platform

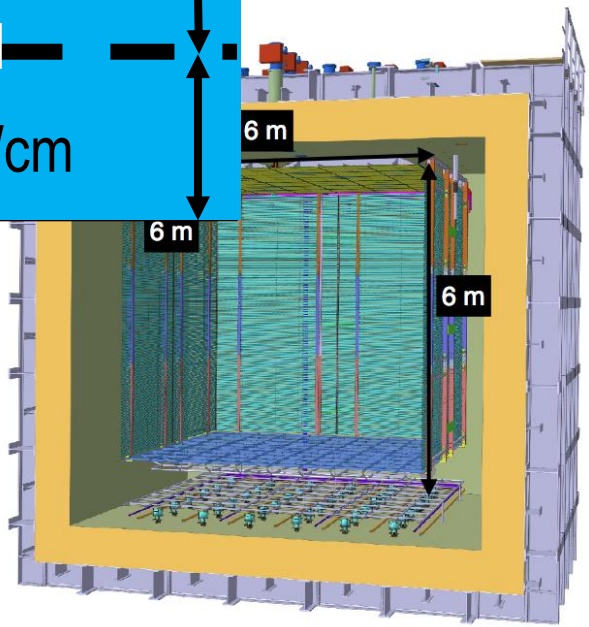
Single Phase:

Dual Phase:





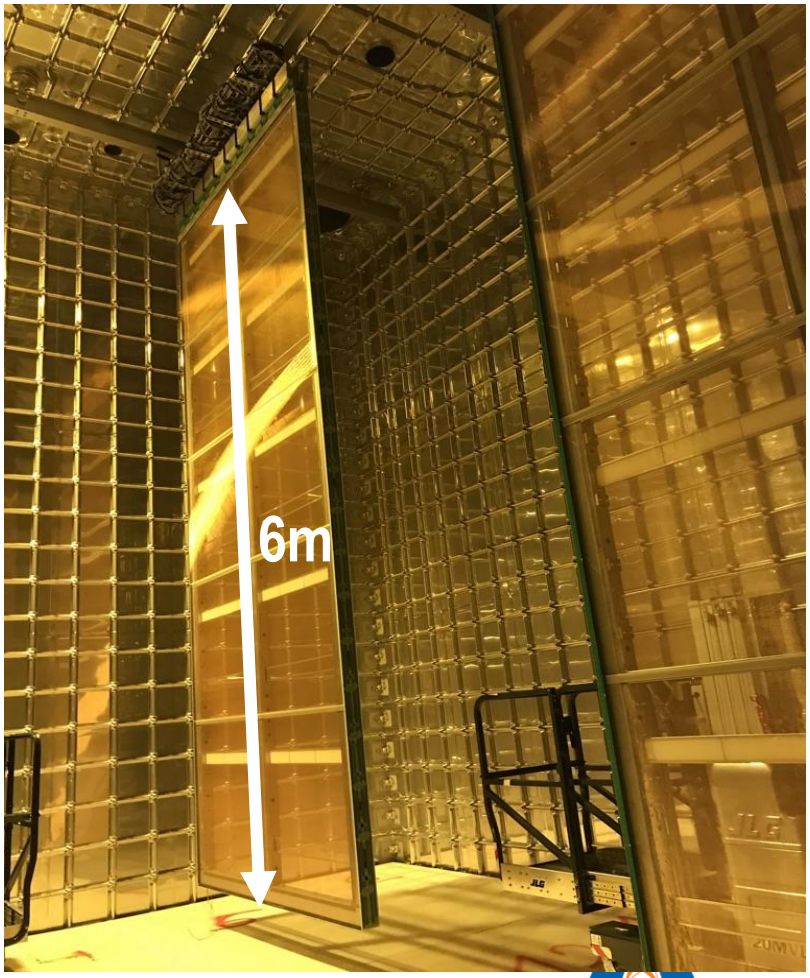
ProtoDUNE SP@CERN 6.9mx7,2mx6m Active volume

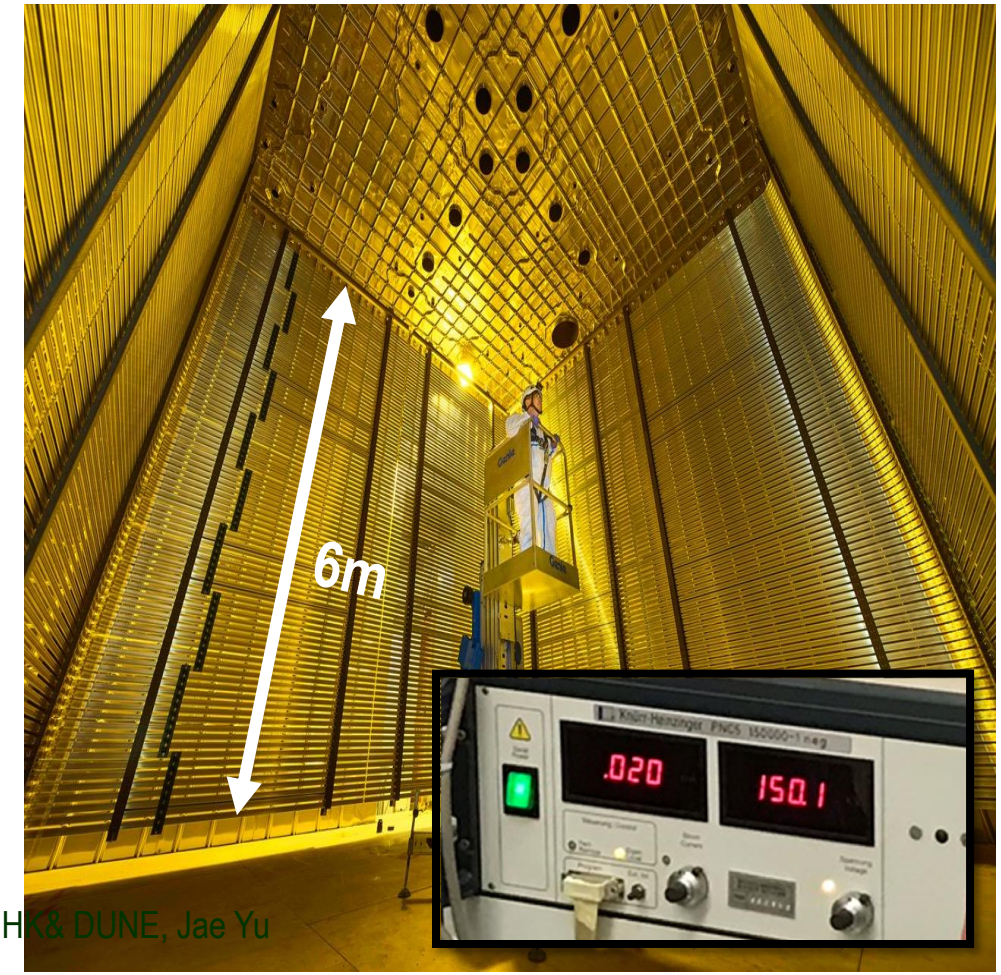


ProtoDUNE DP@CERN 6mx6mx6m Active volume

DUNE Prototype Detectors Today

- SP ProtoDUNE cryostat closed and final detector button up in progress
  - Purge begins any day, cooldown and fill by Aug. 31, 2018➔ Ready for beam in Sept.
- DP ProtoDUNE FC completed & 1st detection plane in cold box testing
  - To close the cryostat Oct. and ready for cosmic data early 2019





DUNE and Hyper-K Timeline

	DUNE	Hyper-K
Cavern Excavation	2018 – 2020	2019 – 2024
FD Construction	2022 – 2024	2024 – 2025
FD Fill	2024 – 2025 (10+10kt V_A)	2025 – 2026 (187kt V_A)
Data Taking	2025 (cosmic) / 2026 (ν beam)	2026
ND Ready	2027	In place

Conclusions!

- The neutrino sector in SM needs to be modified
- Precise understanding of neutrino oscillation phenomena and CPV in lepton sector is essential
- Two complementary next generation LBN experiments (HK & DUNE) with large ν target mass and high power beams as well as precision capabilities are in preparation to accomplish this
- Hyper – K recognized as the priority project by Japan's MEXT and is eagerly awaiting Japanese government approval
- DUNE garners strong financial commitments from US, UK, CERN others ➔ FD site construction fully funded and began in 2017
- Two large, scalable DUNE prototypes to start taking data in 2018
- Construction schedules target beam data in 2026 for both

In the Next Quarter Century

- Discovery of CPV in ν Sector
- A new theoretical framework!
- Discovery of Supersymmetric Particles
- Observation of Dark Matter