



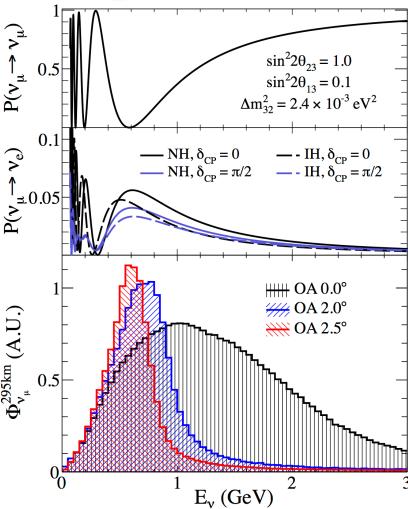
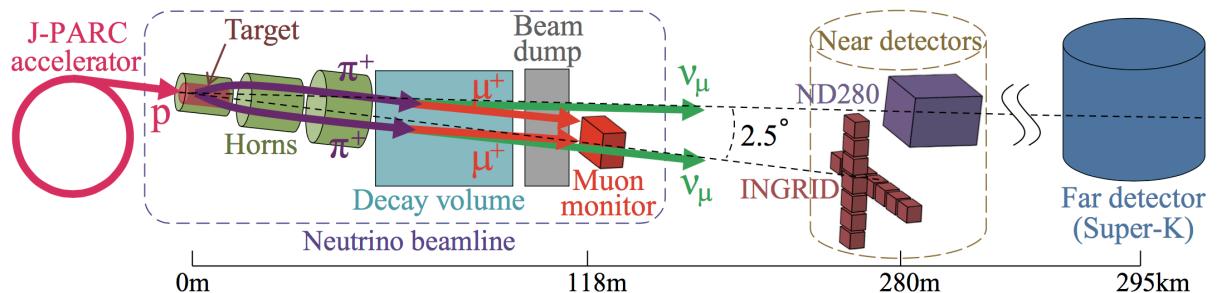
Neutrino Oscillation Physics Potential of T2K Phase 2 - a Possible Extension of The T2K Experiment

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(On behalf of the T2K collaboration)

- ❖ High intensity, almost pure muon (anti) neutrino beam from J-PARC
- ❖ The world's first off-axis designed neutrino experiment
 - ❖ Far Detector (SK) is 2.5^0 off the beam's axis
 - ❖ Narrow band beam, peaked at oscillation maximum (0.6 GeV)



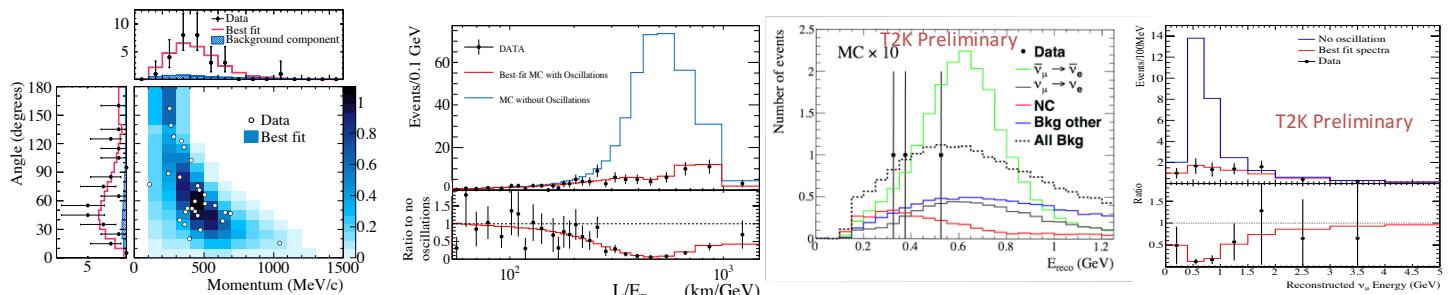
- ❖ Primary goal is to measure precisely neutrino oscillations

$\nu_\mu \rightarrow \nu_e$
[PRL 112, 061802 \(2014\)](#)

$\nu_\mu \rightarrow \bar{\nu}_\mu$
[PRL. 112, 181801 \(2014\)](#)

$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$
[Paper in preparation](#)

$\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$
[arXiv:1515.02495](#)

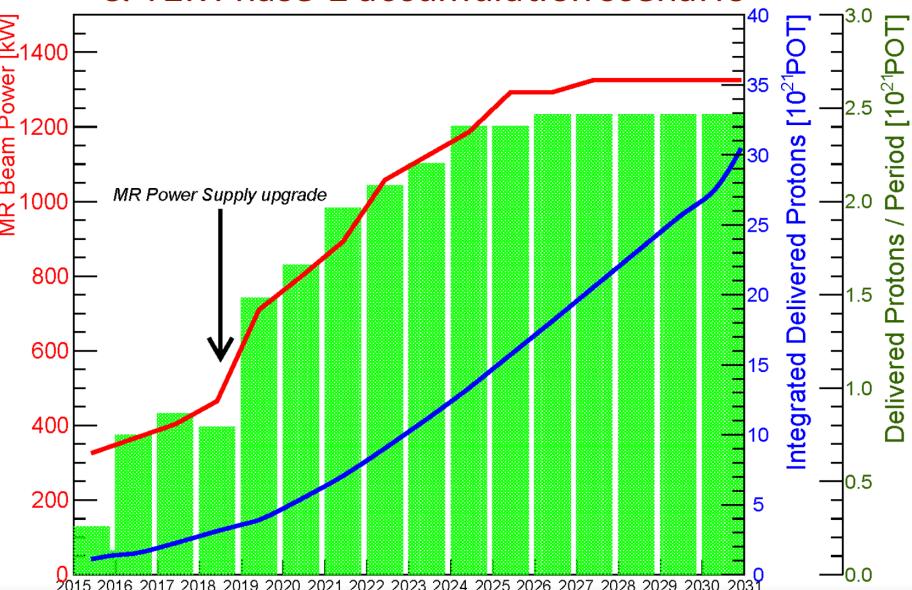


Stay tuned for:

- ❖ Observe $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$
- ❖ CP phase
- ❖ Unknowns...

- ✧ Approved T2K statistics, 7.8×10^{21} POT, can be accumulated by JFY2020
- ✧ Hyper-K and DUNE are expected to start around 2026
- ✧ T2K Phase 2, if extended to JFY2026, collects $\sim 20 \times 10^{21}$ POT
- ✧ Neutrino beamline upgrade & analysis improvements (SK fiducial volume, add new event sample)
→ Effectively add 50% statistics
- ✧ Reduction of systematic uncertainties to enhance CPV sensitivity

J-PARC Main Ring expected beam power & T2K Phase 2 accumulation scenario

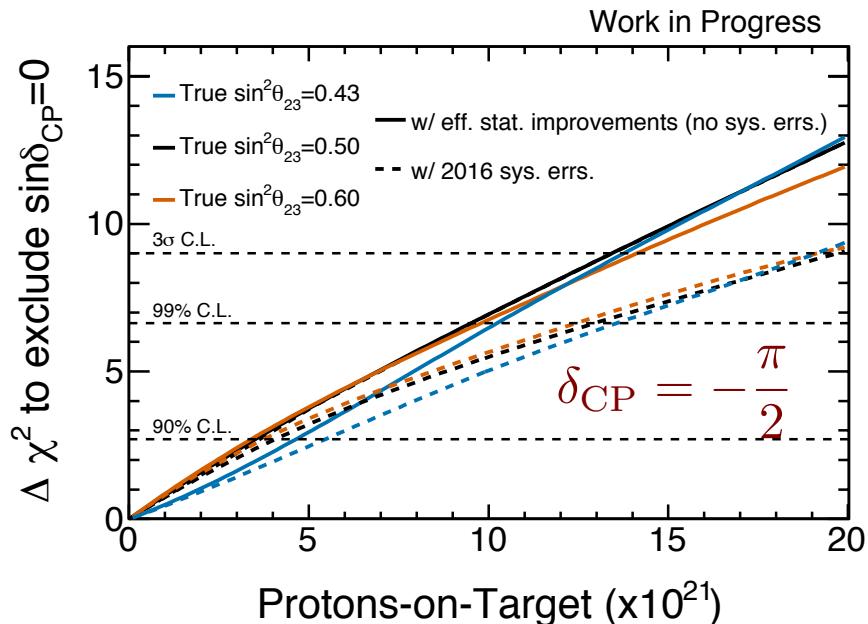
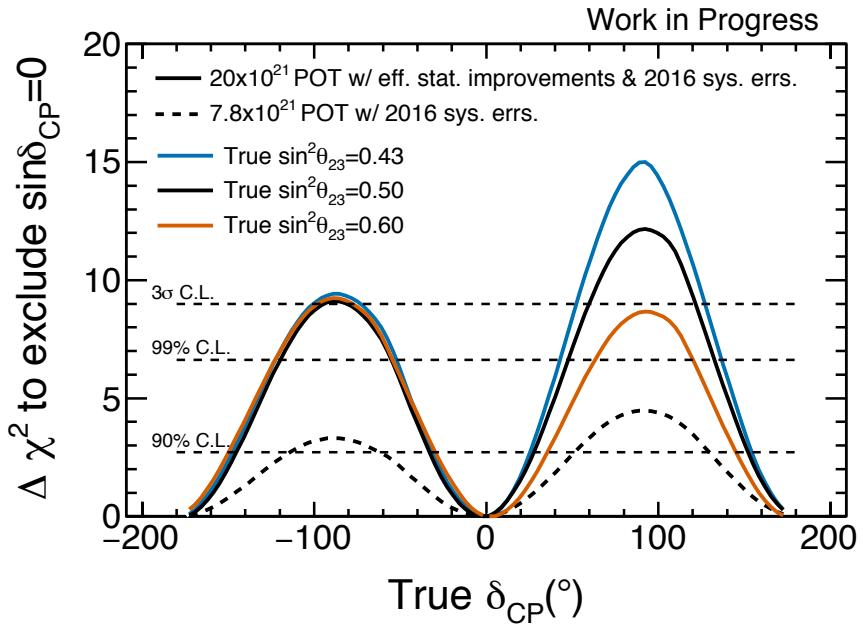


	True δ_{CP}	Total	Signal $\nu_\mu \rightarrow \nu_e$	Signal $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	Beam CC $\nu_e + \bar{\nu}_e$	Beam CC $\nu_\mu + \bar{\nu}_\mu$	NC
ν -mode	0	454.6	346.3	3.8	72.2	1.8	30.5
ν_e sample	$-\pi/2$	545.6	438.5	2.7	72.2	1.8	30.5
$\bar{\nu}$ -mode	0	129.2	16.1	71.0	28.4	0.4	13.3
$\bar{\nu}_e$ sample	$-\pi/2$	111.8	19.2	50.5	28.4	0.4	13.3

	Total	Beam CC ν_μ	Beam CC $\bar{\nu}_\mu$	Beam CC $\nu_e + \bar{\nu}_e$	$\nu_\mu \rightarrow \nu_e + \bar{\nu}_\mu \rightarrow \bar{\nu}_e$	NC
ν -mode ν_μ sample	2612.2	2290.5	150.0	1.6	7.0	163.1
$\bar{\nu}$ -mode $\bar{\nu}_\mu$ sample	1217.5	482.1	672.5	0.6	1.0	61.3

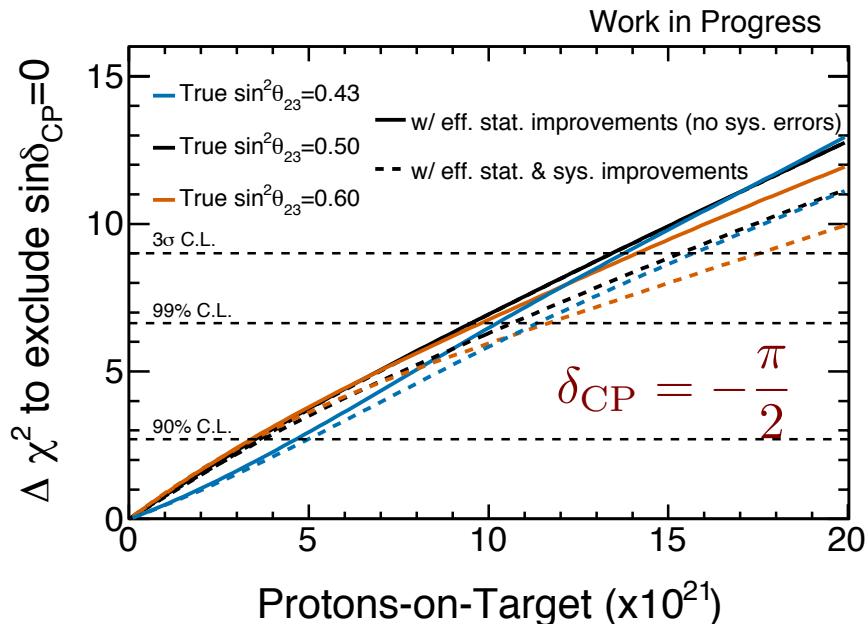
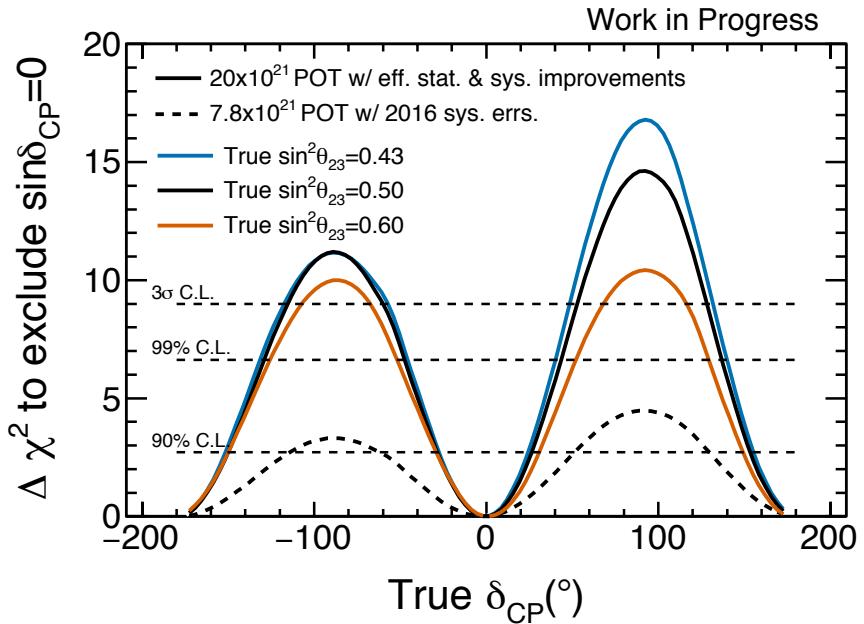
Number of events expected at T2K far detector with full proposed T2K Phase 2 exposure

Assumption: data-taking equally in ν -mode and $\bar{\nu}$ -mode,
known MH and reactor constraint used

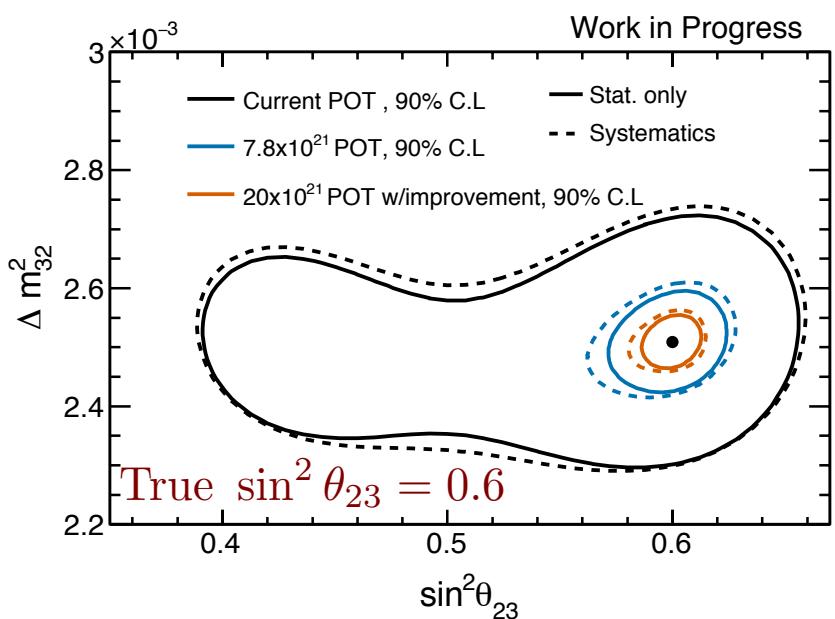
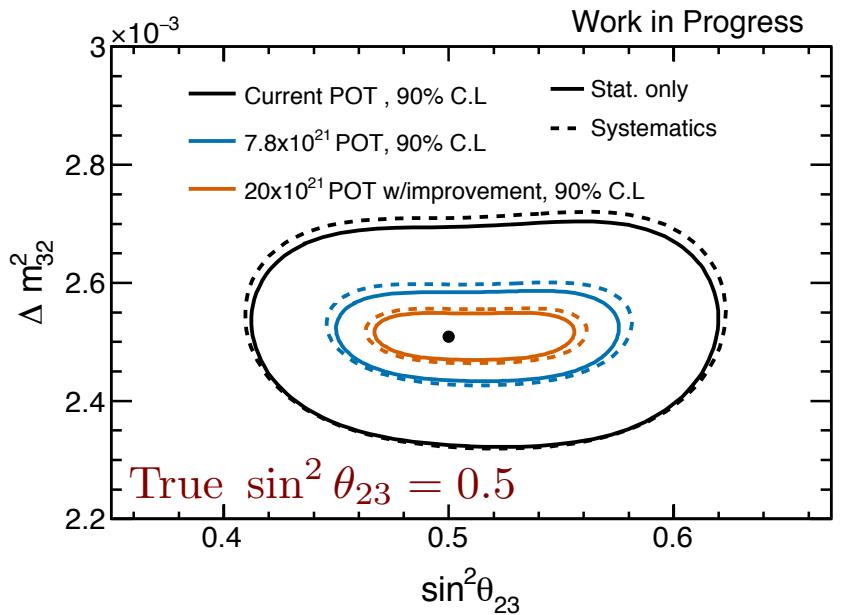


- ❖ 2016 work-in-progress systematic uncertainty is implemented
- ❖ $\sim 3\sigma$ significance sensitivity to CP violation if $\delta_{CP} = -\pi/2$
- ❖ 99% C.L. significance for more than 35% of the possible true values of δ_{CP}

Assumption: data-taking equally in ν -mode and $\bar{\nu}$ -mode,
known MH and reactor constraint used



- ❖ Improvement of systematic uncertainty is considered
- ❖ $> 3\sigma$ significance sensitivity to CP violation if $\delta_{CP} = -\pi/2$
- ❖ 99% C.L. significance for more than 45% of the possible true values of δ_{CP}

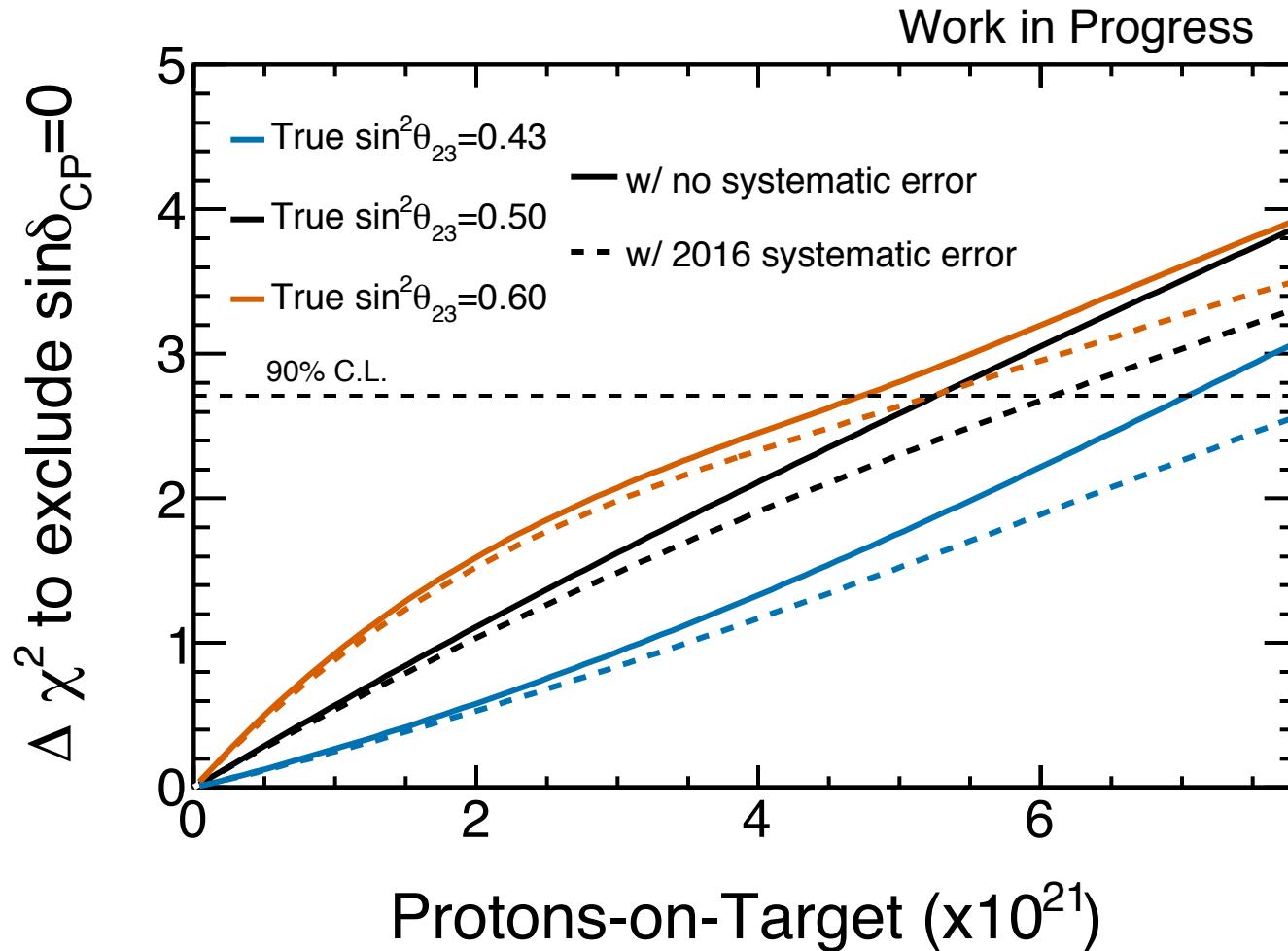


- ✧ 1% precision of Δm_{23}^2
- ✧ $0.5^\circ - 1.7^\circ$ precision of θ_{23} depending on its true value
- ✧ $\sim 3\sigma$ significance for resolving θ_{23} octant if $\sin^2 \theta_{23} > 0.6$ or $\sin^2 \theta_{23} < 0.43$

- ✧ Various new physics opportunities
 - ✧ Sterile neutrino search
 - ✧ Non-standard interactions with matter
 - ✧ CPT and Lorentz invariance test
 - ✧ Other unknowns
 - ✧ Understand neutrino interactions
 - ✧ Explore currently statistic-limited channels
 - ✧ Build a proper model for neutrino interactions
- The proposed T2K Phase 2 attracts a strong interest from the T2K collaboration to pursue exploration of CP violation in a wide range of δ_{CP} , 3σ or higher at maximum CP violation, precise measurement of neutrino parameters and possibility for new physics search.



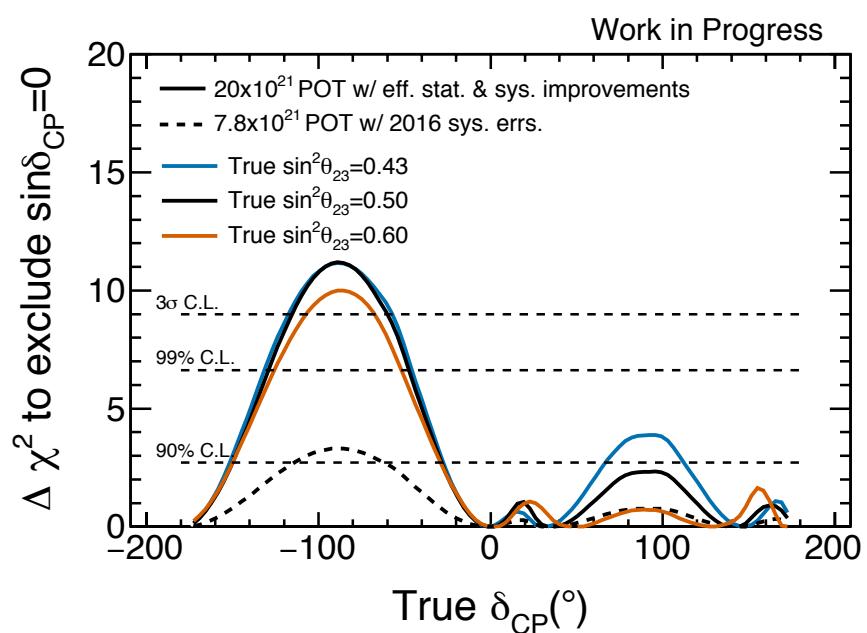
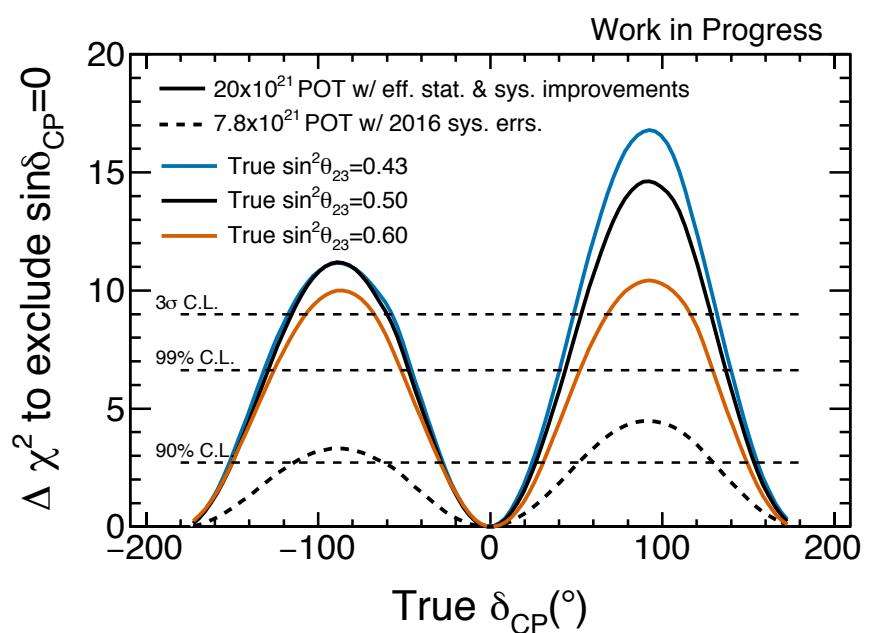
Thank you!



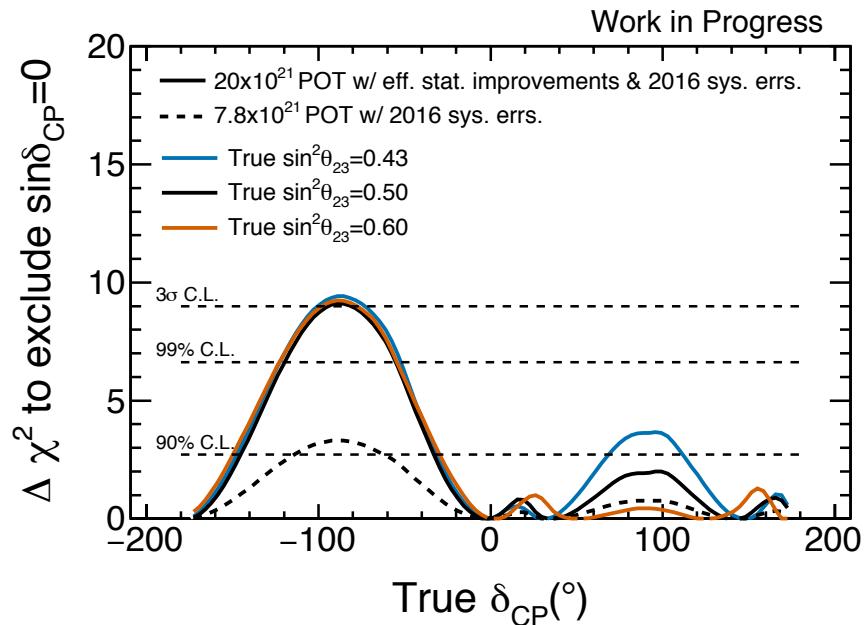
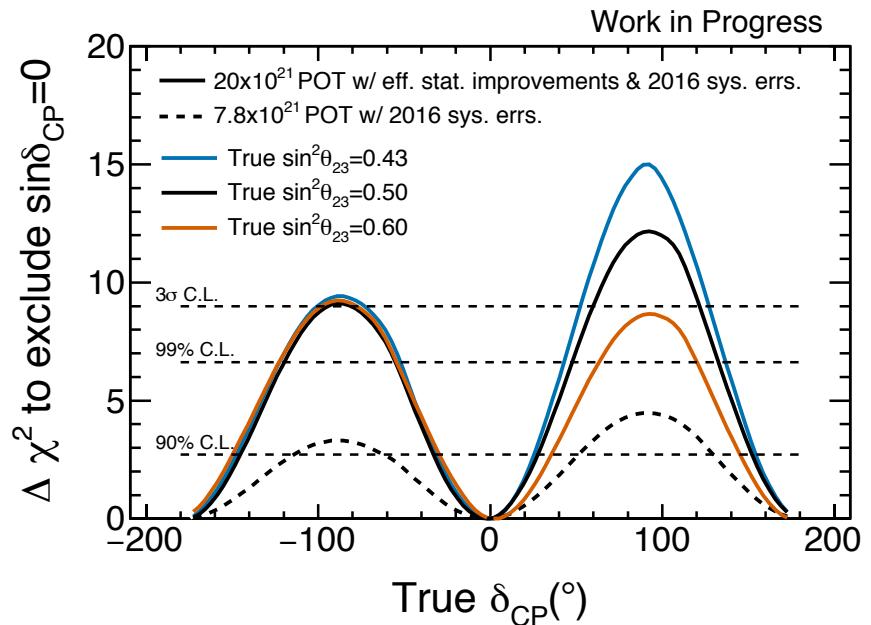
Error Type	$\delta_{N_{SK}}/N_{SK}$ (%)				
	1-Ring μ		1-Ring e		
	ν mode	$\bar{\nu}$ mode	ν mode	$\bar{\nu}$ mode	$\nu/\bar{\nu}$
SK Detector	4.6	3.9	2.8	4.0	1.9
SK Final State & Secondary Interactions	1.8	2.4	2.6	2.7	3.7
ND280 Constrained Flux & Cross-section	2.6	3.0	3.0	3.5	2.4
$\sigma_{\nu_e}/\sigma_{\nu_\mu}, \sigma_{\bar{\nu}_e}/\sigma_{\bar{\nu}_\mu}$	0.0	0.0	2.6	1.5	3.1
NC 1γ Cross-section	0.0	0.0	1.4	2.7	1.2
NC Other Cross-section	0.7	0.7	0.2	0.3	0.1
Total Systematic Error	5.6	5.5	5.7	6.8	5.9
External Constraint on $\theta_{12}, \theta_{13}, \Delta m_{21}^2$	0.0	0.0	4.2	4.0	0.1

✧ Current systematics is 5.5% to 6.8%

✧ Projected systematic error is ~4%



With systematic improvements



Without systematic improvements