Neutrino Oscillation Parameter Measurements at

ELBNF

Michael Mooney (BNL)

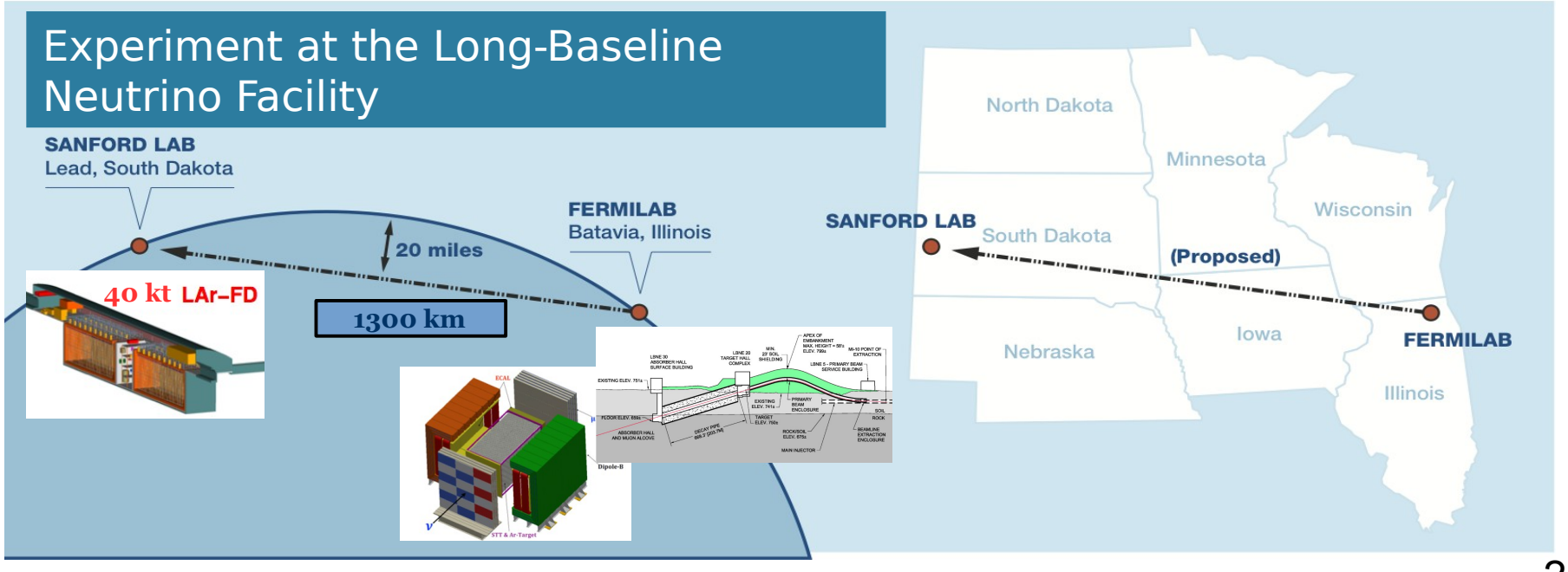
On behalf of the ELBNF Collaboration

Workshop on the Intermediate Neutrino Program (BNL)

February 5th, 2015

ELBNF Overview

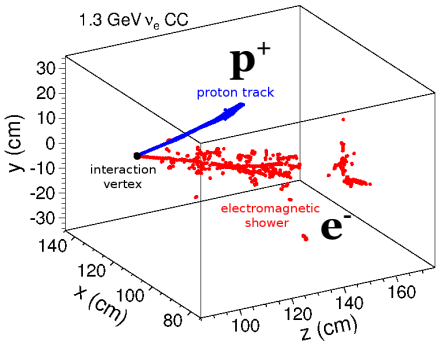
- ELBNF: Experiment at the Long-Baseline Neutrino Facility
  - Protons from Main Injector, new ν_μ beam line
  - Precision near detector (ND)
  - Massive underground far detector (FD)
    - LAr TPC, integrated optical photon detection system
    - 1300 km baseline



Precision Measurements

- ELBNF sensitive to several oscillation parameters
  - Mass Hierarchy (MH), δ_{CP} (CPV), θ_{23} octant, θ_{13}
- Path to sensitivity estimates: **flux, cross sections, detector response (data or full/fast MC) → fitters**
- Full MC simulation done with **LArSoft**
  - Neutrino interactions
  - Particle energy losses, showering in LAr
  - Full reco. in progress (learn from e.g. μBooNE)

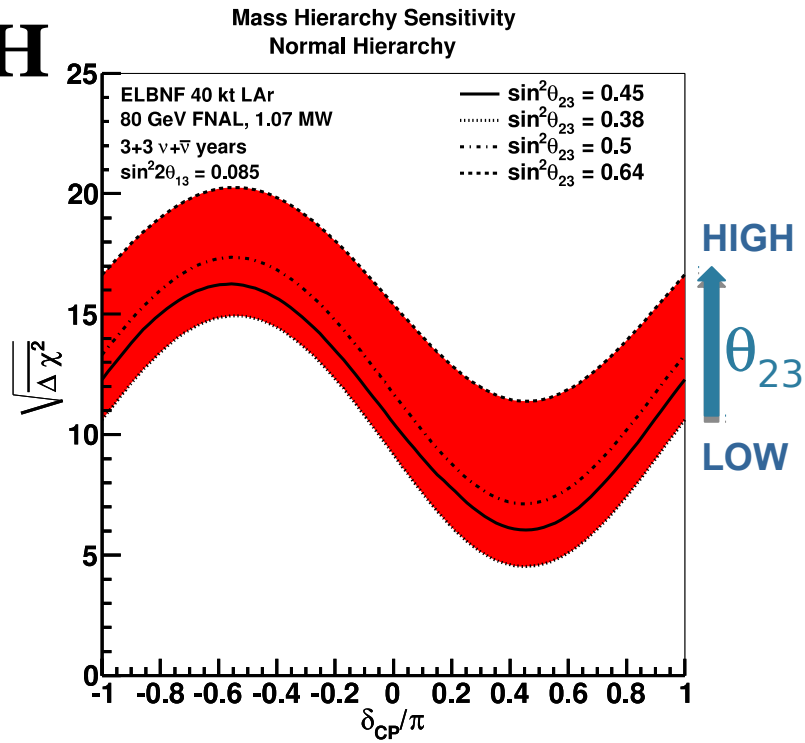
Sim. (LArSoft) + Reco. (PANDORA)



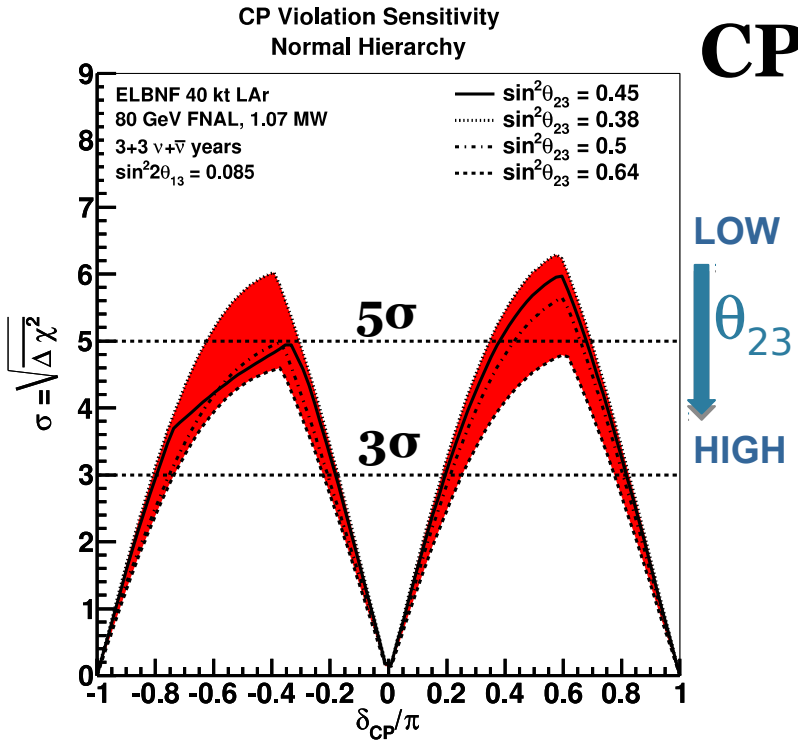
- **Fast MC** – combines flux (GEANT4) and neutrino interaction (e.g. GENIE) simulation with parameterized detector response
- Fitters to extract sensitivity estimates using signal and background yield estimates from MC
  - **VALOR** – fitter adopted from T2K
  - **MGT** ("My GLoBES Tools") – GLoBES-based fitter

MH and CPV Sensitivity

MH



CPV

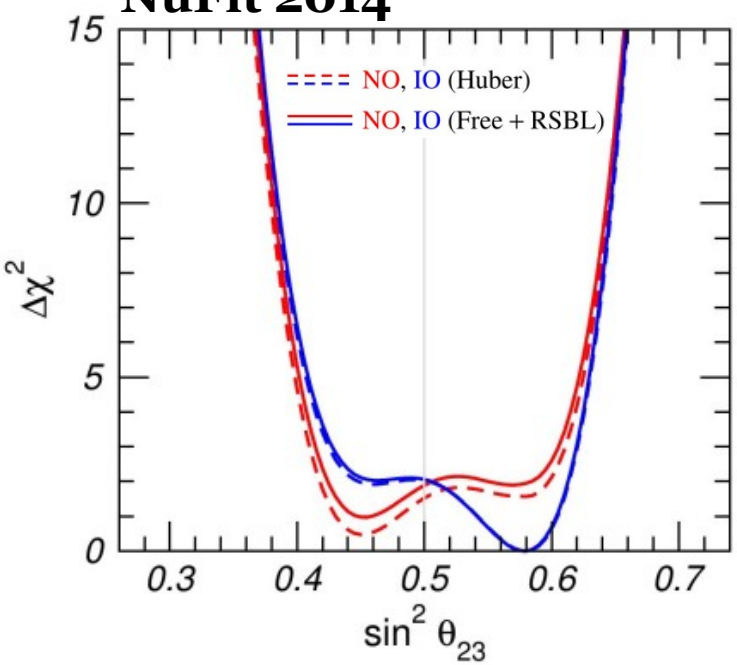


- Above: sensitivity projections for mass hierarchy determination and non-zero (or non-π) CPV phase
  - Assume normal hierarchy (NH) as example
  - Bands indicate variation of θ_{23} within NuFit 2014 allowed range
  - Sensitivity plotted as function of **true δ_{CP}/π**

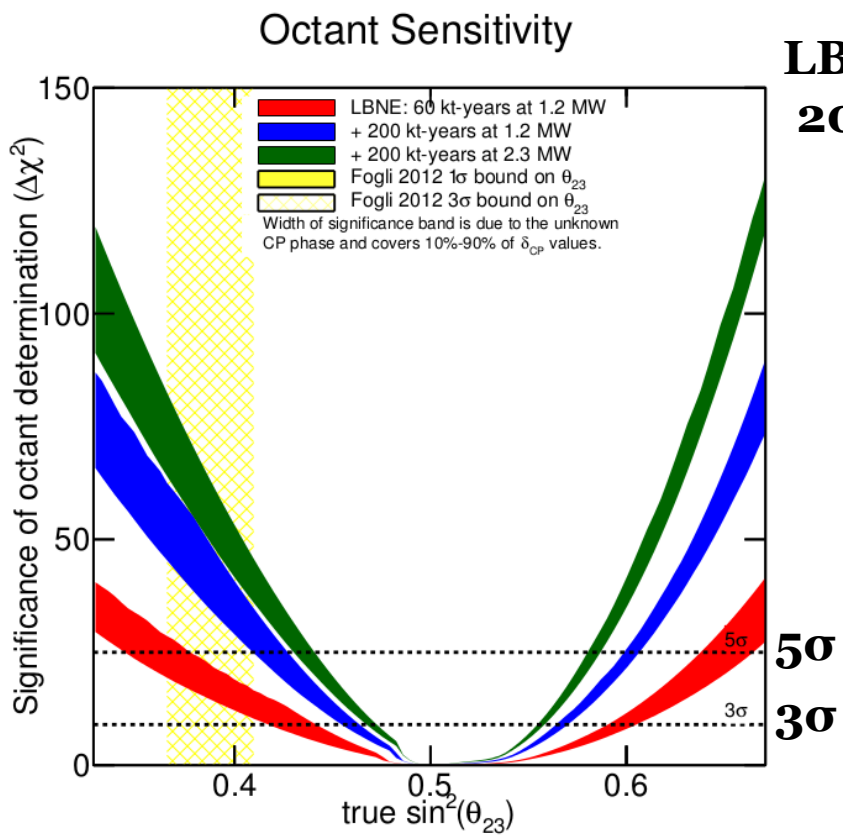
θ_{23} Octant Sensitivity

- Left: global ν-data fits don't strongly prefer particular θ_{23} octant
- Right: sensitivity projections for θ_{23} octant determination
  - Calculated at given true θ_{23} with marginalization over all possible θ_{23} values in other octant
  - NH assumed as example

NuFit 2014



LBNE 2013

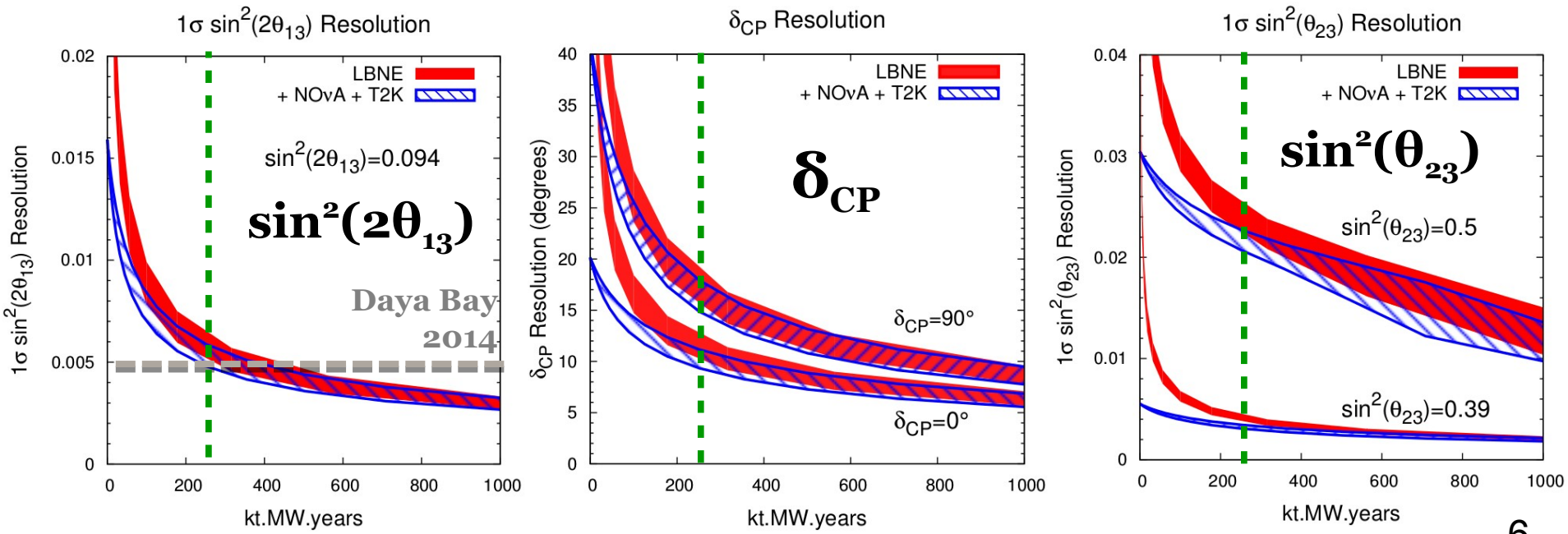


5σ

3σ

Parameter Resolution

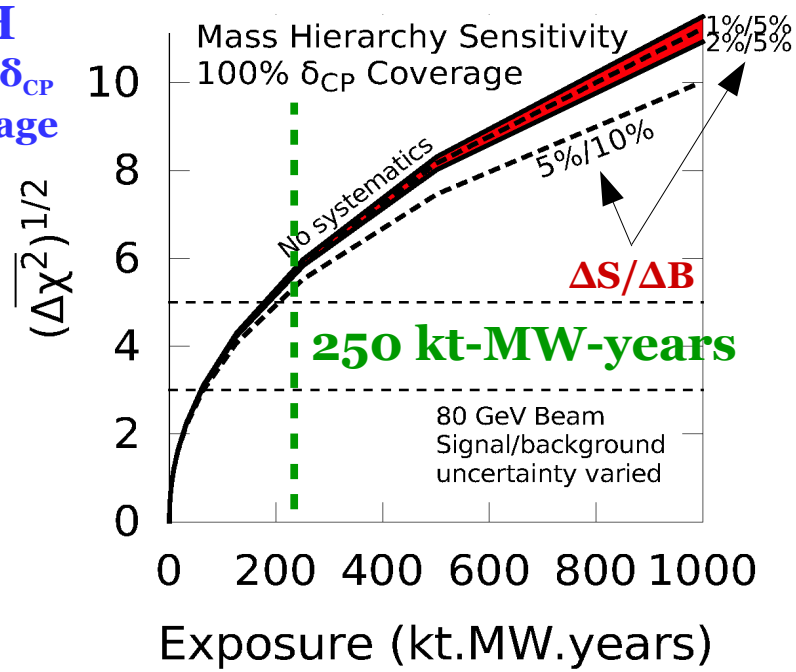
- Determine resolution of oscillation parameters as a function of exposure (represented in kt-MW-years)
- Nominal exposure: **~250 kt-MW-years**
- Width of bands below indicate sensitivity range allowed by various beam designs

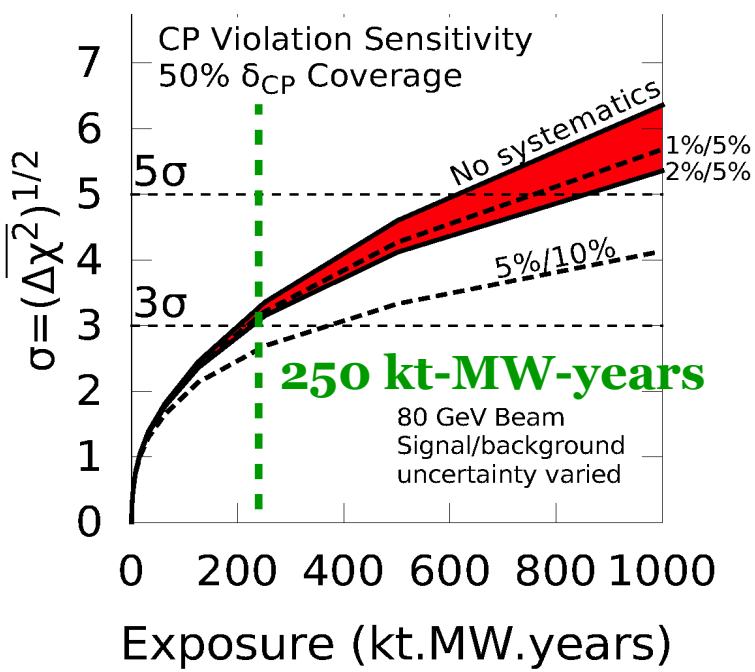


Treatment of Systematics

- GLoBES uses uncorrelated normalization systematics in four-channel $\{\nu_e, \bar{\nu}_e, \nu_\mu, \bar{\nu}_\mu\}$ fit
  - Represent residual uncertainty after ND, four-channel fit constraints
  - Estimated from **other experiments**
- Fast MC allows studies of individual systematic effects via flux, model (cross section, FSI, etc.), and detector response variations

MH
100% δ_{CP} Coverage





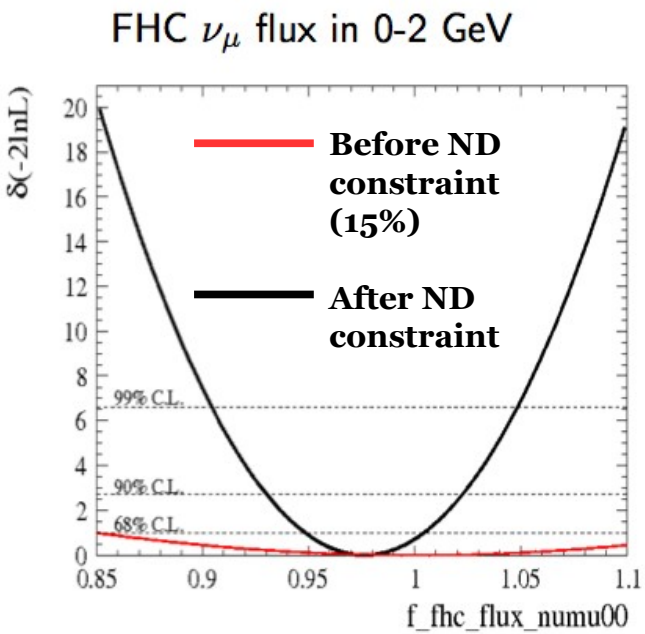
CPV
50% δ_{CP} Coverage

Estimates for Systematics

- Summary of current systematic goals below (% signal yield)
- Full studies need to be performed for **every** systematic (ongoing)
  - First using fast MC, then full MC → updated estimates for systematics
  - Help to drive detector design

Source of Uncertainty	MINOS ν_e	T2K ν_e	ELBNF ν_e	Comments
Beam Flux after N/F extrapolation	0.3%	2.9%	2%	MINOS is normalization only. ELBNF normalization and shape highly correlated between ν_μ/ν_e.
Neutrino interaction modeling				
Simulation includes: hadronization cross sections nuclear models	2.7%	7.5%	~ 2%	Hadronization models are better constrained in the ELBNF LArTPC. N/F cancellation larger in MINOS/ELBNF. X-section uncertainties larger at T2K energies. Spectral analysis in ELBNF provides extra constraint.
Detector effects				
Energy scale (ν_μ)	3.5%	included above	(2%)	Included in ELBNF ν_μ sample uncertainty only in 3-flavor fit. MINOS dominated by hadronic scale.
Energy scale (ν_e)	2.7%	3.4% includes all FD effects	2%	Totally active LArTPC with calibration and test beam data lowers uncertainty.
Fiducial volume	2.4%	1%	1%	Larger detectors = smaller uncertainty.
Total	5.7%	8.8%	3.6 %	Uncorrelated ν_e uncertainty in full ELBNF 3-flavor fit = 1-2%.

Example: flux constraint from ND fit (VALOR)



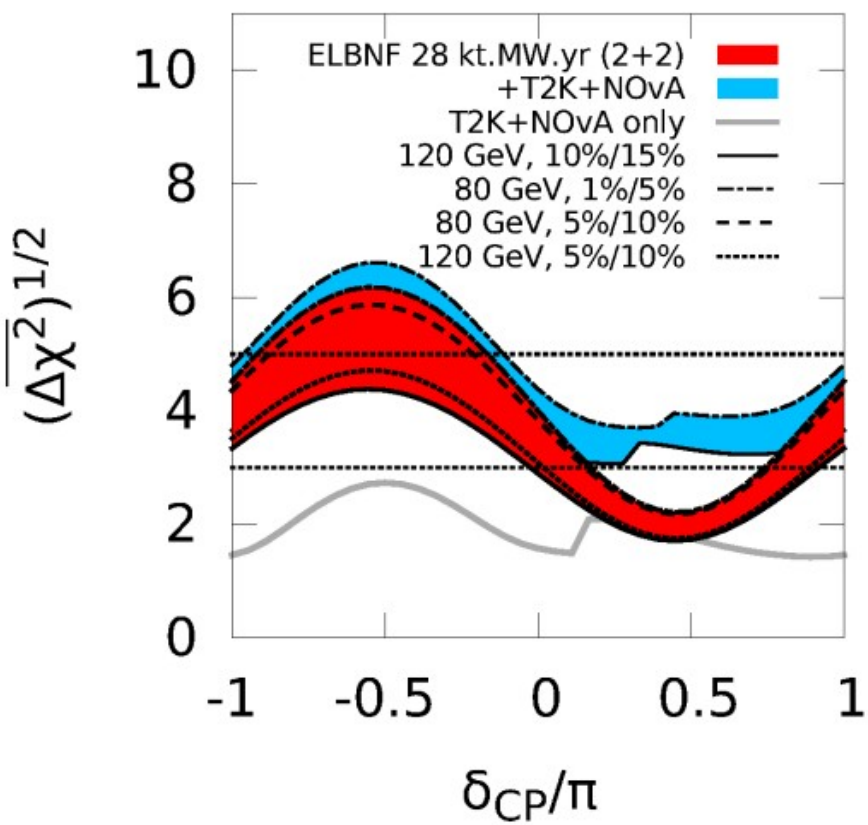
Summary

- ELBNF will simultaneously measure multiple oscillation parameters
  - Mass Hierarchy (MH), δ_{CP} (CPV), θ_{23} octant, θ_{13}
  - Nominal exposure sensitivities:
    - **MH** (NH or IH): $\overline{\Delta\chi^2} > 25$ (100% δ_{CP} coverage)
    - **CPV** (0/π or not): $\sigma > 3$ (50% δ_{CP} coverage)
- Much effort going into better understanding systematics
  - Currently make large use of input from **other experiments**
    - Expect further constraints from existing and intermediate neutrino program… very important!
  - Looking toward **full MC simulation and reconstruction**
  - Is there input from outside the collaboration on treatment of systematics?

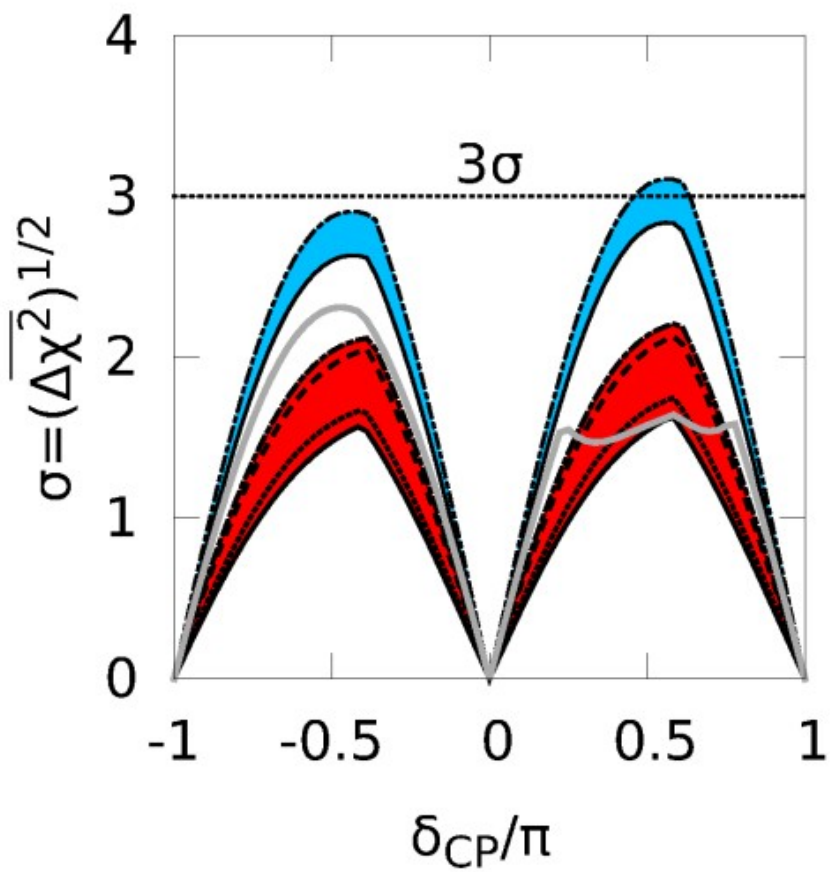
BACKUP SLIDES

ELBNF+T2K+NOvA Combo

MH



CPV

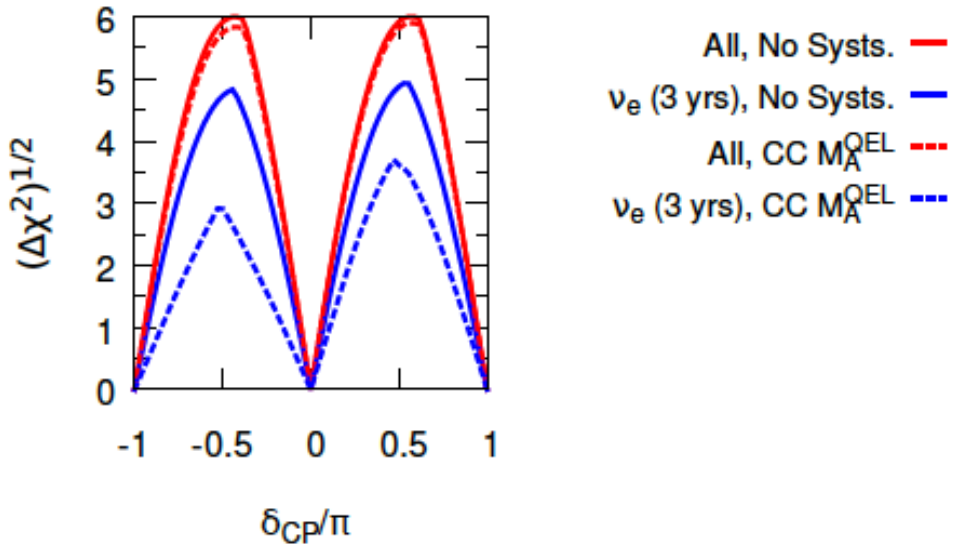


NOTES: Reduced ELBNF Exposure, NH Assumed

Fast MC Sensitivities w/ Syst.

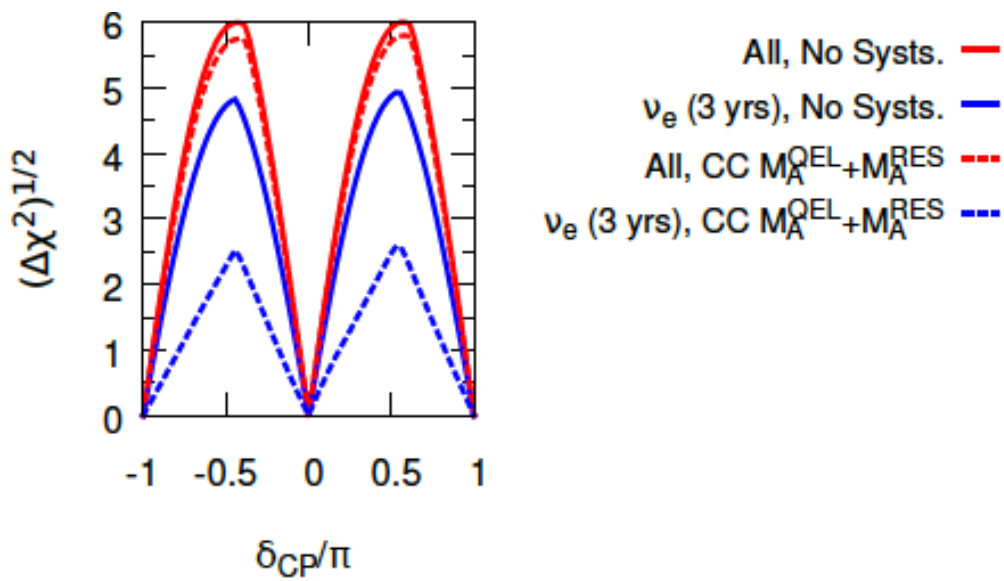
With/Without

CC $M_{A,QEL}$



With/Without

CC $M_{A,QEL}$ + CC $M_{A,RES}$



NOTES: Earlier LBNE Study, 20% Syst. Uncert.