

Introduction to T2K-upgrade session

- Actually, it may not upgrade but more...-

A.K.Ichikawa, Kyoto University

We just released $\bar{\nu}_e$ appearance search and $\bar{\nu}_\mu$ disappearance measurement.

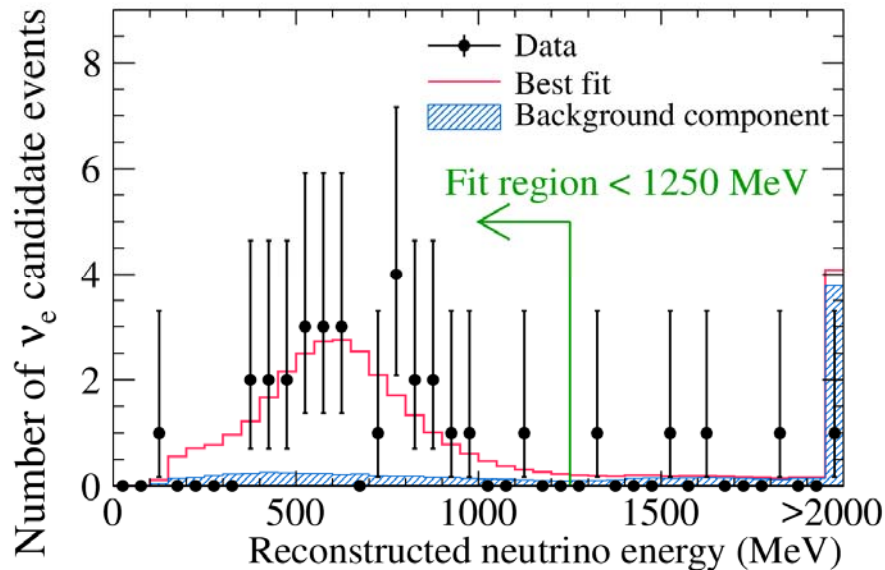
But, here I show just the summary of Run1-4 (2014) ν -mode beam data result.

Where are we now?

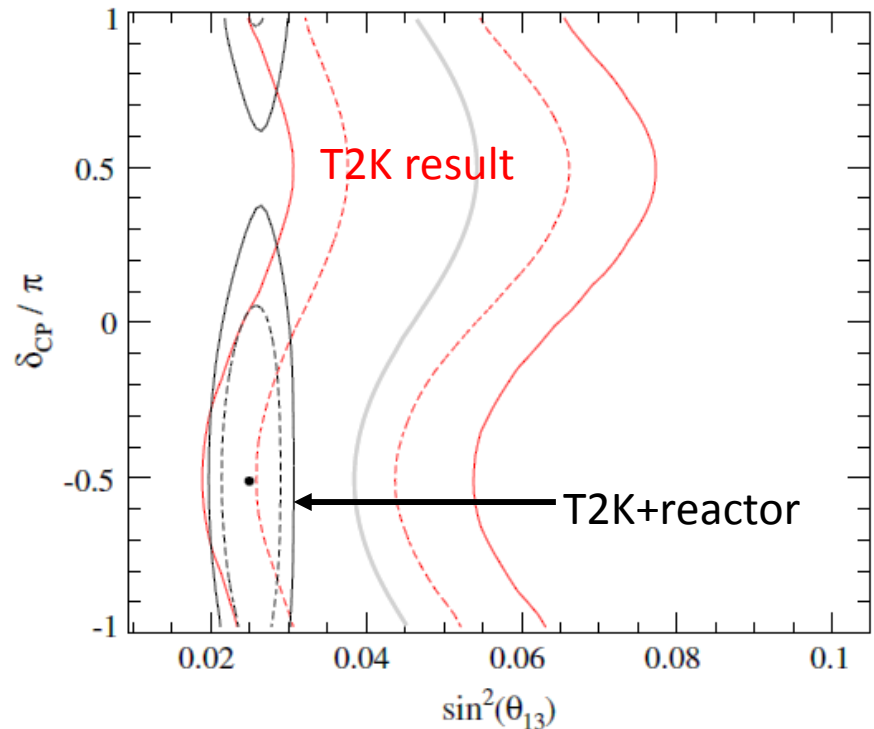
ν_e appearance by T2K

released in August 2013 w/ data till May 2013

Phys. Rev D.91, 072010(2015)



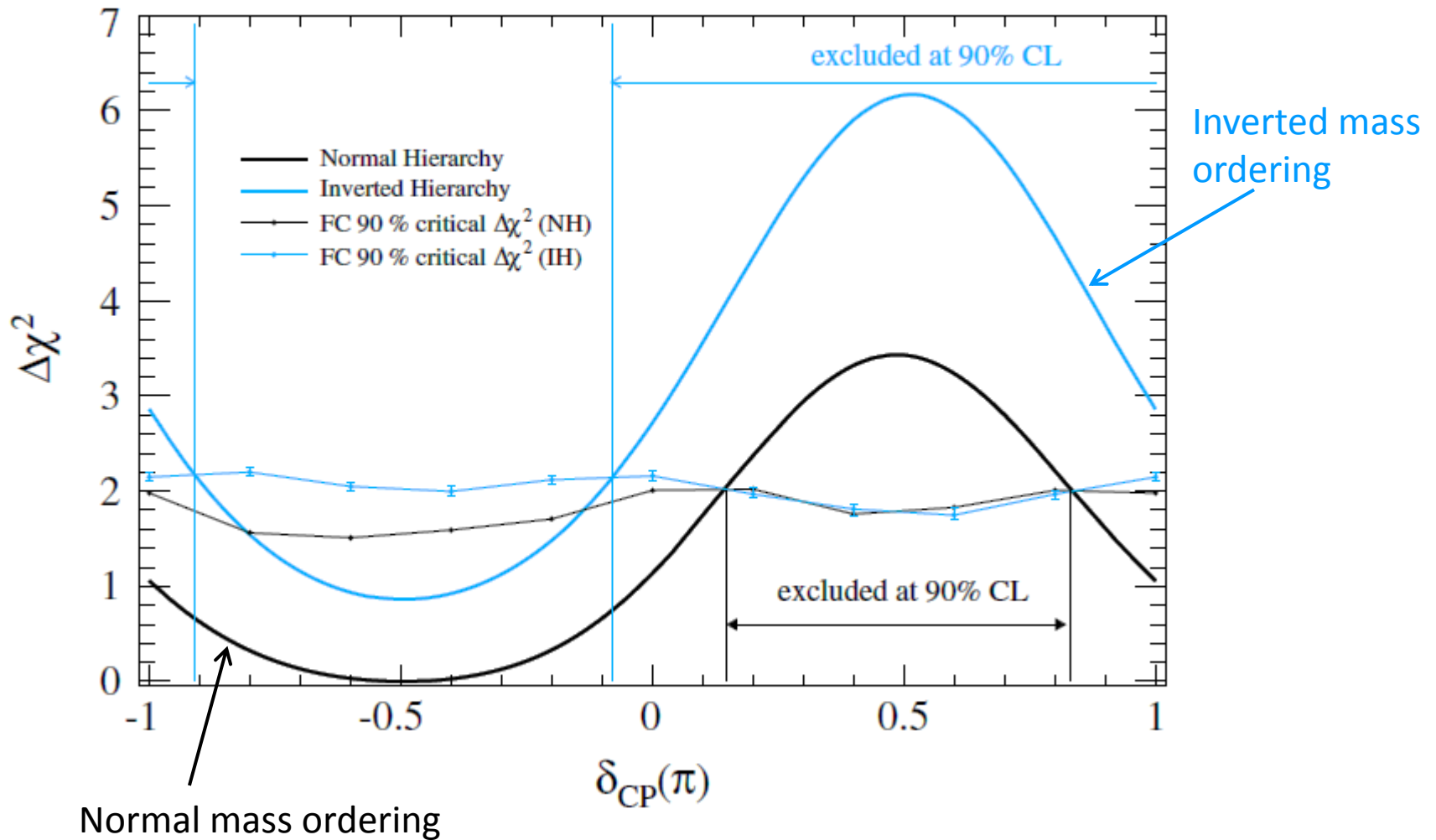
PhysRevLett.112.061802 (2014)



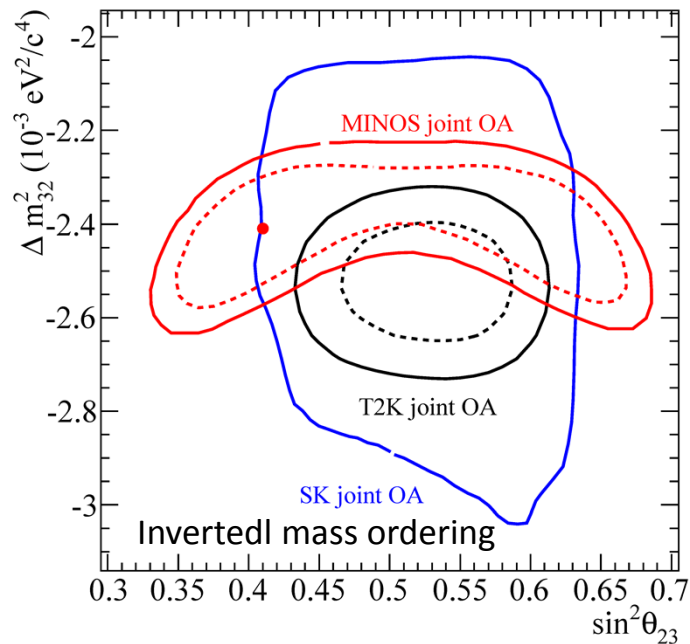
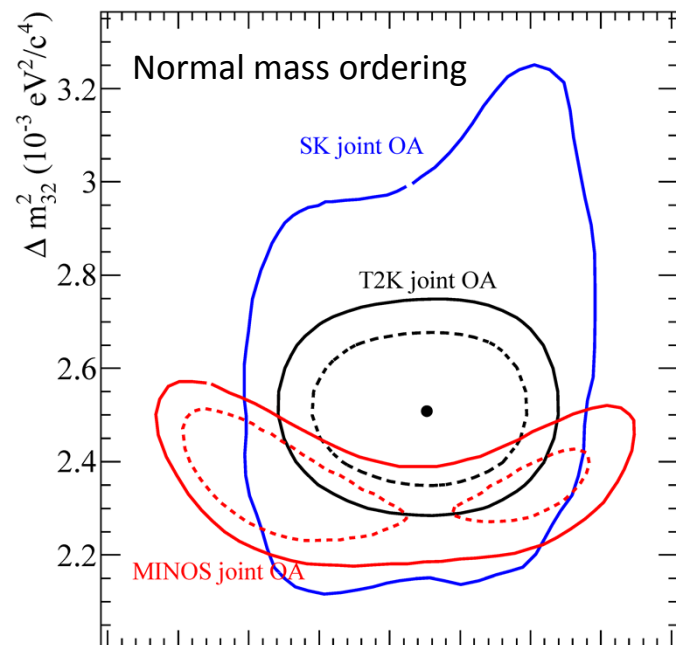
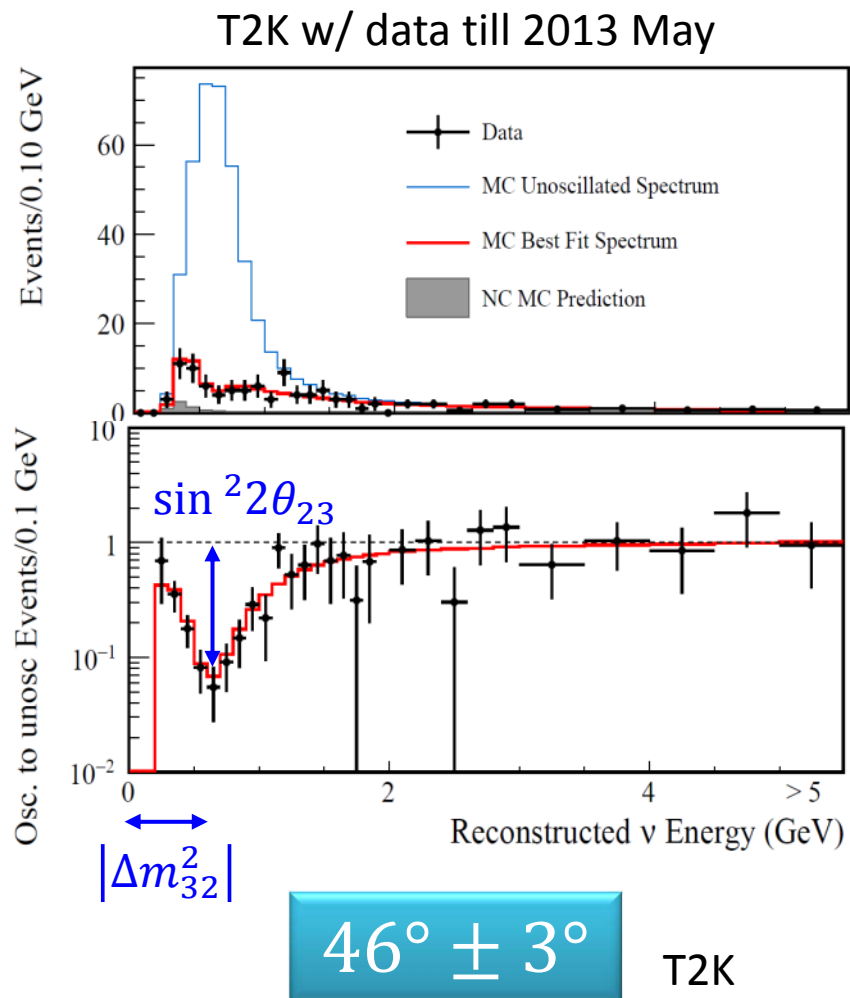
- - - - - T2K+Reactor 68% Credible Region - - - - - T2K Only 68% Credible Region
 ——— T2K+Reactor 90% Credible Region ——— T2K Only 90% Credible Region
 • T2K+Reactor Best Fit Point — T2K Only Best Fit Line

28 events observed over 4.92 ± 0.55 bkg $\rightarrow 7.3\sigma$ excess
 First Confirmation of 'Appearance phenomenon' w/ $> 5\sigma$ significance.

First constraint on δ_{CP} by T2K



θ_{23}



Where are we supposed to go?

T2K at the end

- Full POT endorsed by PAC = $7.8\text{E}21$ POT
 - Current = $1.1\text{E}21$ POT (15%)
- Statistics at full POT
 - assuming 1: ν -mode: $\bar{\nu}$ -mode running

ν_e appearance sample

* bkg includes wrong-sign

	ν_e signal	ν_e bkg.	$\bar{\nu}_e$ signal	$\bar{\nu}_e$ bkg.
$\delta = 0$	98.2	26.8	25.6	16.3
$\delta = -90^\circ$	121.4	26.4	19.0	17.2

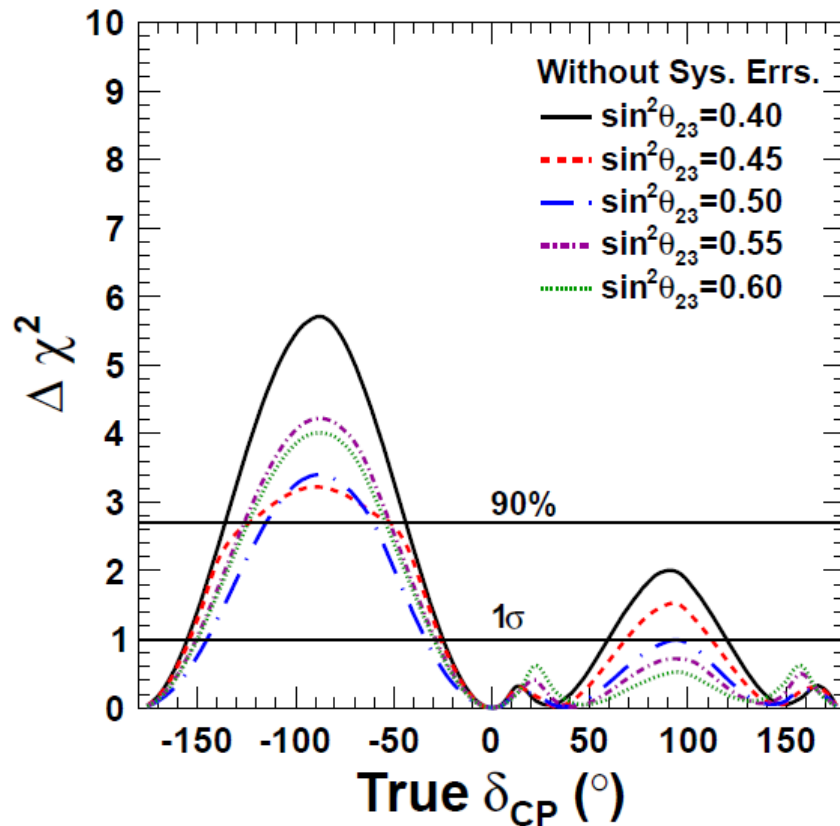
ν_μ disappearance sample

	ν_μ -mode	$\bar{\nu}_\mu$ -mode
w/o oscillation	2,648	1,007
w/ oscillation	741	342

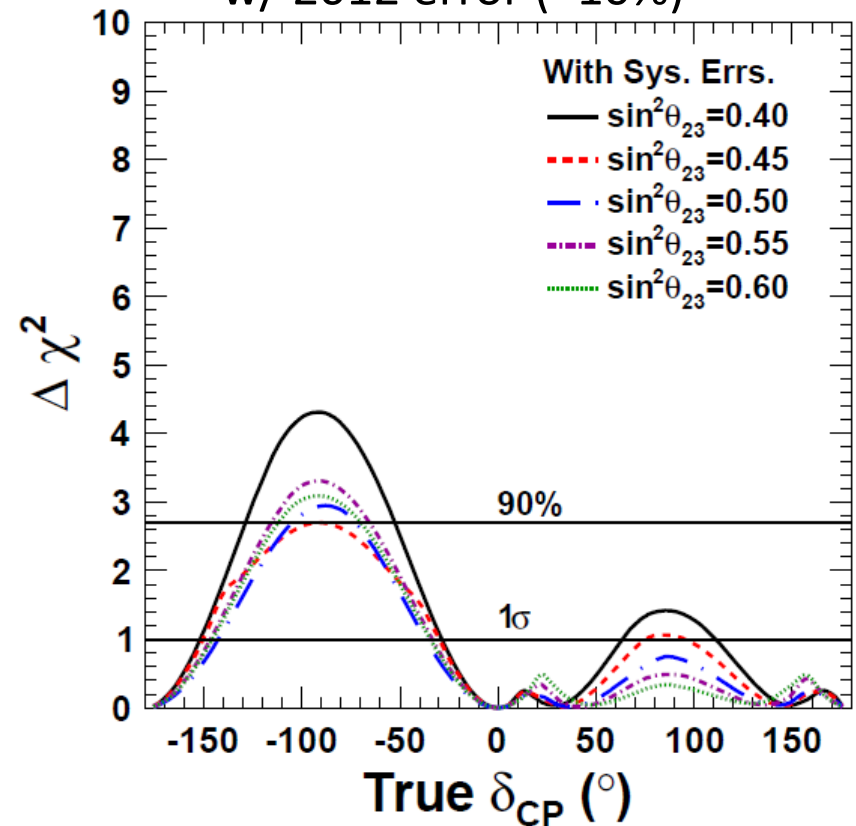
Sensitivity to CP violation at 7.8E21 POT

NH case (IH case gives better sensitivity)
1:1 ν -mode: $\bar{\nu}$ -mode running

Stat. error only



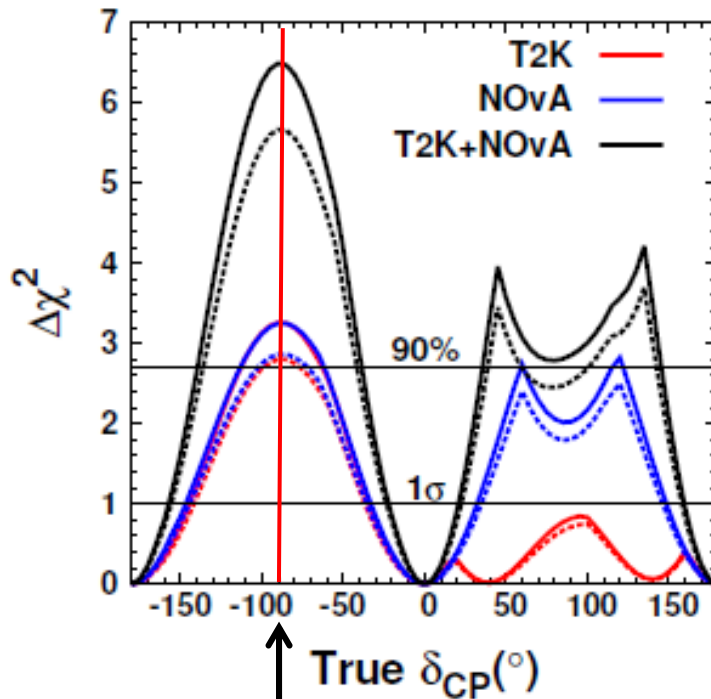
w/ 2012 error ($\sim 10\%$)



T2K has $> 90\%$ C.L. sensitivity if $\delta_{CP} = -90^\circ$

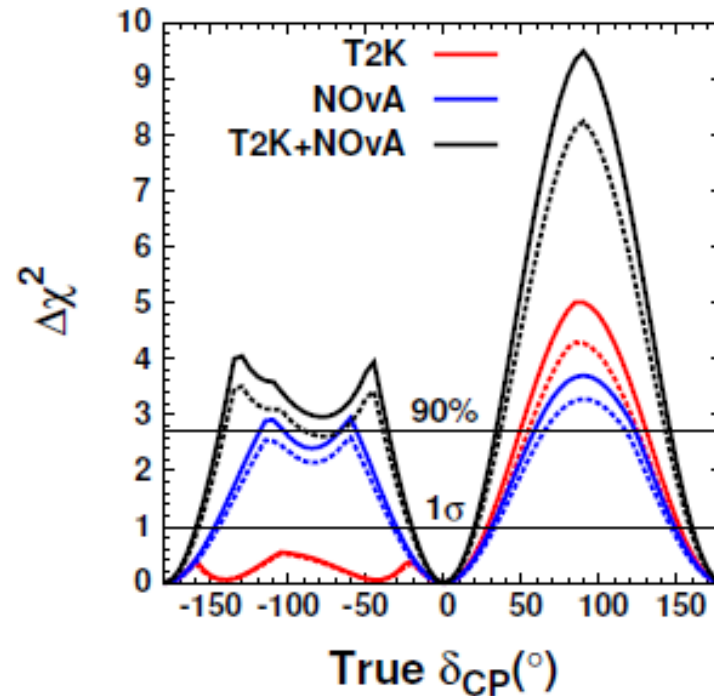
combining w/ NOvA

NH case



Current most
probably situation.
(NH, $\delta_{CP} = -90^\circ$)

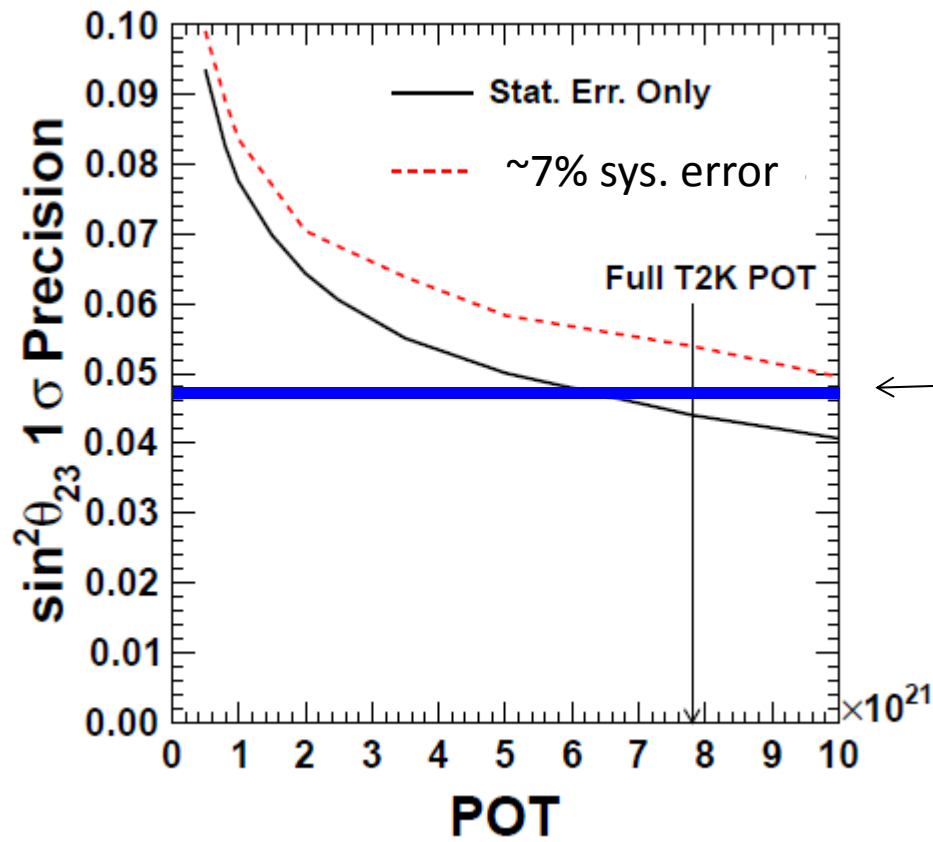
IH case



- $\sin^2 \theta_{23} = 0.5$
- solid : stat. only
- dash: 5% sys. error

- Both competition and cooperation with NOvA are really important.
- combination w/ SuperK etc. would also enhance the sensitivity

sensitivity to θ_{23} at 7.8E21 POT



Actually, already achieved.
(due to stat. fluctuation, non-maximal best fit point etc.)

T2K systematic uncertainty

Fractional error on number-of-event prediction

2014 → 2015

		ν_μ sample	ν_e sample		$\bar{\nu}_\mu$ sample	$\bar{\nu}_e$ sample
ν flux		16%	11%		7.1%	8%
ν flux and cross section	w/o ND measurement	21.8%	26.0%		9.2%	9.4%
	w/ ND measurement	2.7%	3.1%		3.4%	3.0%
ν cross section due to difference of nuclear target btw. near and far		5.0%	4.7%		10%	9.8%
Final or Secondary Hadronic Interaction		3.0%	2.4%		2.1%	2.2%
Super-K detector		4.0%	2.7%		3.8%	3.0%
total	w/o ND measurement	23.5%	26.8%		14.4%	13.5%
	w/ ND measurement	7.7%	6.8%		11.6%	11.0%

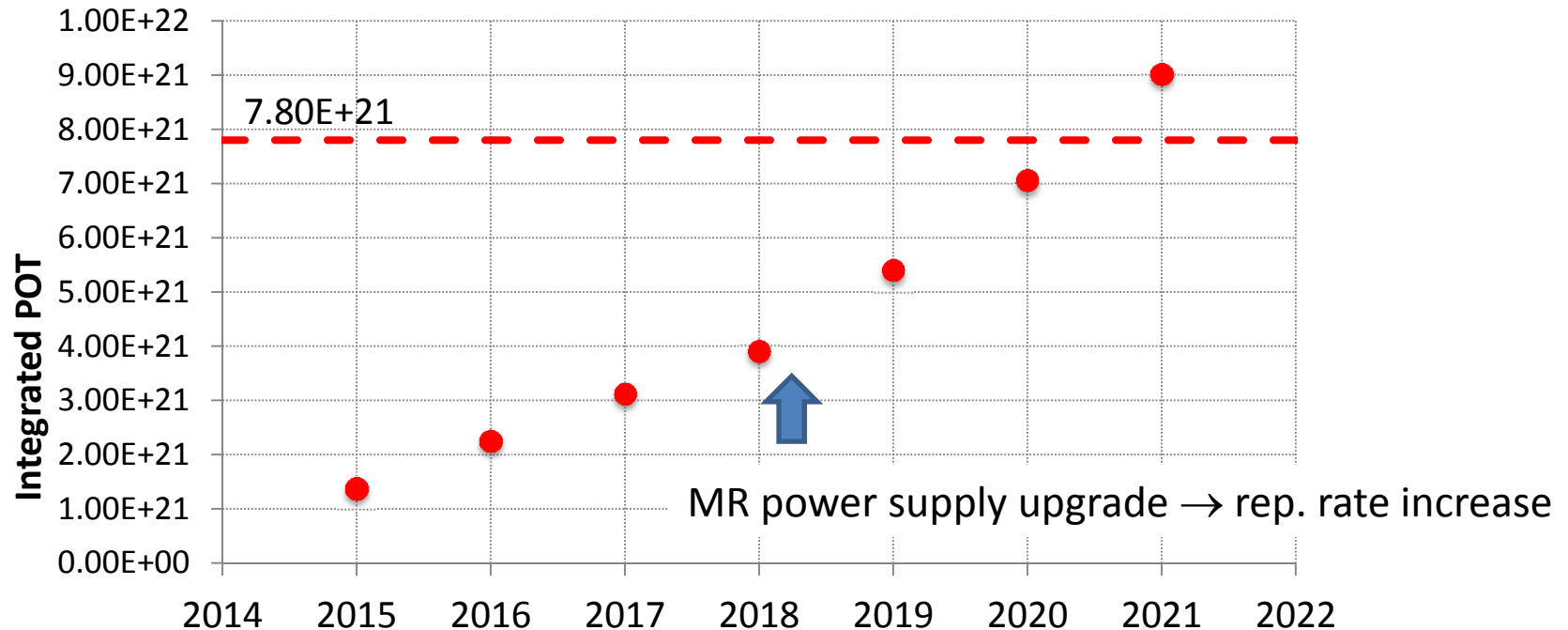


Many improvements

* 2014 error does not include the effect of multi-nucleon at the neutrino-nucleus interaction.

Where should we go?

POT accumulation expectation



- This is not an official expectation, but working assumption made with 'good condition' assumption.
- It will take till ~2021 to accumulate full T2K POT.
- 2 or 3 years after the power upgrade.

Given 90%C.L. sensitivity at the best case($=\delta_{CP} = -90^\circ$), questions may arise

- Is T2K worth to continue until ~ 2021 ?
- Is MR power supply worth to buy for 2 years of T2K running?

What is the best strategy for neutrino program, especially for the quest of CP-violation in the lepton sector (and for the verification of leptogenesis)?

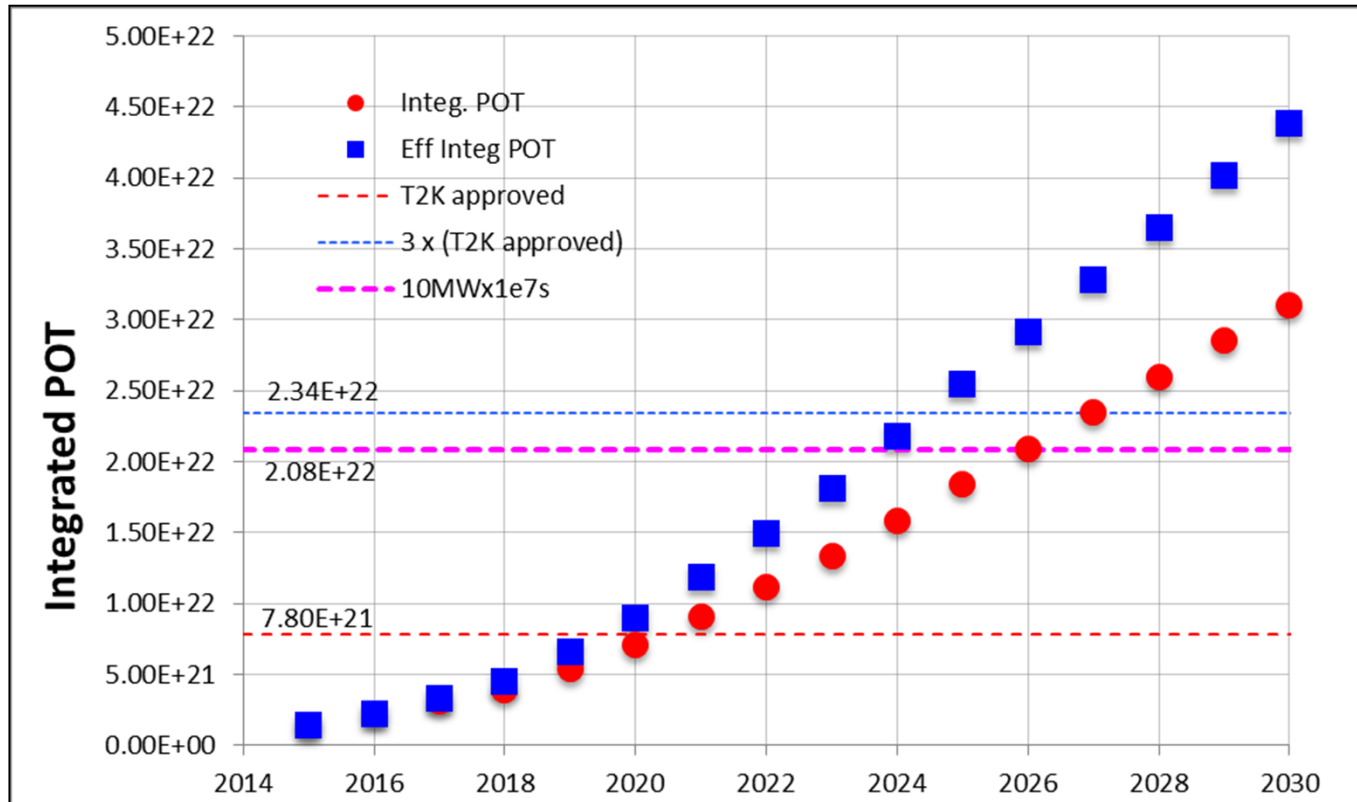
Does **continuation** of T2K with upgraded MR power supply contribute or interrupt global strategy?

- Prospect of the future acc.-based LBL project is not yet clear.
 - It would start in 2025(?) in the earliest case.
 - Beam power upgrade would require a few years time scale.
 - Stop of T2K may result in long delay or end(=worst case) of neutrino physics progress.
- Some people have started a discussion to extend the T2K running
 - ‘T2K-upgrade’? ‘T2K2’? ‘T2K++’? ‘T2Kmore’?
- It seems 3σ discovery of CP violation (if it is maximally violated) by 2026 is possible with ‘efforts’ from both facility side and collaboration side → Megan’s talk

What is required to reach 3σ sensitivity by 2026?

- 1.3 MW(at the end) beam with MR power supply upgrade in 2018 ?
- Collaboration efforts equivalent to 1.5? times statistical increase
 - horn current?
 - new samples at SK?
 - SK fiducial volume enlargement?
 - systematic error reduction?
2% ??? 3%?? 7%?
- 'effective' POT target = $25E21$ for 2% sys. error → Megan's talk
- Presented today would be a consideration by individual speakers, not T2K official statement

Working assumption and Summary



Hope:

- Start wide activity triggered by this workshop
- submit a new proposal or LOI? by the PAC in the winter??

BACKUP

Details of working assumption

FY	2015					2016					2017					2018					2019					2020				
	4	7	10	1		4	7	10	1		4	7	10	1		4	7	10	1		4	7	10	1		4	7	10	1	
Acc off																	MR-PS													
Neutrino																														
Month	1	2				1	5				0	5				0	3				0	5				0	5			
Days/Month	22	22				22	23				23	23				23	23				23	23				23	23			
Days	22	44				22	115				0	115				0	69				0	115				0	115			
Live days	19.8	39.6				19.8	103.5				0.0	103.5				0.0	62.1				0.0	103.5				0.0	103.5			
Hours	475.2	950.4				475.2	2484.0				0.0	2484.0				0.0	1490.4				0.0	2484.0				0.0	2484.0			
Rep rate	2.48	2.48				2.48					2.48										1.30						1.25			
ppb	2.10E+13	2.35E+13					2.60E+13					3.00E+13					2.40E+13					2.70E+13					2.90E+13			
ppp	1.68E+14	1.88E+14					2.08E+14					2.40E+14					1.92E+14					2.16E+14					2.32E+14			
Power(kW)	325.6	364.4					403.1					465.1					709.9					798.6					892.1			
pot	1.16E+20	2.59E+20				1.30E+20	7.50E+20				0.00E+00	8.65E+20				0.00E+00	7.92E+20				0.00E+00	1.49E+21				0.00E+00	1.66E+21			
Integ. POT	1.11E+21	1.37E+21				1.50E+21	2.25E+21				2.25E+21	3.12E+21				3.12E+21	3.91E+21				3.91E+21	5.40E+21				5.40E+21	7.06E+21			
Integ. POT	1.37E+21					2.25E+21					3.12E+21					3.91E+21					5.40E+21					7.06E+21				
MW.1e7s	0.66					1.08					1.50					1.88					2.59					3.39				
T2K experiment side improvements																														
Horn Fac	1.00	1.00				1.00	1.00				1.00	1.10				1.10	1.10				1.10	1.10				1.10	1.10			
Fid vol	1.00	1.00				1.00	1.00				1.00	1.00				1.00	1.20				1.20	1.20				1.20	1.20			
SK ev smple	1.00	1.00				1.00	1.00				1.00	1.10				1.10	1.10				1.10	1.10				1.10	1.10			
Overall impro	1.00	1.00				1.00	1.00				1.00	1.21				1.21	1.45				1.45	1.45				1.45	1.45			
Eff Integ POT	1.11E+21	1.37E+21				1.50E+21	2.25E+21				2.25E+21	3.30E+21				3.30E+21	4.45E+21				4.45E+21	6.61E+21				6.61E+21	9.02E+21			
Eff Integ POT	1.37E+21					2.25E+21					3.30E+21					4.45E+21					6.61E+21					9.02E+21				
Eff MW.1e7s	0.66					1.08					1.59					2.14					3.18					4.33				

Details of working assumption

FY	2021				2022				2023				2024				2025				2026			
	7	10	1	4	7	10	1	4	7	10	1	4	7	10	1	4	7	10	1	4	7	10	1	4
Acc off																								
Neutrino																								
Month	0	5			0	5			0	5			0	5			0	5			0	5		
Days/Month	23	23			23	23			23	23			23	23			23	23			23	23		
Days	0	115			0	115			0	115			0	115			0	115			0	115		
Live days	0.0	103.5			0.0	103.5			0.0	103.5			0.0	103.5			0.0	103.5			0.0	103.5		
Hours	0.0	2484.0			0.0	2484.0			0.0	2484.0			0.0	2484.0			0.0	2484.0			0.0	2484.0		
Rep rate	1.20				1.20				1.20				1.16				1.16				1.16			
ppb																								
ppp																								
Power(kW)																								
pot	0.00E+00	1.97E+21			0.00E+00	2.09E+21			0.00E+00	2.21E+21			0.00E+00	2.41E+21			0.00E+00	2.41E+21			0.00E+00	2.47E+21		
Integ. POT	7.06E+21	9.02E+21			9.02E+21	1.11E+22			1.11E+22	1.33E+22			1.33E+22	1.57E+22			1.57E+22	1.81E+22			1.81E+22	2.06E+22		
Integ. POT	9.02E+21				1.11E+22				1.33E+22				1.57E+22				1.81E+22				2.06E+22			
MW.1e7s	4.34				5.34				6.40				7.56				8.71				9.90			
T2K experiment																								
Horn Fac	1.10	1.10			1.10	1.10			1.10	1.10			1.10	1.10			1.10	1.10			1.10	1.10		
Fid vol	1.20	1.20			1.20	1.20			1.20	1.20			1.20	1.20			1.20	1.20			1.20	1.20		
SK ev smple	1.10	1.10			1.10	1.10			1.10	1.10			1.10	1.10			1.10	1.10			1.10	1.10		
Overall impro	1.45	1.45			1.45	1.45			1.45	1.45			1.45	1.45			1.45	1.45			1.45	1.45		
Eff Integ POT	9.02E+21	1.19E+22			1.19E+22	1.49E+22			1.49E+22	1.81E+22			1.81E+22	2.16E+22			2.16E+22	2.51E+22			2.51E+22	2.87E+22		
Eff Integ POT	1.19E+22				1.49E+22				1.81E+22				2.16E+22				2.51E+22				2.87E+22			
Eff MW.1e7s	5.71				7.16				8.70				10.38				12.06				13.78			

Details of working assumption

FY	2025				2026				2027				2028				2029				2030			
		7	10	1		4	7	10	1		4	7	10	1		4	7	10	1		4	7	10	1
Acc off																								
Neutrino																								
Month	0	5			0	5			0	5			0	5			0	5			0	5		
Days/Month	23	23			23	23			23	23			23	23			23	23			23	23		
Days	0	115			0	115			0	115			0	115			0	115			0	115		
Live days	0.0	103.5			0.0	103.5			0.0	103.5			0.0	103.5			0.0	103.5			0.0	103.5		
Hours	0.0	2484.0			0.0	2484.0			0.0	2484.0			0.0	2484.0			0.0	2484.0			0.0	2484.0		
Rep rate	1.16				1.16				1.16				1.16				1.16				1.16			
ppb				3.90E+13				4.00E+13				4.00E+13				4.00E+13				4.00E+13				4.00E+13
ppp				3.12E+14				3.20E+14				3.20E+14				3.20E+14				3.20E+14				3.20E+14
Power(kW)				1292.8				1325.9				1325.9				1325.9				1325.9				1325.9
pot	0.00E+00	2.41E+21			0.00E+00	2.47E+21			0.00E+00	2.47E+21			0.00E+00	2.47E+21			0.00E+00	2.47E+21			0.00E+00	2.47E+21		
Integ. POT	1.57E+22	1.81E+22			1.81E+22	2.06E+22			2.06E+22	2.31E+22			2.31E+22	2.55E+22			2.55E+22	2.80E+22			2.80E+22	3.05E+22		
Integ. POT	1.81E+22				2.06E+22				2.31E+22				2.55E+22				2.80E+22				3.05E+22			
MW.1e7s	8.71				9.90				11.08				12.27				13.45				14.64			
T2K experiment																								
Horn Fac	1.10	1.10			1.10	1.10			1.10	1.10			1.10	1.10			1.10	1.10			1.10	1.10		
Fid vol	1.20	1.20			1.20	1.20			1.20	1.20			1.20	1.20			1.20	1.20			1.20	1.20		
SK ev smple	1.10	1.10			1.10	1.10			1.10	1.10			1.10	1.10			1.10	1.10			1.10	1.10		
Overall impro	1.45	1.45			1.45	1.45			1.45	1.45			1.45	1.45			1.45	1.45			1.45	1.45		
Eff Integ POT	2.16E+22	2.51E+22			2.51E+22	2.87E+22			2.87E+22	3.23E+22			3.23E+22	3.58E+22			3.58E+22	3.94E+22			3.94E+22	4.30E+22		
Eff Integ POT	2.51E+22				2.87E+22				3.23E+22				3.58E+22				3.94E+22				4.30E+22			
Eff MW.1e7s	12.06				13.78				15.50				17.22				18.95				20.67			