Towards a Near Detector CDR

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DUNE ND general meeting

December 19th, 2018

Introduction

- This talk is meant to be an introduction to a discussion on how we move forward with the near detectors
- It follows some of the structure of my recent presentation to the Long Baseline Neutrino Committee (LBNC) meeting held at CERN
- And includes some of the committee's feedback which will be useful in considering our path forward

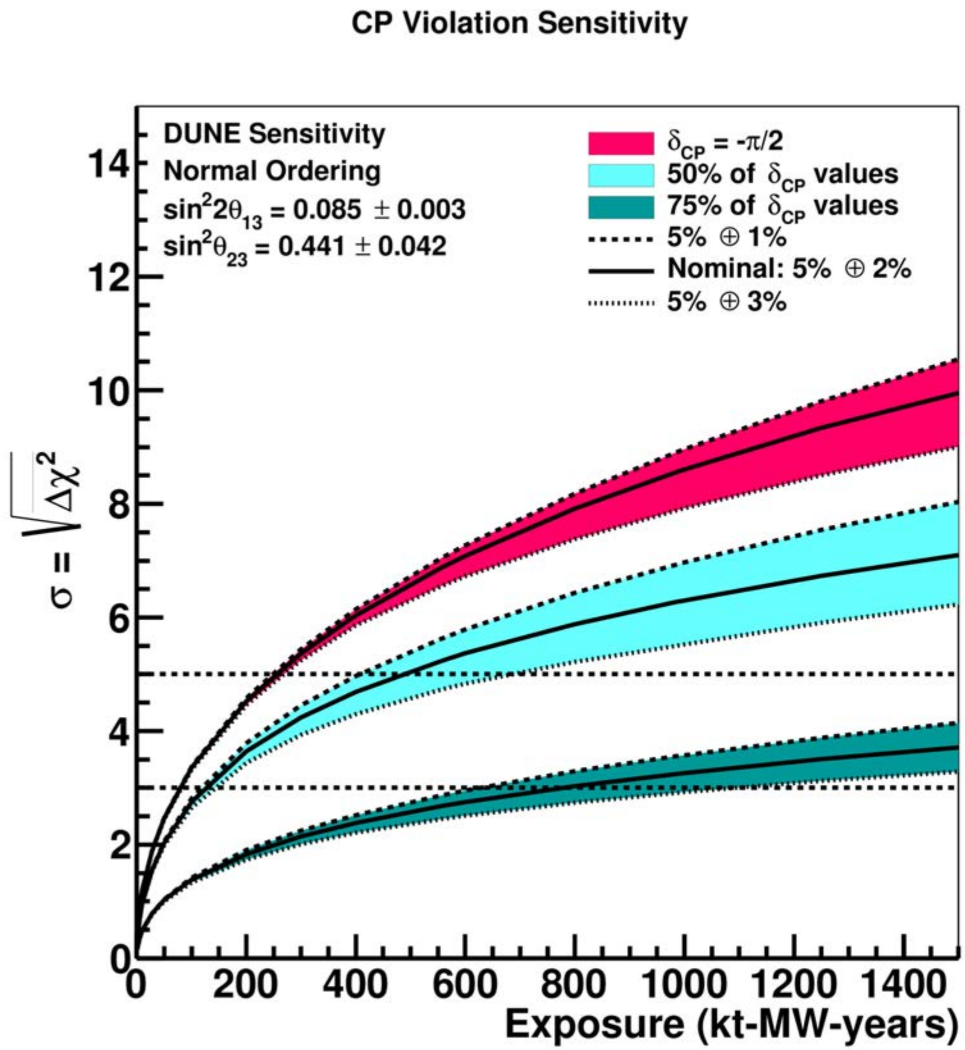
Main Near Detector Recommendations (EB)

- The recommended concept is a near detector suite consisting of a LArTPC (not in a magnetic field), a Multi-Purpose Detector (MPD) consisting of a HPgTPC, an ECAL and 3D Scintillator Tracker (3DST) in a magnet.
  - 3DST possibly in separate magnet (stand-alone) or in same magnet
- The design of a mobile LAr detector that can make measurements at one or more off-axis positions should go forward (DUNE-PRISM). Study option of moving MPD also
- The experimental floor area should be at least 42.5m x 17m and the hook height must be at least 13m, measured from the floor. The minimum lateral dimension of hall needs further study, and will ultimately be settled in EFIG.
- The option of filling the HPgTPC with hydrogen should also be investigated.

Why do we need near detector(s)

Primary purpose

The significance with which CP violation, defined as δCP not equal to zero or π, as a function of exposure in kt-MW-years, for equal running in FHC and RHC mode. True normal ordering is assumed. The width of the band corresponds to the difference in sensitivity between ν_e signal normalization uncertainty of 1% and 3% with 5% uncertainty on the ν_μ disappearance mode.



Measuring the # of events, near & far

- Oscillation probabilities

$$P_{\nu_\mu \rightarrow \nu_e}(E_\nu) = \frac{\phi_{\nu_e}^{far}(E_\nu)}{\phi_{\nu_\mu}^{far,no-osc}(E_\nu)} = \frac{\phi_{\nu_e}^{far}(E_\nu)}{\phi_{\nu_\mu}^{near}(E_\nu) * F_{far/near}(E_\nu)}$$

- Number of events

$$\frac{dN_\nu^{det}}{dE_\nu} = \phi_{\nu_\mu}^{det}(E_\nu) * \sigma_{\nu_\mu}^{Ar}(E_\nu)$$

ν flux systematics

Limited data on xsec on Ar

- In reality

$$\frac{dN_\nu^{det}}{dE_{rec}} = \int \phi_\nu^{det}(E_\nu) * \sigma_\nu^{target}(E_\nu) * T_{\nu_\mu}^{det}(E_\nu, E_{rec})\ dE_\nu$$

Detector systematics

- Flux, cross section, detector smearing are all coupled
  - Needs unfolding

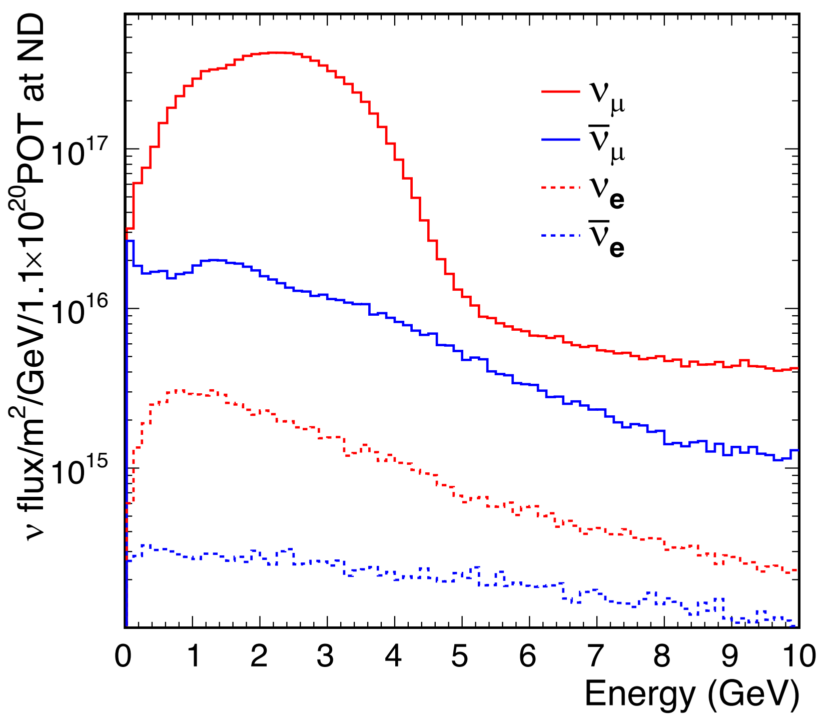
Also extensive program for beyond νSM physics

- The near detector facility will provide a very powerful tool to study:
  - Boosted dark matter
  - Sterile neutrinos
  - Neutrino tridents
  - millicharged particles
  - Mono-νs
  - Unknown, unknowns

See: POND^2
Physics Opportunities in the Near DUNE Detector Hall
https://indico.fnal.gov/event/18430/overview

Also powerful program for νSM (interactions) physics @ ND574

Optimized CPV tune



FHC, Events/ton_Ar-year

Event class	Number of events per ton-year
ν_μ CC Total	1.64×10^6
ν_μ NC Total	5.17×10^5
ν_μ CC Coherent	8.35×10^3
ν_μ NC Coherent	4.8×10^3
ν_μ - electron elastic	135
ν_μ CC π^0 inclusive	4.47×10^5
ν_μ NC π^0 inclusive	1.96×10^5
ν_μ Low ν (250 MeV)	2.16×10^5
ν_μ Low ν (100 MeV)	7.93×10^4
$\bar{\nu}_\mu$ CC Coherent ($\bar{\nu}$ mode)	6.90×10^3
ν_e CC Total	1.89×10^4
ν_e NC Total	5.98×10^3
ν_e CC Coherent	93
ν_e NC Coherent	52

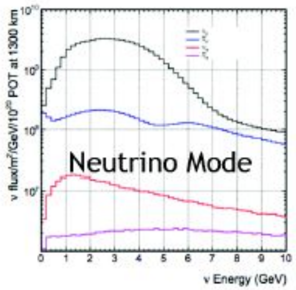
Plus unique opportunities with the high-energy tune (τ)

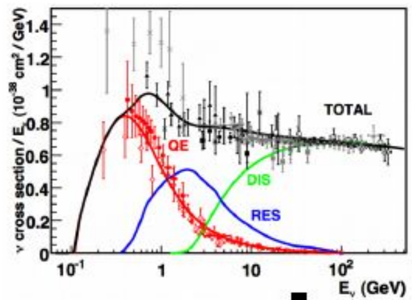
Long-Baseline Physics Analysis for the TDR

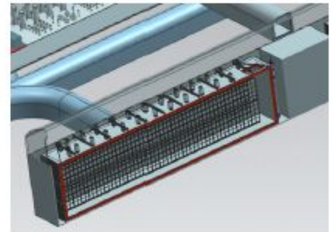
- CPV sensitivity studies
- Create a set of “test” FD samples with a set of oscillation parameters
- Create another set at the null hypothesis ($\delta_{CP} = [0,\pi]$)
- **Adjust the systematics** on the null hypothesis sample until the χ^2 with the other samples is minimized
- Sensitivity = $\sqrt{\chi^2_{min}}$
- **Include ND samples to constrain systematics**

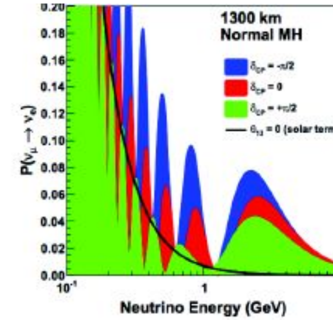
- **Results input to NDDG**

LBL physics analysis

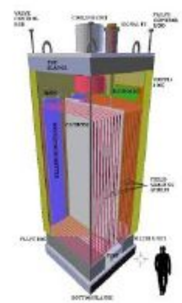


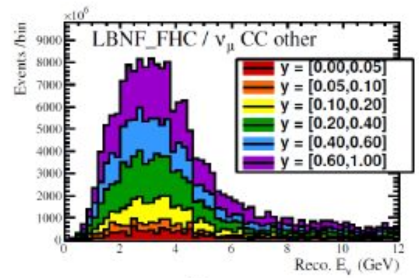


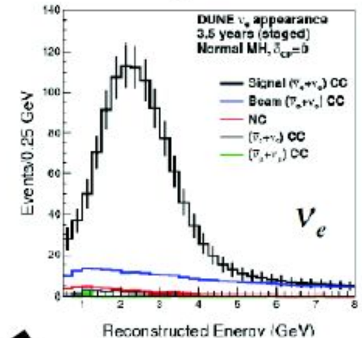


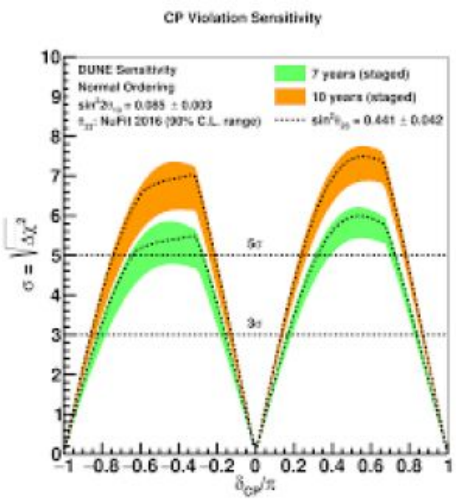


Dan Cherdack

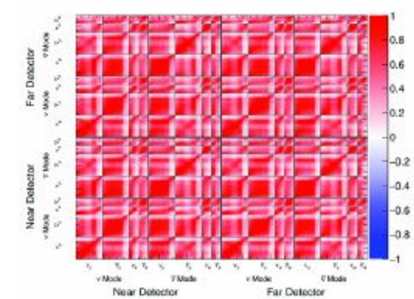








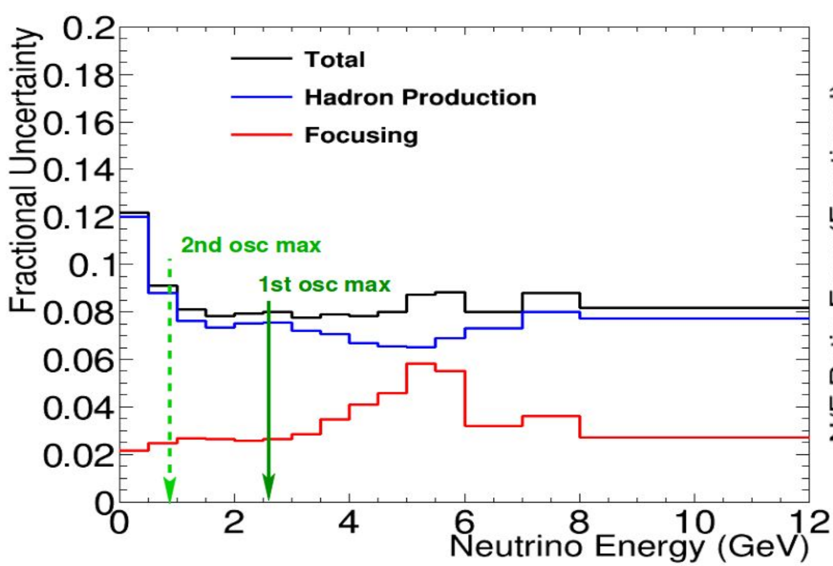
$$\sqrt{\Delta\chi^2}$$

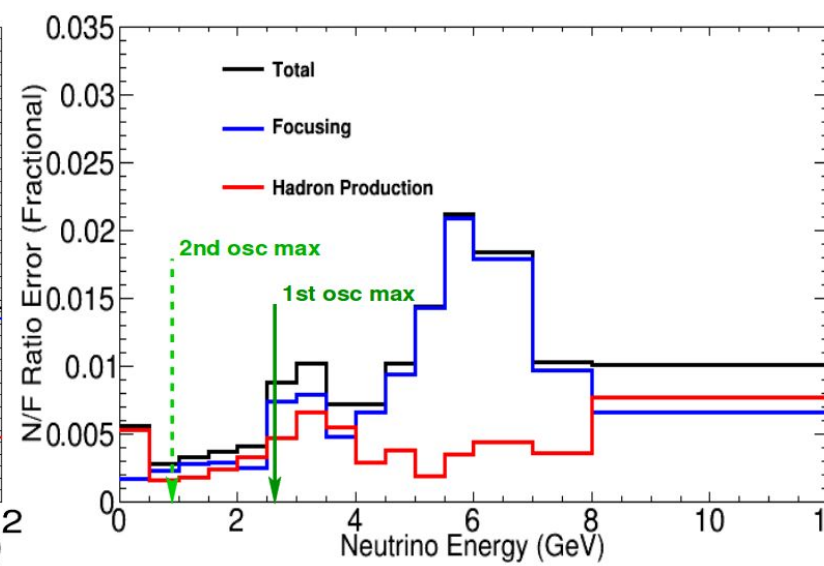


Beam systematics

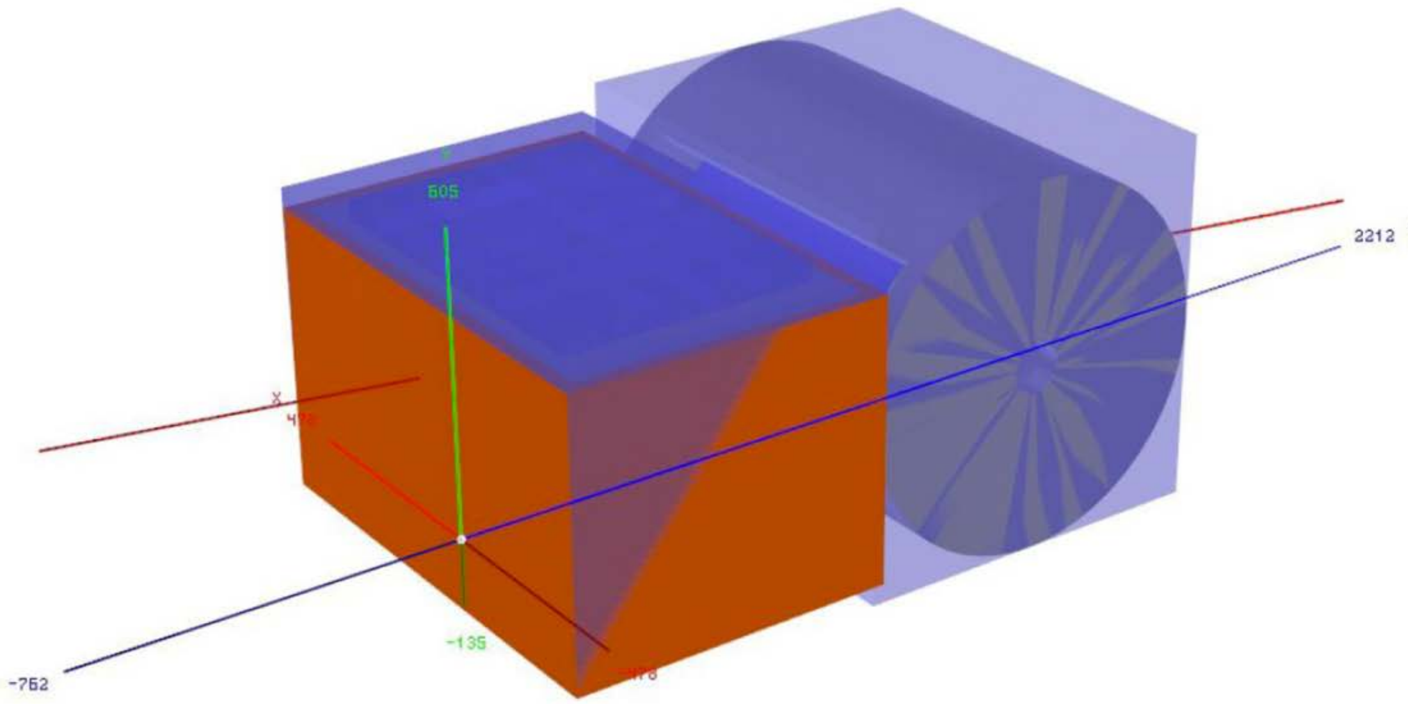
- Work continues on understanding beam
- Hadron production measurements
  - NA61/SHINE
  - EMPHATIC
    - Uses the FNAL Test Beam Facility (FTBF), either MTest or Mcenter
  - Flux spectrometer
    - Exact mock up of LBNF target horn system with multiparticle spectrometer, PID, etc.
- Beam line instrumentation development continues

2X improvement





LBL Physics Study: ND Geometry



- 7m x 3m x 5m LAr Active Volume (ArgonCube)
- Downstream magnetized HPgTPC
- New geometry, ND Task Force style “reconstruction”

Generating ND Samples for Fits

- LArTPC
  - Geometry set
  - GAr TPC acts as downstream spectrometer
  - NDTF style "Reconstruction"
  - Integrated with:
    - DUNErwt
    - Fitting software (cafana)
  - Event samples have been generated
  - Needed:
    - Analysis sample breakdowns
    - Detector systematics
    - Off-axis sample generation

- GAr TPC
  - Geometry set
  - Lower thresholds/lower rates
  - NDTF style "Reconstruction"
  - Integrated with:
    - DUNErwt
    - Fitting software (cafana)
  - Needed:
    - "Reconstruction"
    - Analysis samples
    - Sample generation
    - Detector systematics

Our Multi-pronged approach

- **Prong 1: State-of-the-art Ar detectors:**
  - LAr - non-magnetized
    - **~75t fiducial target mass**
    - Pixelated (raw 3D data), Optically segmented modules
  - Multi-purpose Detector (MPD)
    - High-Pressure (10ATM) gas TPC (HPgTPC)
      - **1t fiducial target mass**
    - In ~0.5T field (magnetic spectrometer)
    - Surrounded by high-performance ECAL and muon tagger
- **Prong 2: DUNE-PRISM**
  - Move LAr and possible MPD off axis
- **Prong 3: Three-dimensional scintillator (CH) tracker (3DST)**
  - **≧ 6t fiducial target mass**
  - Magnetized
  - With external tracking and ECAL

Justification/Motivation

Prong I

- LAr
  - Very large (100M/yr) sample of ν interactions on Ar: Precision measurements of cross section on Ar in many exclusive channels
  - Flux normalization via ν – electron elastic
- MPD
  - High-resolution containment of tracks leaving LAr
  - Large (1.5M/yr) sample of ν interactions on Ar with very-low track threshold
  - Sign analysis (ν_μ/ν_μ-bar, ν_e/ν_e-bar)

Prong 2

- Move detectors off-axis to disentangle flux and x-section effects using different fluxes

Prong 3

- Large sample (~0.5M/yr) ν interactions on H
- Remain on-axis when Ar detectors move off-axis
  - Very-high quality beam monitor

Near Detector CDR overview

- Executive Summary
- Overview
- Oscillation Physics
  - Flux constraints / measurements
  - Detector systematics
  - Cross-section systematics / model tuning
  - Beam monitoring
- Non-oscillation physics (beyond νSM)
- Facility
  - Hall
  - LAr Detector
  - Multi-Purpose Detector (MPD)
    - HPgTPC, ECAL, Magnet, Muon tagger
  - 3DST
- Engineering integration
  - Detector motion concept (PRISM)

Timeline:
ND Executive Summary for Physics TDR: March 2019
CDR: December 2019
TDR: 2nd half of 2020

LBNC meeting at CERN (12/7-9)

Informed them on the move to the NDDG and details of our "baseline" plan:

- Powerful, high-precision, full capability (calorimetric, spectrometer, PID, multiple target nuclei, off-axis measurements) detector systems
  - LAr, MPD (HPgTPC+ECAL+Magnet+μ tagger), 3DST
    - Basic technical/engineering foundations in place for most
- With these detectors and the LBNF beam, we will accumulate enormous statistics in all channels, including neutrino-electron elastic scattering.
  - **~1.5M ν_μCC events/yr-ton (FHC)**
- Aggressive 3-pronged approach to CPV
- Opportunities to study physics beyond the νSM are extensive

LBNC meeting: Comments

- The strength of what we propose was appreciated, but the scale raised many concerns and questions
- The thrust of the questions pertained to what was really needed (minimum?) to reach CPV goals (P5 mandate – 50% coverage at 5σ). Some provocative:
  - Do you really need near detector(s)?
  - What if you only get LAr?
  - What if you only get LAr + MPD (no DUNE-PRISM)?
  - What does an active scintillator target add to the CPV reach?
- **Connection between detector performance spec and physics achievables (quantifiable)**
  - This is being stressed for the Far Detector
- In the CDR, they would like to see a table where each component of the facility (including the width of the Hall), is enumerate in such a way that its impact on the CP Violation ultimate systematic uncertainty can easily be understood

Moving forward

- There will certainly be hard decisions to make in the coming months in order to produce the CDR
- Quantifying how each decision impacts our physics achievables will be required from us
- Although at this time, we are not required to provide costing data, we must keep costs in mind

An Example →

Larger cavern – cost savings?

- Although LBNF, DUNE and Fermilab management understands the benefits of the larger cavern and access shaft for the DUNE physics program
- Trying to see if some costs can be saved while keeping the larger hall footprint and larger access shaft
- Bring Down the Roof