DUNE physics impact of the Fermilab 2.4 MW beam upgrade

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for the DUNE collaboration

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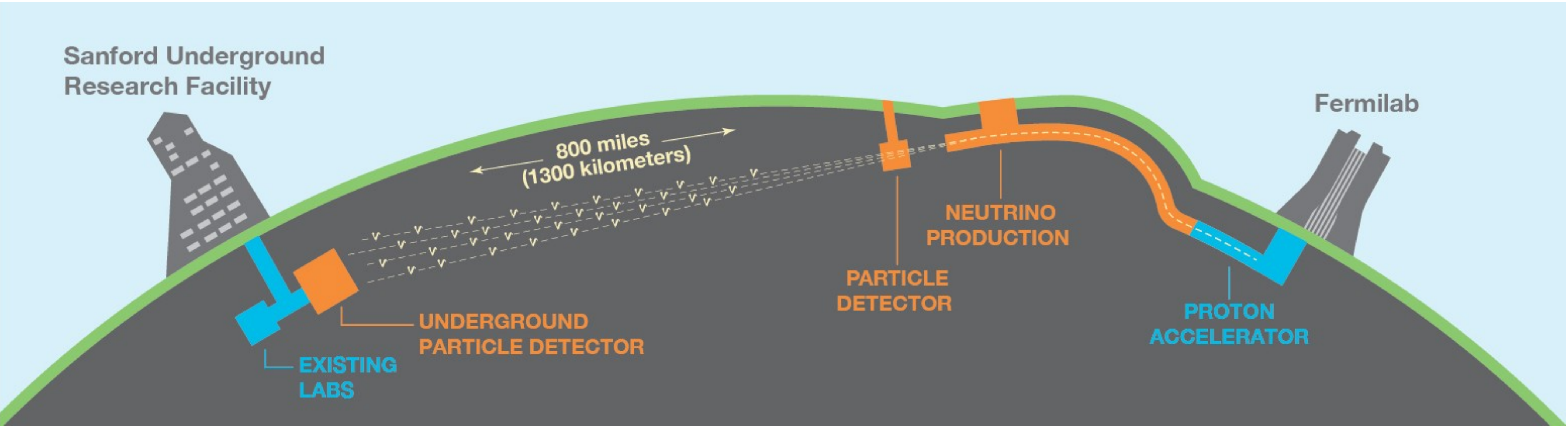
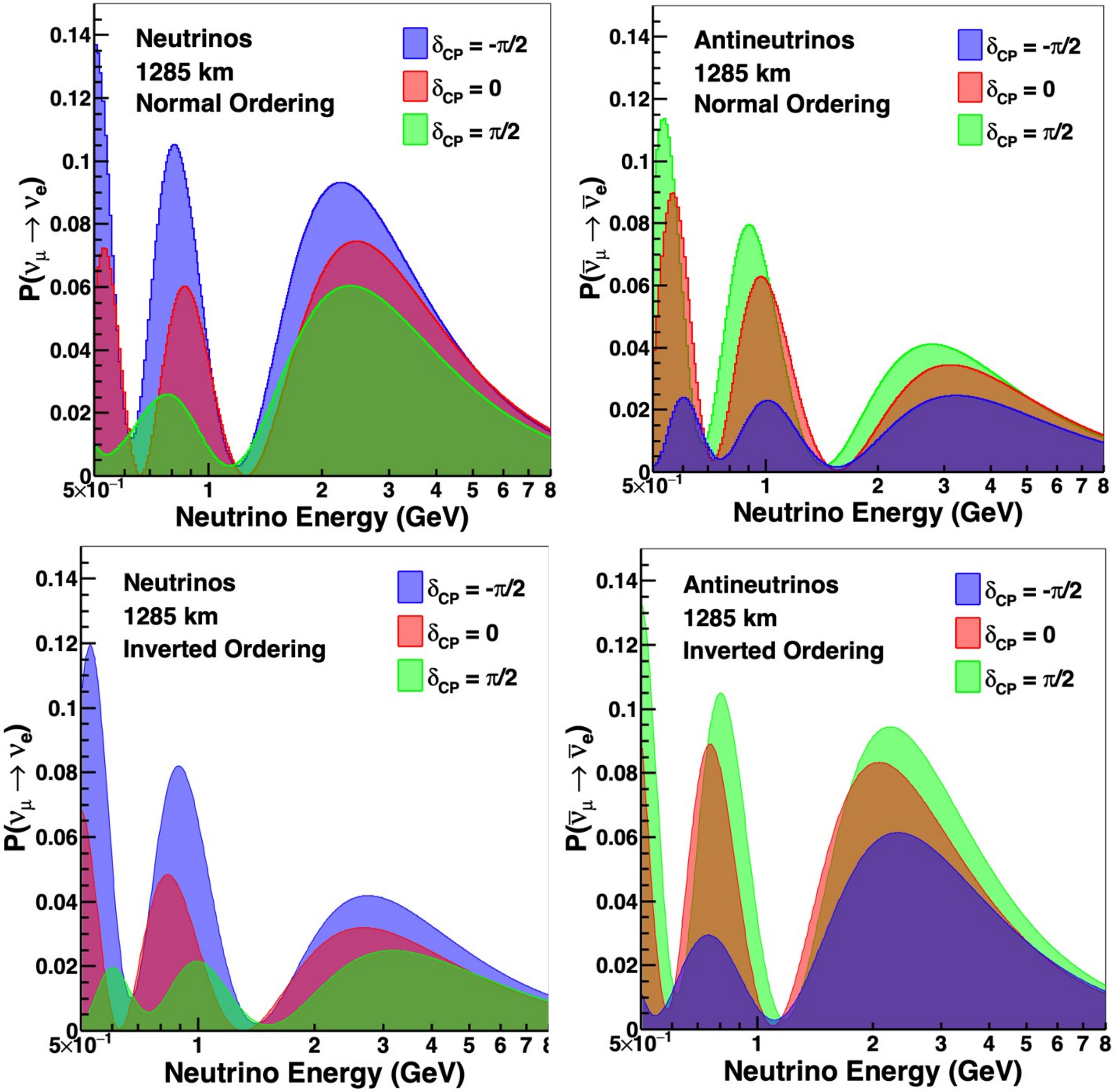
DEEP UNDERGROUND NEUTRINO EXPERIMENT



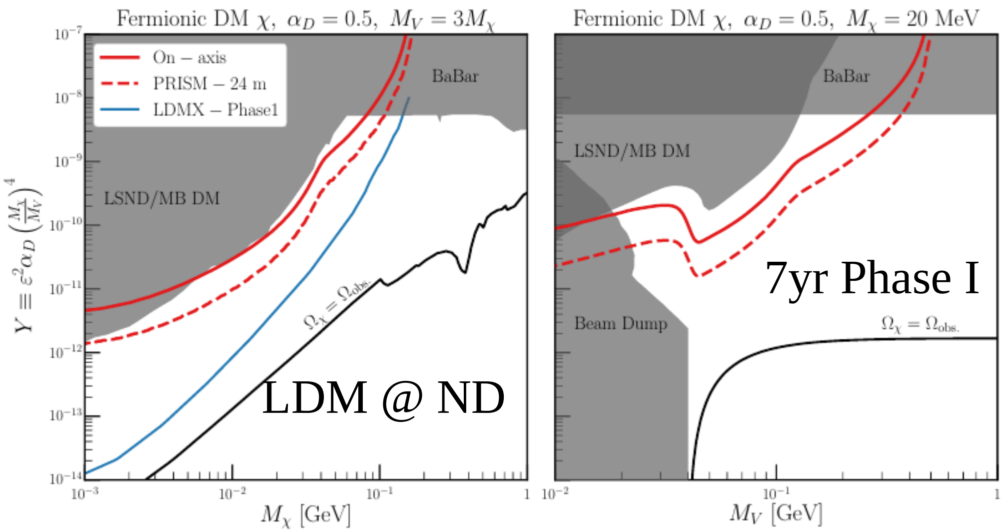
- Next-generation international neutrino & underground science experiment hosted in the United States (37 countries + CERN)
- High intensity neutrino beam, near detector complex at Fermilab
- Large, deep underground LArTPC far detectors at SURF
- Precision neutrino oscillation measurements, MeV-scale neutrino physics, broad program of physics searches beyond the Standard Model

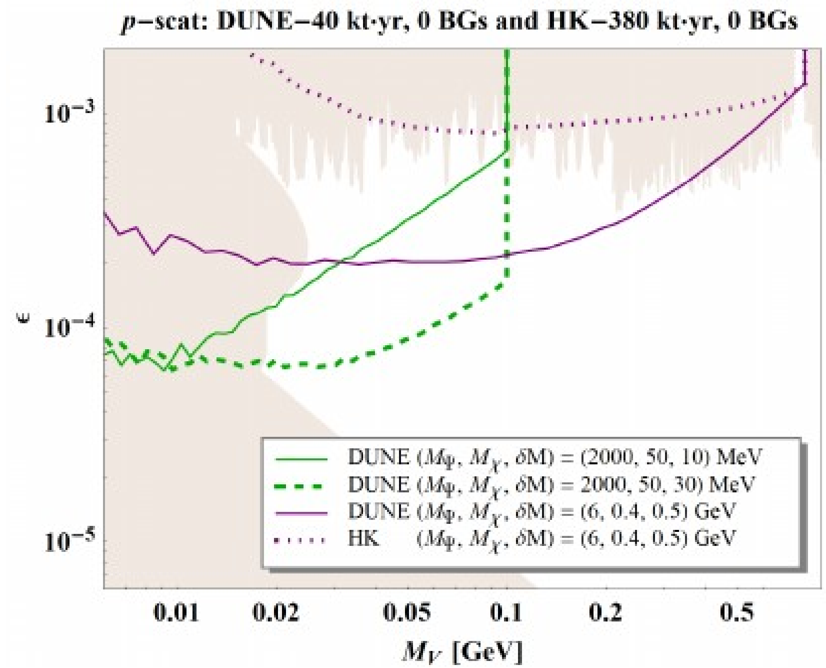
DUNE measures $\nu_\mu \rightarrow \nu_e$ vs. L/E in wideband beam



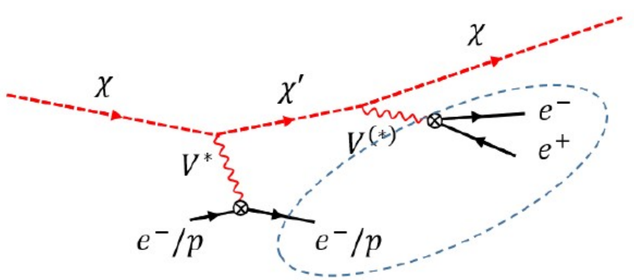
- DUNE is designed to resolve degeneracies by measuring flavor transitions as a function of energy over more than a full oscillation period
- Determine the mass ordering, measure δ_{CP}, θ_{23}, and θ_{13}, regardless of the true values
- Precise measurements of subtle effects → very high statistics are required

Direct detection in DUNE:
Dark matter at DUNE ND & FD

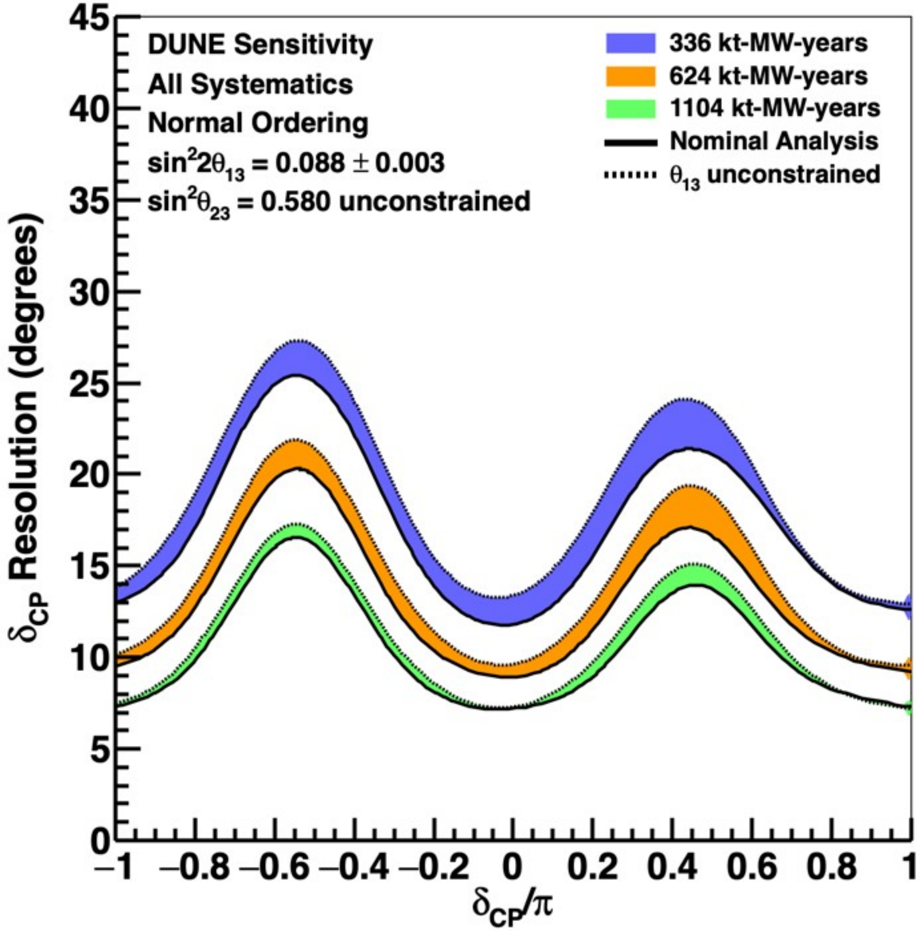


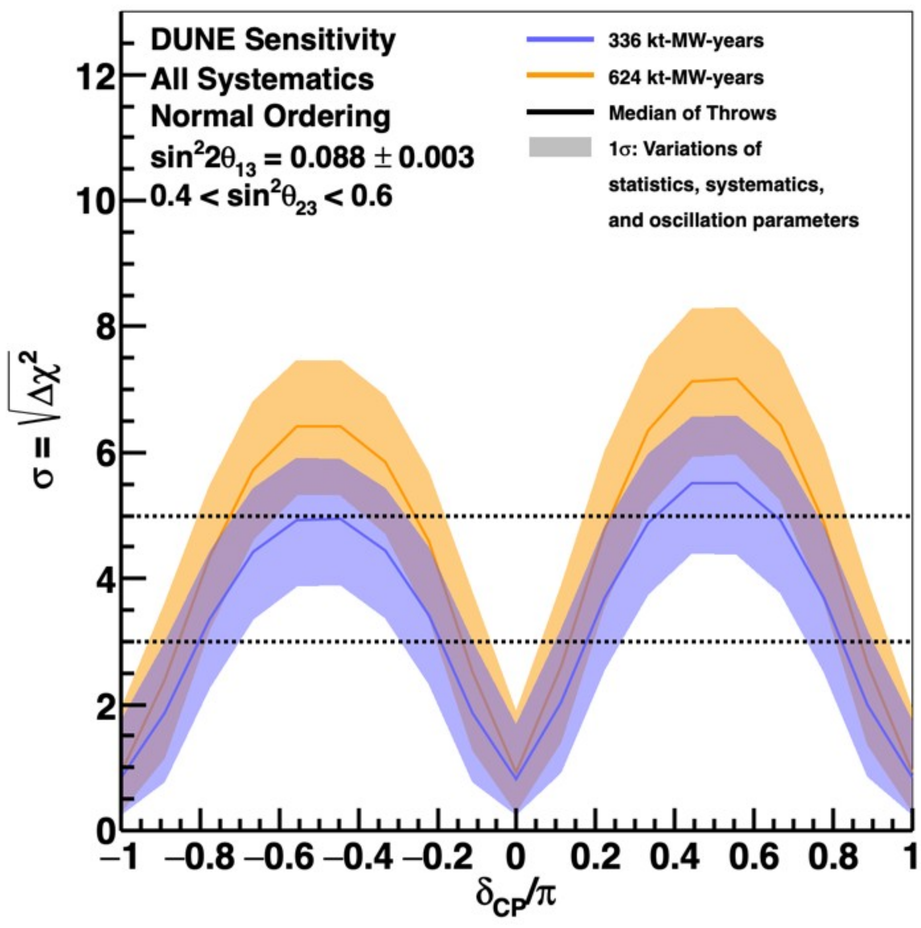


- Light DM produced in the beamline, measured in ND → signal is proportional to beam intensity
- DM of cosmic origin, measured in FD → signal independent of beam intensity



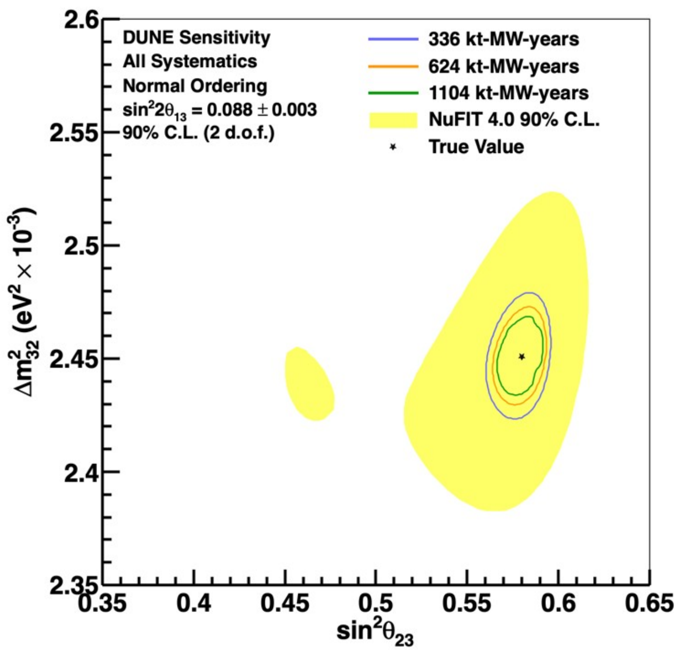
Physics potential: high-precision neutrino oscillation measurements

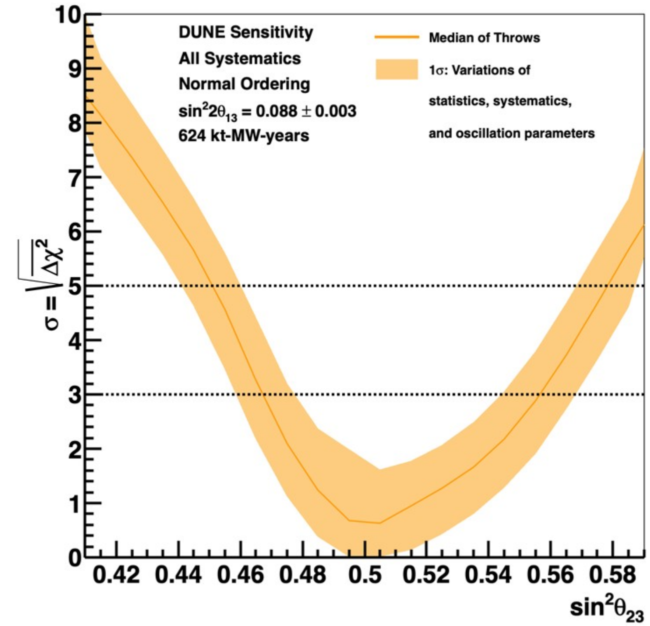


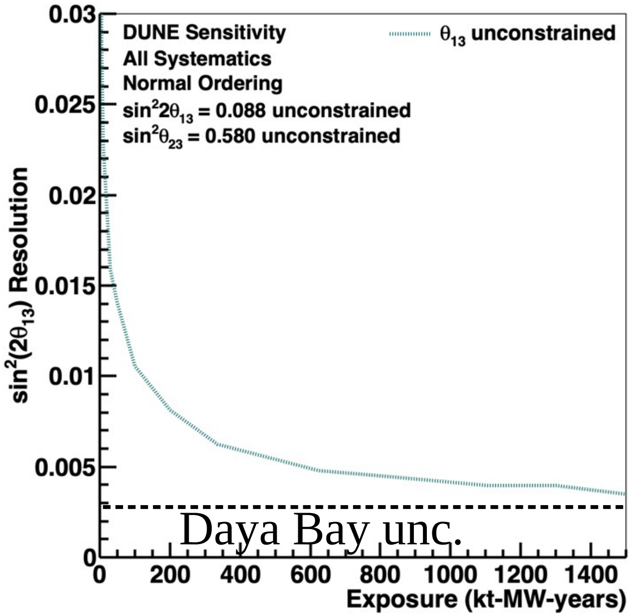


- 7° resolution to δ_{CP}, discovery sensitivity to CPV over a broad range of values
- Note the exposure required for ultimate sensitivity is > 1000 kt-MW-yrs

Physics potential: precision measurements, non-unitarity tests



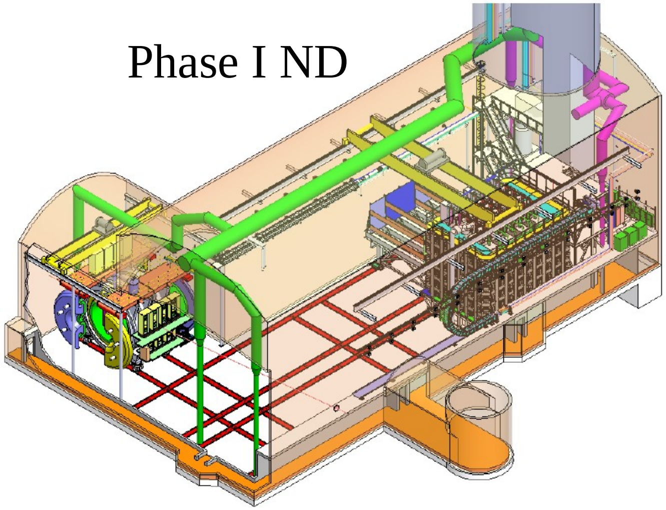


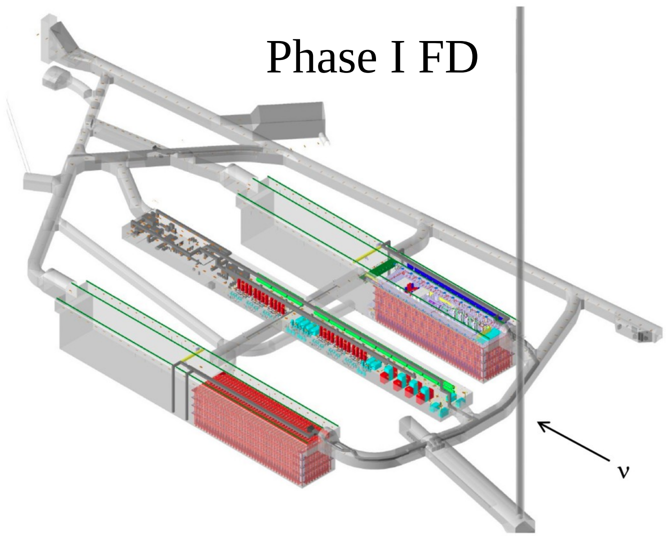


- Excellent on Δm^2_{32} and θ_{23}, including octant, and unique PRISM measurement technique that is less sensitive to systematic effects
- Ultimate reach does not depend on external θ_{13} measurements, and comparison with reactor data directly tests PMNS unitarity

Getting there: phased construction

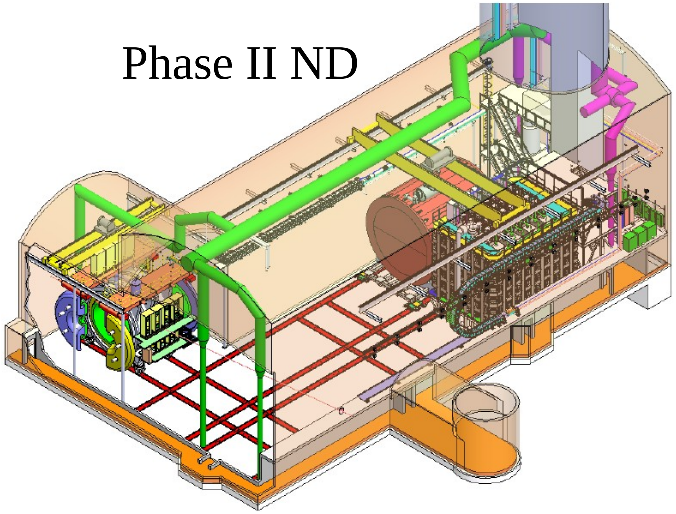
- DUNE was always envisioned to use a phased construction
- DUNE Phase I:
  - Neutrino beam with 1.2 MW intensity
  - Two 17kt LAr TPC FD modules, but underground facilities and cryogenic infrastructure to support four modules
  - Near detector: ND-LAr + TMS (movable) + SAND
- The US DOE scope of Phase I was reviewed last week in CD1-RR

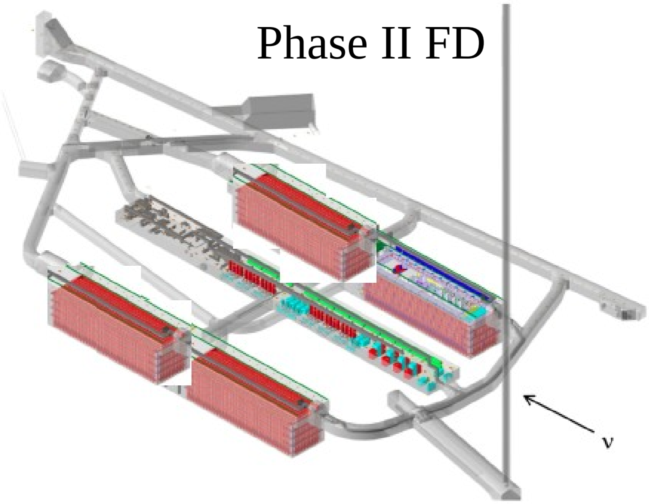




Getting there: Phase II upgrades

- DUNE Phase II:
  - **Fermilab proton beam upgrade to 2.4 MW**
  - Two additional 17kt FD modules
  - Near detector: ND-LAr + MCND (movable) + SAND
- ND upgrade is driven by improved performance at reducing systematics, has nothing to do with beam intensity
- What DUNE needs is basically twice as many neutrinos, and the details don't really matter (with one exception)





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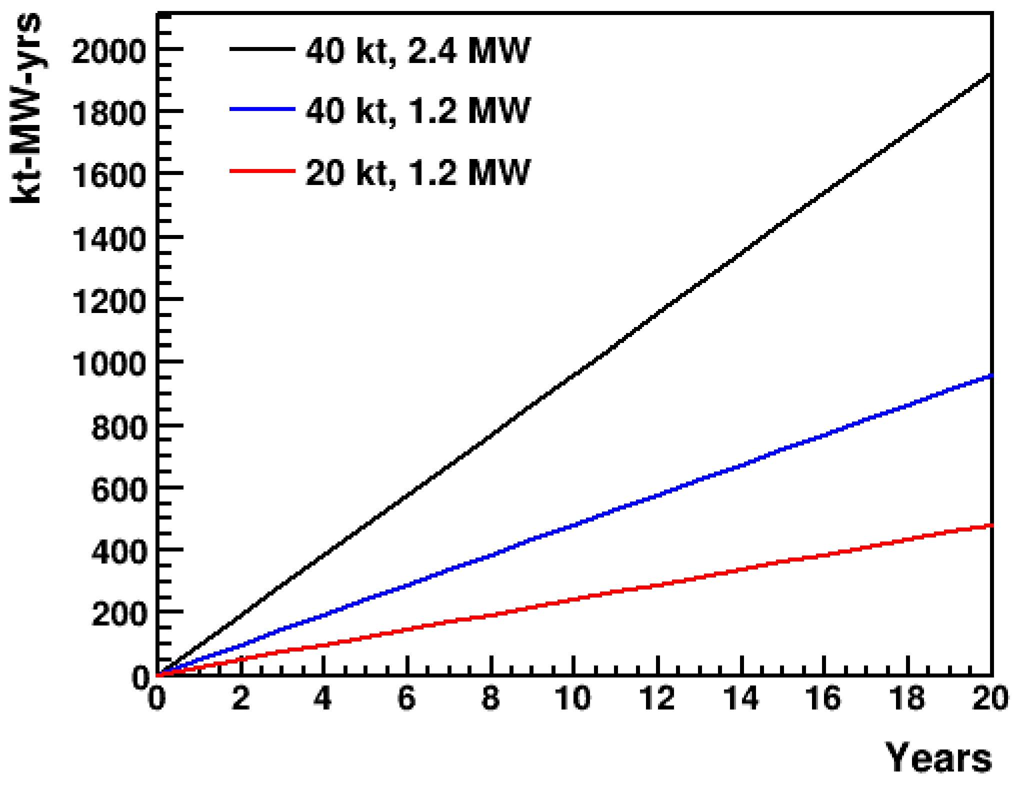
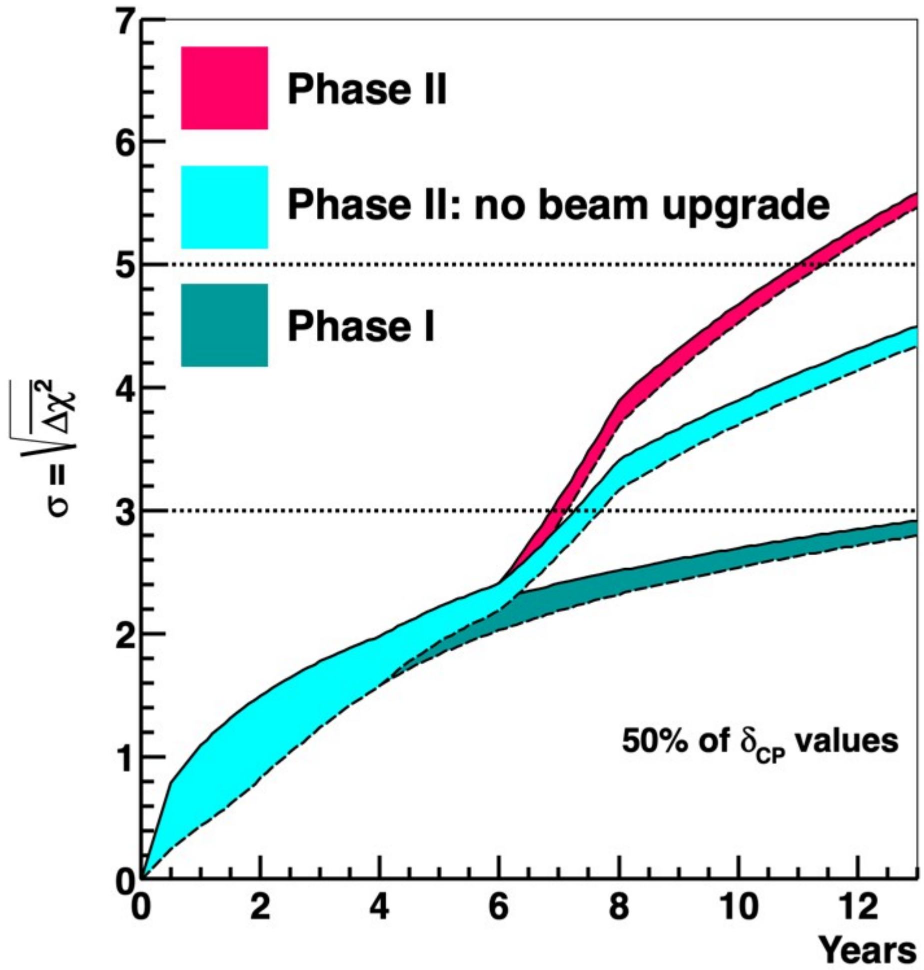
Why DUNE needs 2.4 MW: math



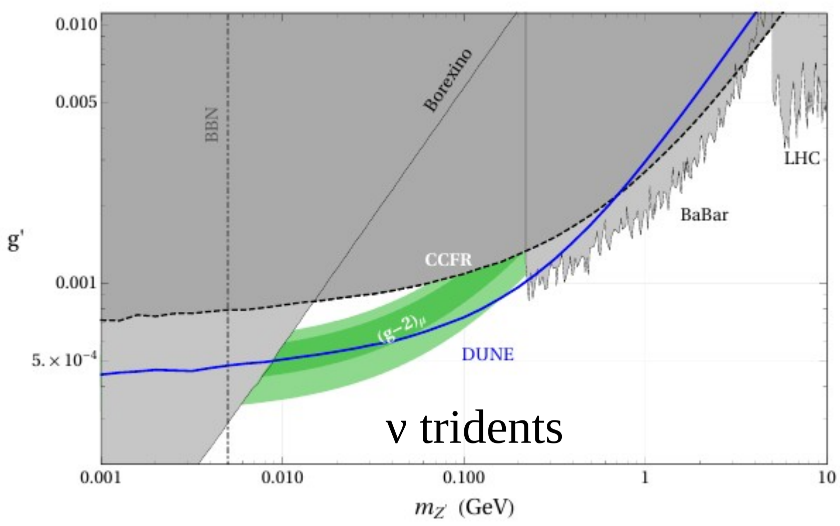
- Precision physics of DUNE requires O(1000) kt-MW-yr beam exposure
- We want to achieve this in ~1 decade
  - 46 years in Phase I
  - 23 years with 40 kt but still 1.2 MW
  - 11.5 years with 40 kt and 2.4 MW

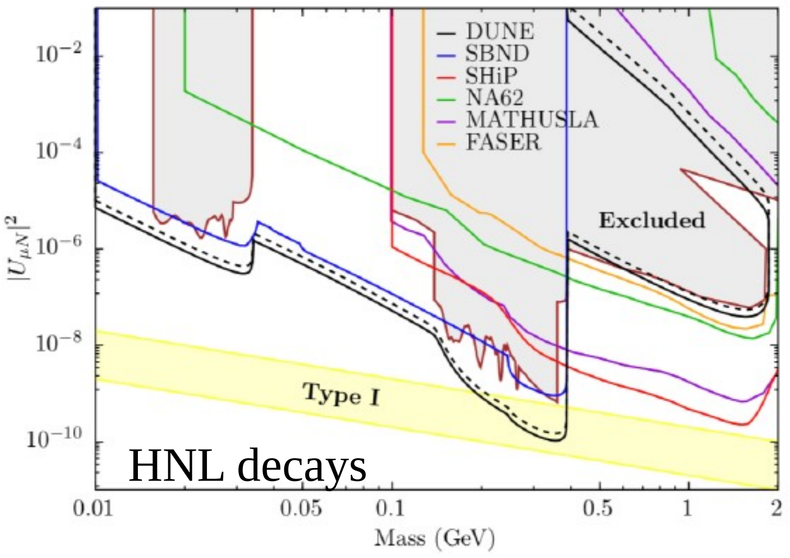
Precision physics requires 2.4 MW



- With the 2.4 MW beam upgrade, and 40 kt FD fiducial mass, we accumulate statistics 4x faster than in Phase I
- This allows DUNE to reach its precision physics goals, such as 5σ CPV for 50% of δ_{CP} values, on a reasonable timescale

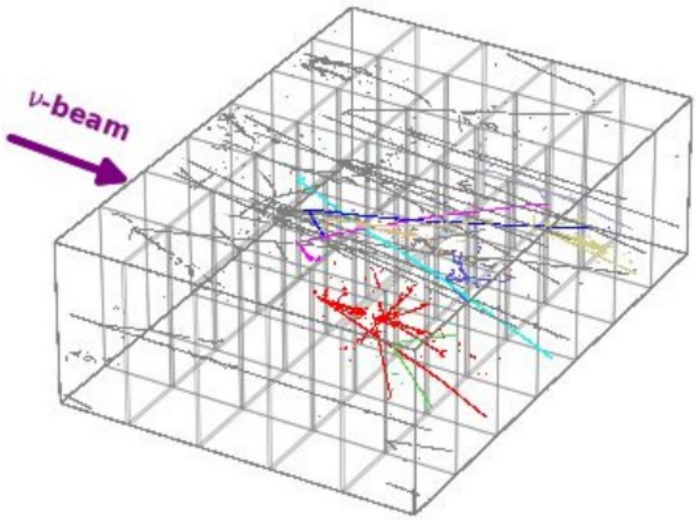
Many beam-induced BSM searches also benefit from 2.4 MW

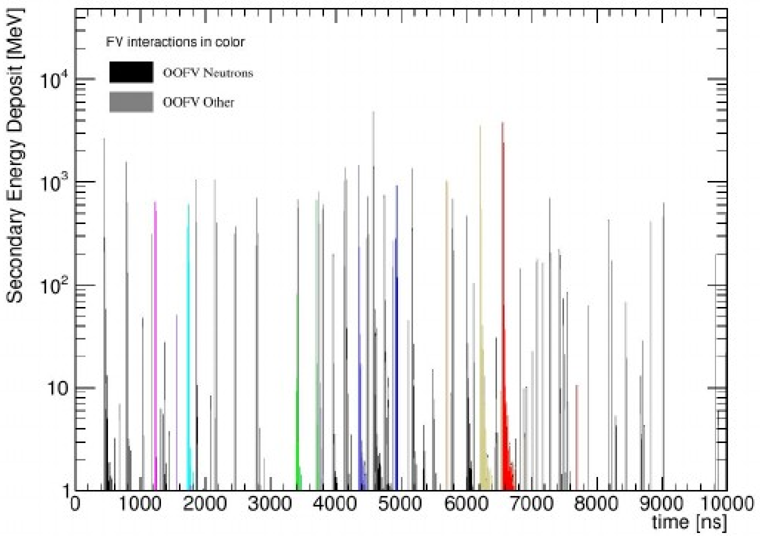




- Many BSM searches at the ND will benefit from the beam upgrade:
  - Neutrino tridents
  - Milicharged particles
  - Heavy neutral leptons
  - Light dark matter
  - Anomalous ν_τ appearance
  - etc.

One other consideration: timing structure





- ND-LAr observes activity from ~50 neutrino interactions per 1.2 MW beam spill (7.5E13 POT)
  - The charge readout is ~300 μs, so there is no timing resolution within the 10 μs beam spill
  - The light readout is expected to have O(few ns) timing resolution, and can separate optical signals
- DUNE ND-LAr is assuming that the 2.4 MW beam will just be twice as many protons with the same 10 μs spill
  - The substructure doesn't really matter
- Unless the spill length is >>300 μs, the only thing that matters for ND-LAr is the total number of protons per spill

Conclusions

- The 2.4 MW upgrade is critical for DUNE to achieve its precision long-baseline neutrino oscillation physics goals, and benefits many BSM searches

Thank you

DUNE Collaboration, May 2022, Fermilab

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