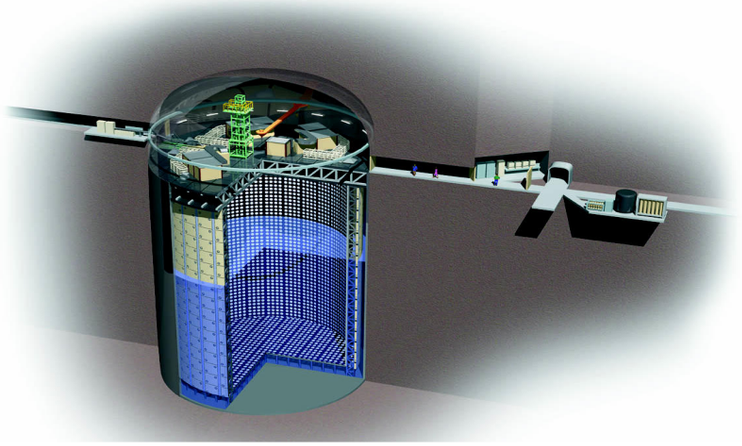
The NNN water detector satellite meeting
Oct. 27, 2015 in Stony Brook University

Plan for an Extended T2K Run

T. Nakaya (Kyoto)

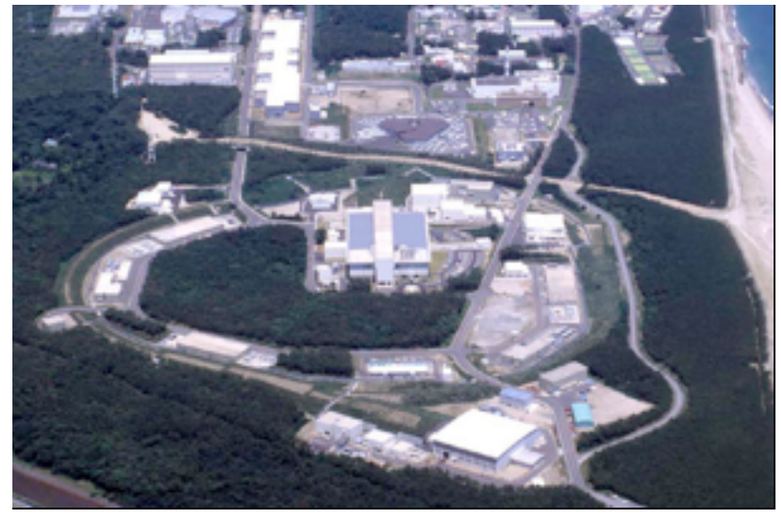
T2K (Tokai to Kamioka)

Super-K@Kamioka



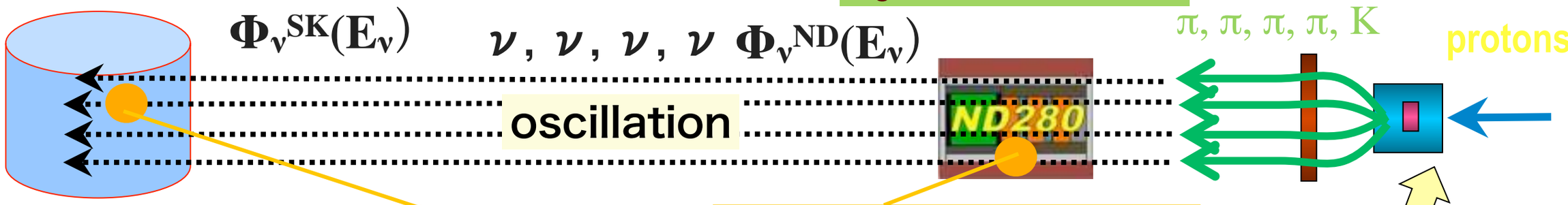
Big Neutrino Detector

J-PARC@Tokai

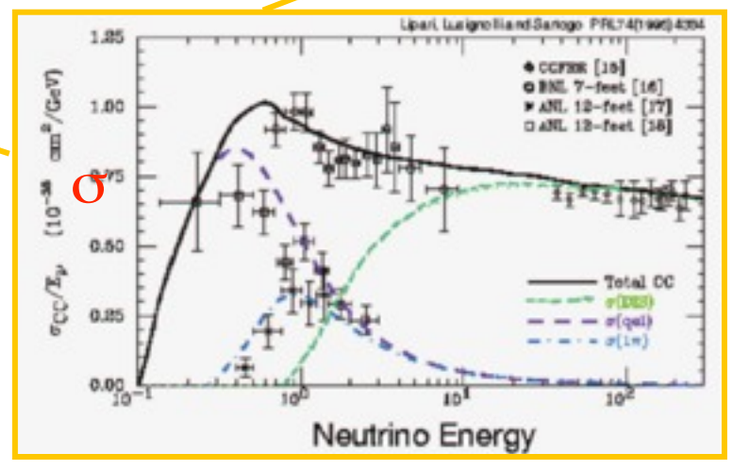


Intense beam

High Resolution Detector

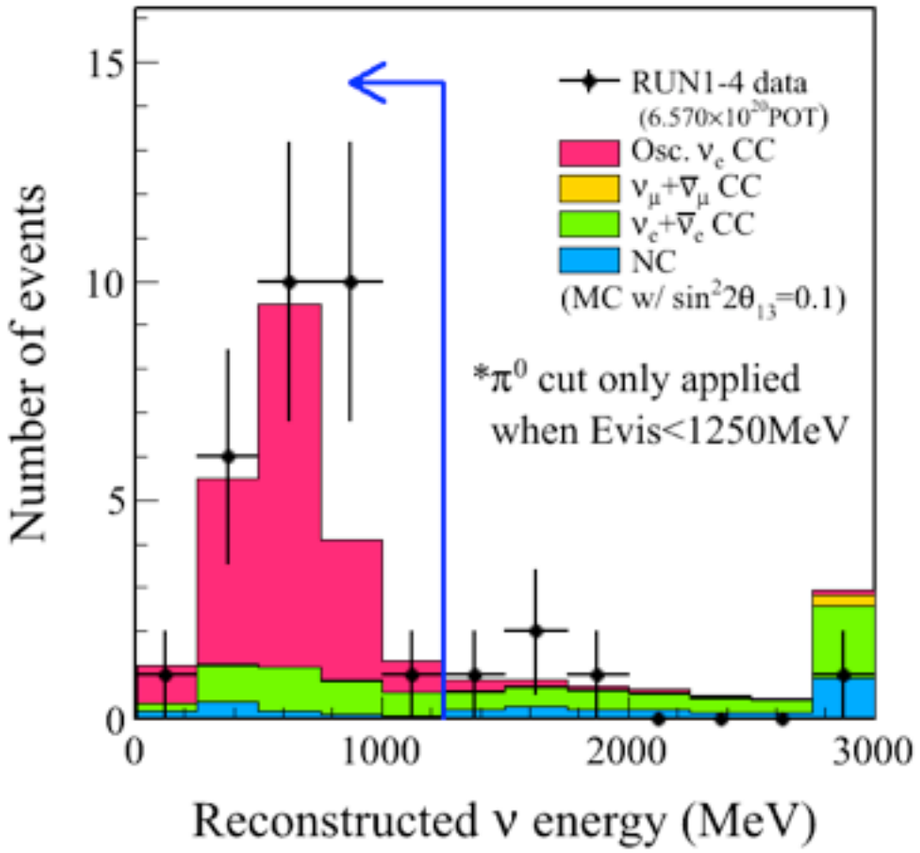


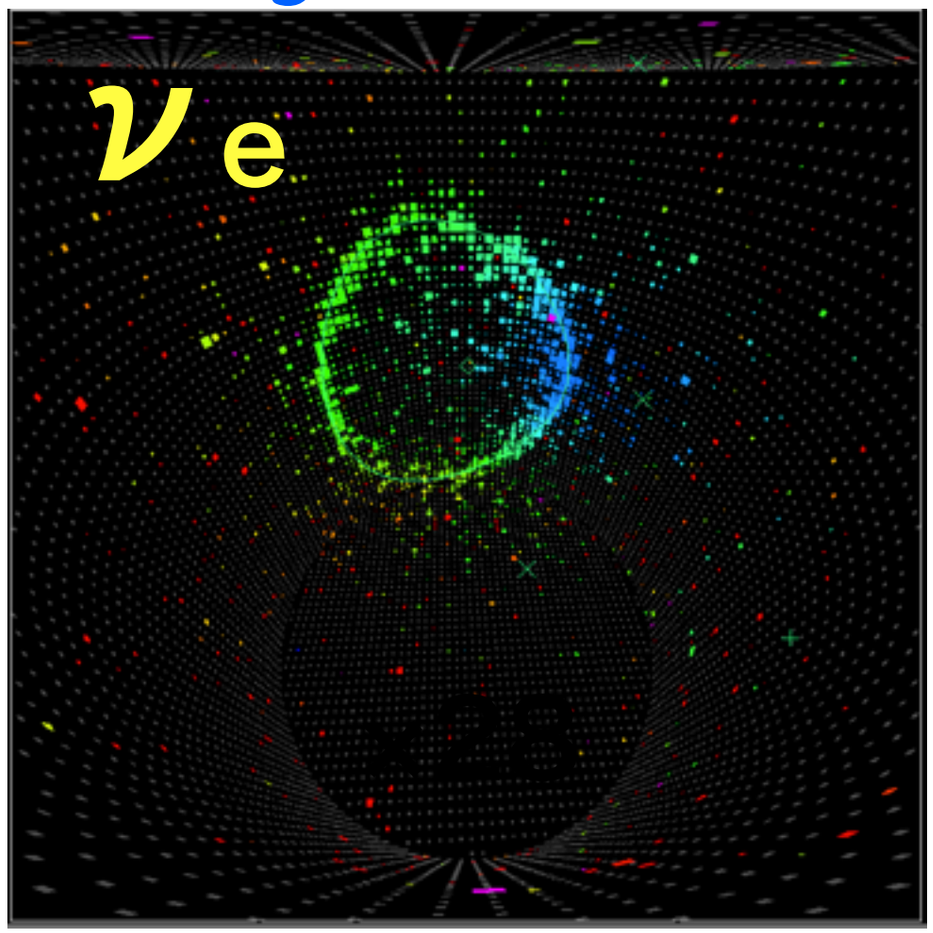
- High Power Accelerator
- Intense Neutrino Beam
- High Resolution Near Detector
- Big Far Detector



CERN
NA61 Hadron
Production

T2K History

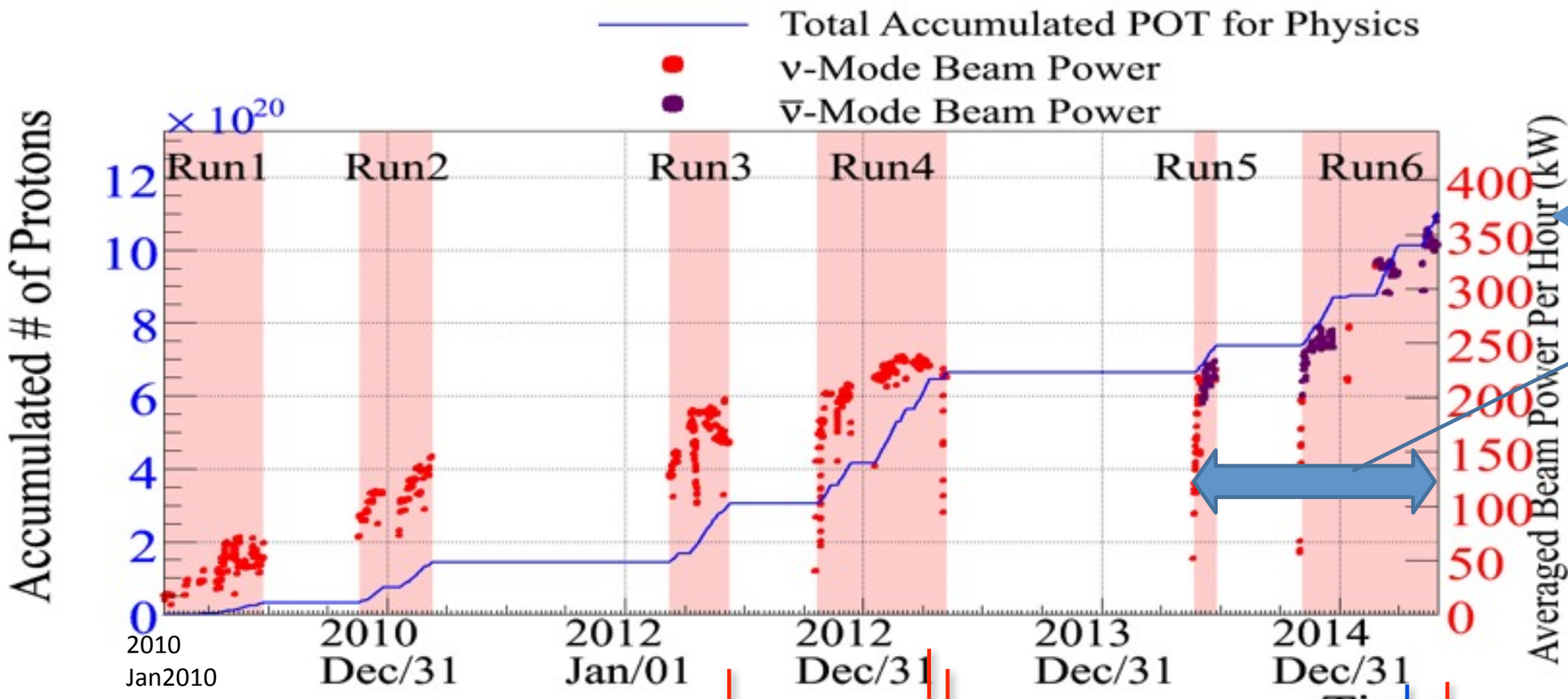




- **Discovery of $\nu_\mu \rightarrow \nu_e$**
  - In 2011, T2K found the clear indication of $\nu_\mu \rightarrow \nu_e$.
    - PRL 107 (2011) 041801 citations：**1059**
  - In 2012, Daya Bay, RENO and Double Chooz measured θ_{13}.
  - In 2013, T2K observed $\nu_\mu \rightarrow \nu_e$ with 7.3σ significance.
    - The constraint to neutrino CPV with the reactor θ_{13} value.

by A.K. Ichikawa

T2K Data taking record



14% of goal

data used for EPS2015

ν_e appear. 2.5σ

ν_e appear. 7.3σ

ν_e appear. 3.1σ

first constraint on δ_{CP}

first anti-ν_e appear. search

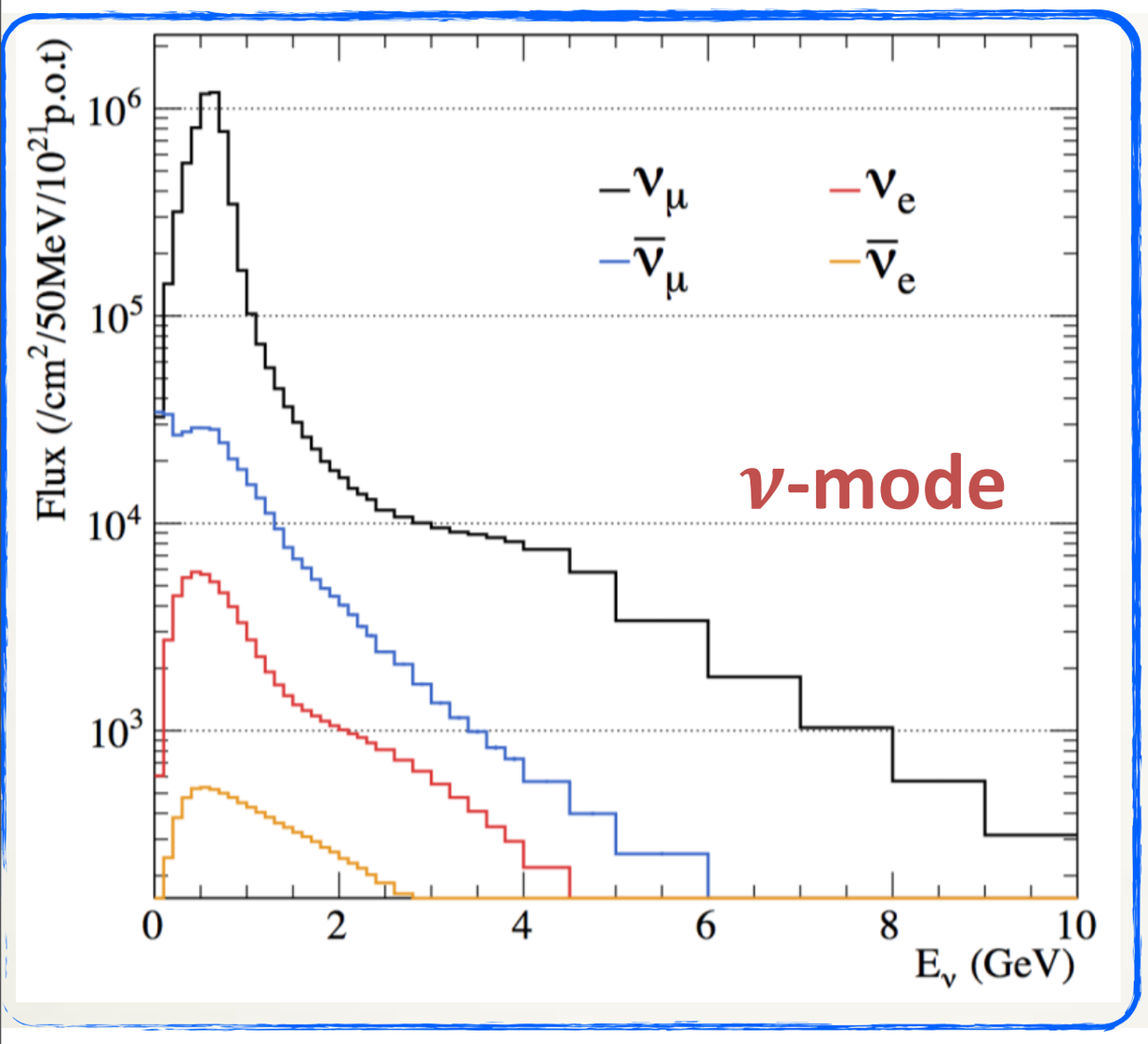
first anti-ν_μ result

ν_μ 1st release

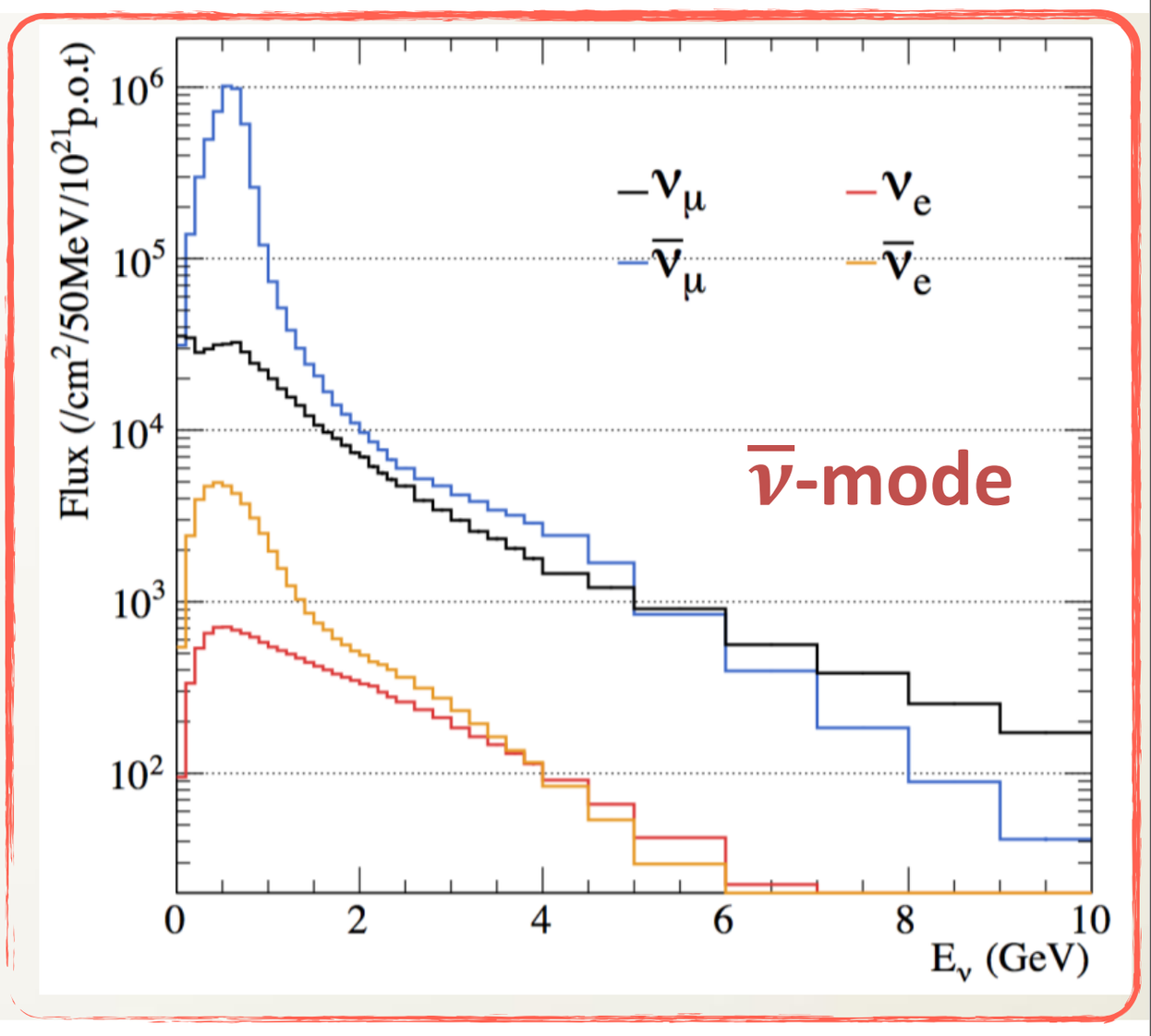
ν_μ highest precision on θ_{23}

T2K Neutrino Beam

Neutrino Beam mode



Anti-Neutrino Beam mode



Future Prospect

- **More Information at the Workshops in J-PARC**
  - HINT2015: Future potential of High INTensity Proton Accelerator for Particle and Nuclear Physics, October 13-15, 2015
    - http://j-parc.jp/pn/HINT2015/
  - Neutrino Programs with facilities in Japan, August 4-6, 2015
    - http://www-conf.kek.jp/ws_nu_prog_in_jp/
    - http://www-conf.kek.jp/ws_nu_prog_in_jp/program/program.html

by T. Koseki at HINT2015

J-PARC

Mid-term plan of MR

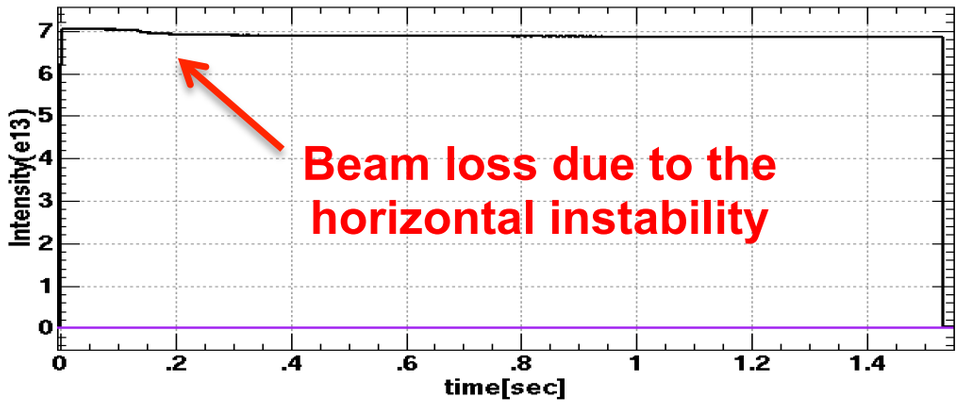
FX: The high repetition rate scheme is adopted to achieve the design beam intensity, 750 kW. Rep. rate will be increased from ~ 0.4 Hz to ~1 Hz by replacing magnet PS's, RF cavities and some injection and extraction devices.
SX: Parts of stainless steel ducts are replaced with titanium ducts to reduce residual radiation dose. The beam power will be gradually increased toward 100 kW watching the residual activity.

JFY	2014	2015	2016	2017	2018	2019	2020
	Li. current upgrade		New PS buildings				
FX power [kW] (study/trial)	320	> 360	400	450	700	800	900
SX power [kW] (study/trial)	-	33 - 40	50	50-70	50-70	~100	~100
Cycle time of main magnet PS New magnet PS	2.48 s	R&D → Large scale 1st PS		Mass production installation/test →	1.3 s	1.3 s	1.2 s
High gradient rf system 2nd harmonic rf system VHF cavity		Manufacture, installation/test → R&D, manufacture, installation/test → R&D →					
Ring collimators		Add.collimators (2 kW)	Add.collimators (3.5kW)				
Injection system FX system		Kicker PS improvement, Septa manufacture /test → Kicker PS improvement, LF septum, HF septa manufacture /test →					
SX collimator / Local shields		Local shields →					
Ti ducts and SX devices with Ti chamber	Beam ducts	ESS					

High Intensity beam study in June 2015 (cont'd)

- at the new betatron tune (22.239, 21.310) -

High power trial with two bunches



Extracted beam : 3.41e13 ppb
6.82e13 ppp (132 kW eq. ,2 bunches)

Beam loss[Watt]

INJ(K1+K2+K3+K4)	144	7.43e+11
P2 --> +90ms	241	1.00e+12
P2+90ms --> +120ms	31	1.30e+11
P2+100ms ---> EXT		1.83e+11

Total beam loss ~ 420 W

Near future tunable knobs to reduce the beam loss:
Injection kicker, BxB feed-back,
2nd harmonic cavity, VHF cavity, etc.

	Bunch number	repetition period (sec)	Beam power (kW)	Beam loss (kW)	Notes
1	2	2.48	132	0.42	measurement
2	8	2.48	529	1.7	estimation
3	8	1.3	1009	3.2	estimation

The MR has capability to reach 1MW with the high repetition rate operation.

T2K can accept 1.3MW beam with upgrade

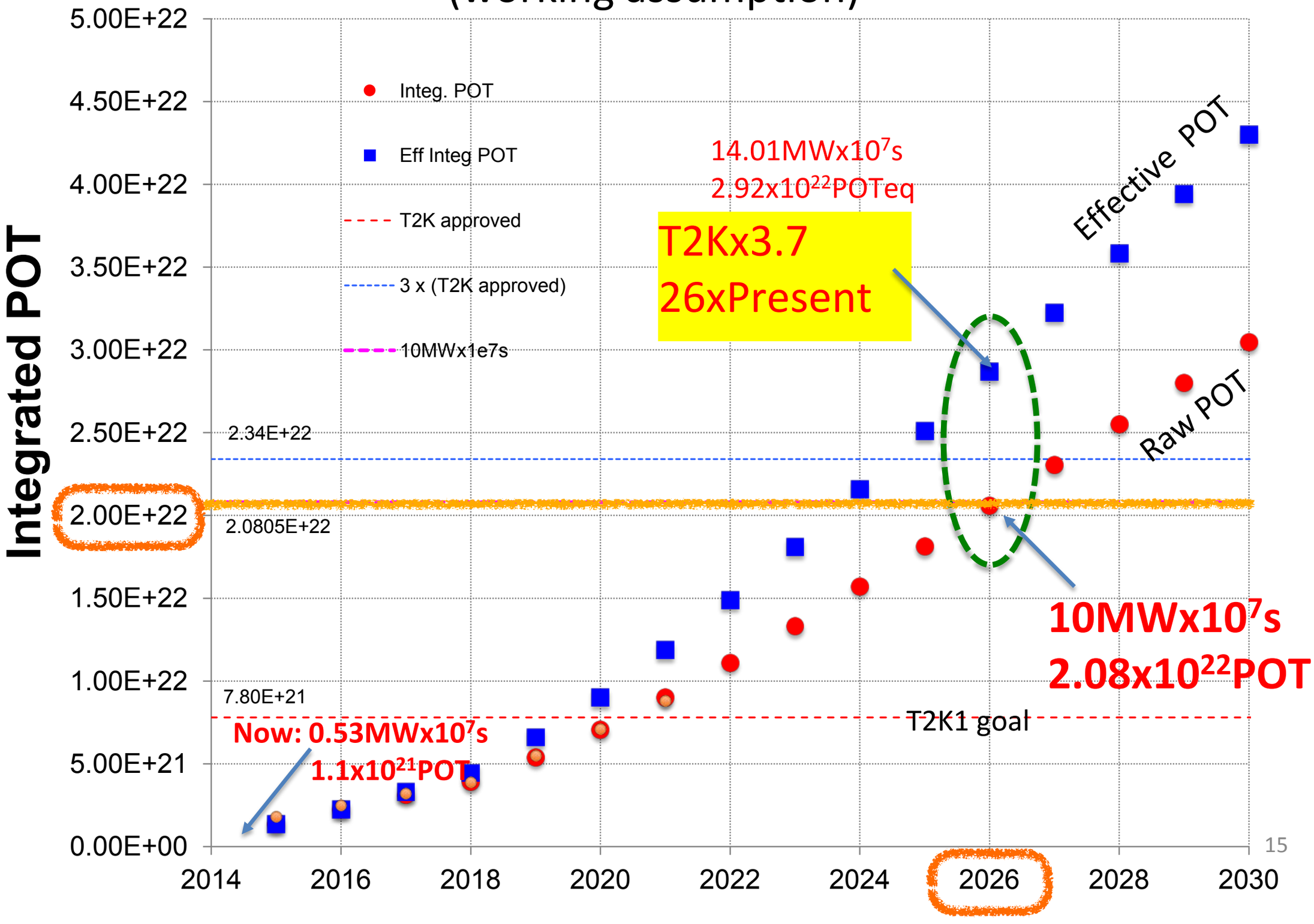
by T. Sekiguchi at HINT2015

Improved Acceptable Beam Power

Conponent	Limiting factor	Acceptable value
Target	Thermal shock	3.3×10^{14} ppp
	Cooling capacity	>1.5 MW
Horn	Conductor cooling	2 MW
	Stripline cooling	>1.25 MW
	Hydrogen production	>1 MW
	Operation	1 sec. & 320 kA
He Vessel	Thermal stress	4 MW
	Cooling capacity	>1.5 MW
Decay Volume	Thermal stress	4 MW
	Cooling capacity	>1.5 MW
Beam Dump	Thermal stress	3 MW
	Cooling capacity	>1.5 MW
Radiation	Radioactive air disposal	>1 MW
	Radioactive water	0.75→1.3 or 2 MW

Integrated POT projection

(working assumption)



T2K Prospect

- T2K will collect the proposed POT (7.8E21) data by around 2020 when J-PARC could provide ~1MW beam.
- Why won't we use the high power (>1MW) beam of J-PARC after 2020? [NOTE] Hyper-K and/or DUNE will start beam data taking for CPV after 2025.
- **The proposal of T2K extension (T2K-II) is seriously discussed/considered now.**
  - Before 2025, J-PARC could provide 20E21 POT to T2K with 1.3 MW beam power, by which we have 3σ CPV discovery sensitivity for $\delta_{CP}=-\pi/2$.
  - By improving the T2K efficiency, we may count the effective POT as 25E21.

by M. Friend at Neutrino Workshop in J-PARC

- http://www-conf.kek.jp/ws_nu_prog_in_jp/

T2K Sensitivities at 25×10^{21} POT

M. Friend

KEK

August 5, 2015

Nominal Assumptions

The following were used in these studies unless otherwise stated:

- Joint fit of $\nu_e + \nu_\mu + \bar{\nu}_e + \bar{\nu}_\mu$
  - Fit to the Asimov (nominal) data-set – not the average of an ensemble of toy experiments
- True oscillation parameters: $\sin^2 2\theta_{13} = 0.1$, $\delta_{CP} = -90°$, $\sin^2 \theta_{23} = 0.5$, $\Delta m^2_{32} = 2.4 \times 10^{-3}$ eV^2, normal mass hierarchy
  - $\sim$ T2K, global best fit values
  - All four of these oscillation parameters are fit
- 5% error constraint on $\sin^2 2\theta_{13}$ from external (reactor) experiments (conservative "ultimate expected error")
- $\sim$2% systematic errors – see next slide
  - Fully correlated between ν- and $\bar{\nu}$-mode
- $\pm$250 kA horn current
- Assuming enhanced π0 rejection using SK fiTQun π0 cut
- See: Prog. Theor. Exp. Phys. (2015) 043C01 (T2K future sensitivity paper) for details about the fit procedure

Highlighted points are studied here

Statistics at 7.8×10^{21} and 25×10^{21} POT

		ν_e signal	ν_e bkg.	$\bar{\nu}_e$ signal	$\bar{\nu}_e$ bkg.
7.8E21 POT	$\delta = 0$	98.2	26.8	25.6	16.3
	$\delta = -90°$	121.4	26.4	19.0	17.2
25E21 POT	$\delta = 0$	314	85.9	82.1	52.2
	$\delta = -90°$	389	84.6	60.9	55.1

300~400 $\nu_\mu \rightarrow \nu_e$

60~80 $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$

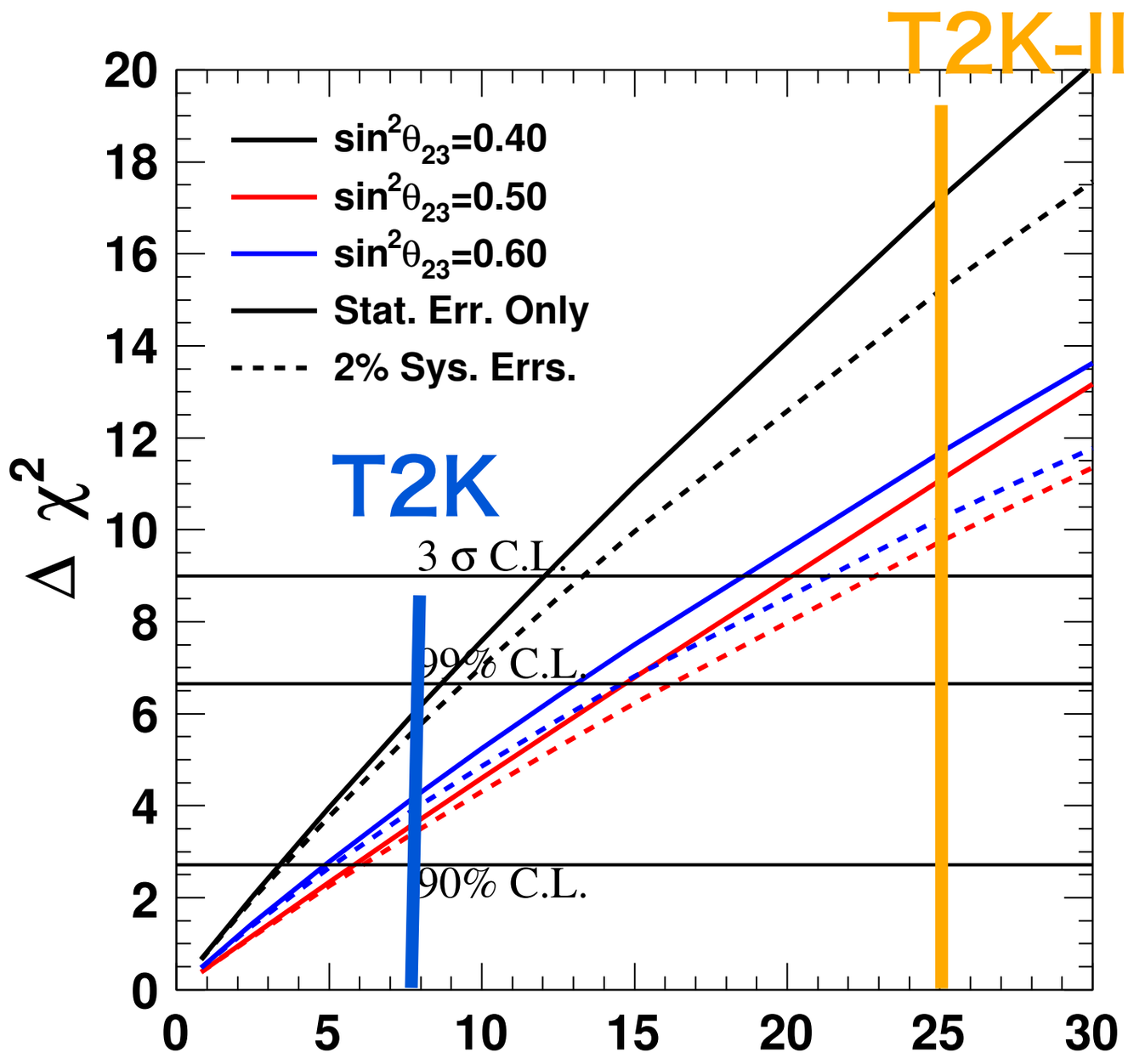
* bkg includes wrong-sign

		ν_μ-mode	$\bar{\nu}_\mu$-mode
7.8E21 POT	w/o oscillation	2,648	1,007
	w/ oscillation	741	342
25E21 POT	w/o oscillation	8,519	3,228
	w/ oscillation	2,375	1,096

50% ν- + 50% $\bar{\nu}$-mode

$\Delta\chi^2$ for resolving non-zero δ_{CP} vs. POT

50% ν- + 50% $\bar{\nu}$-mode

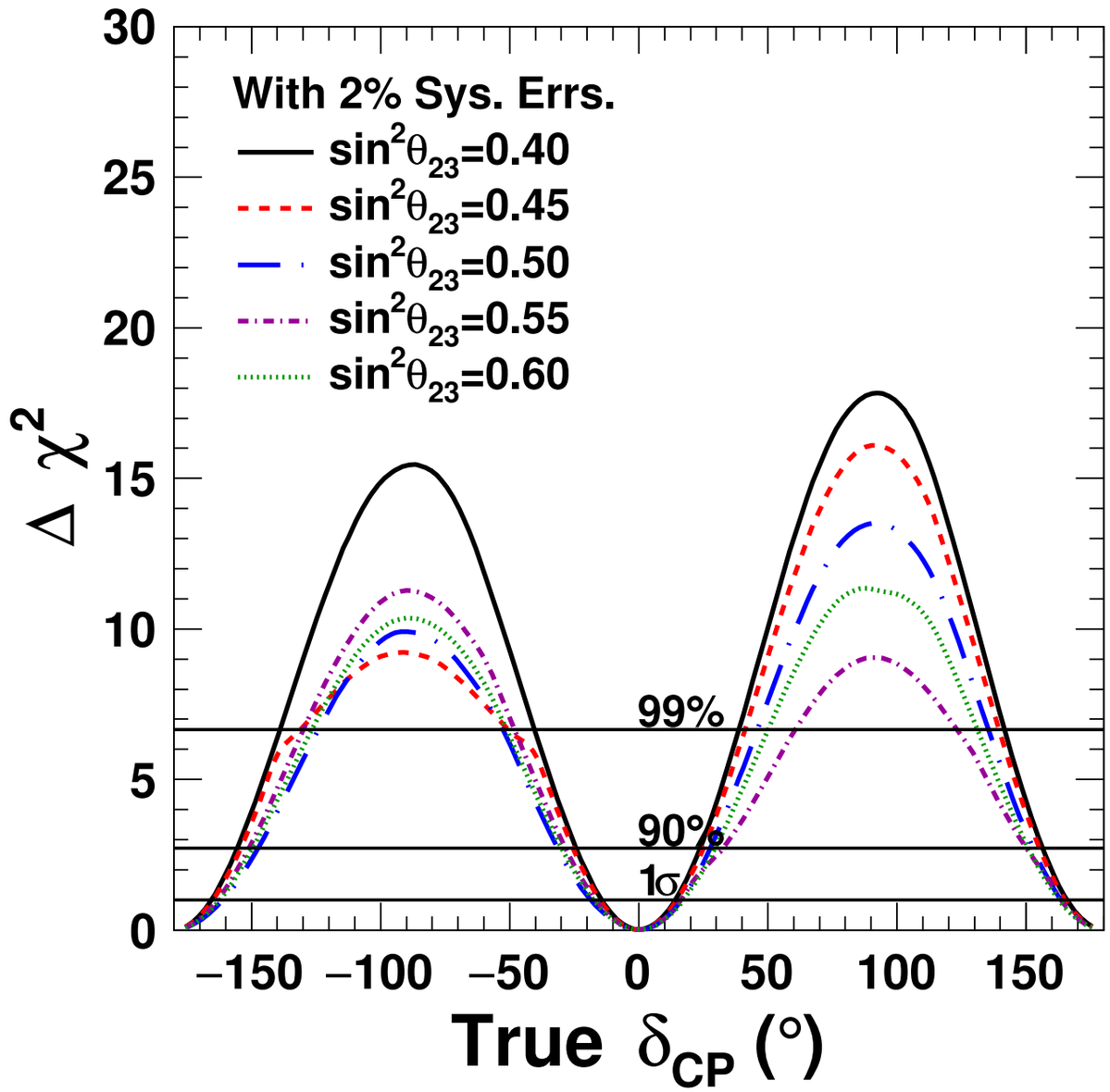


50% ν- + 50% $\bar{\nu}$-mode

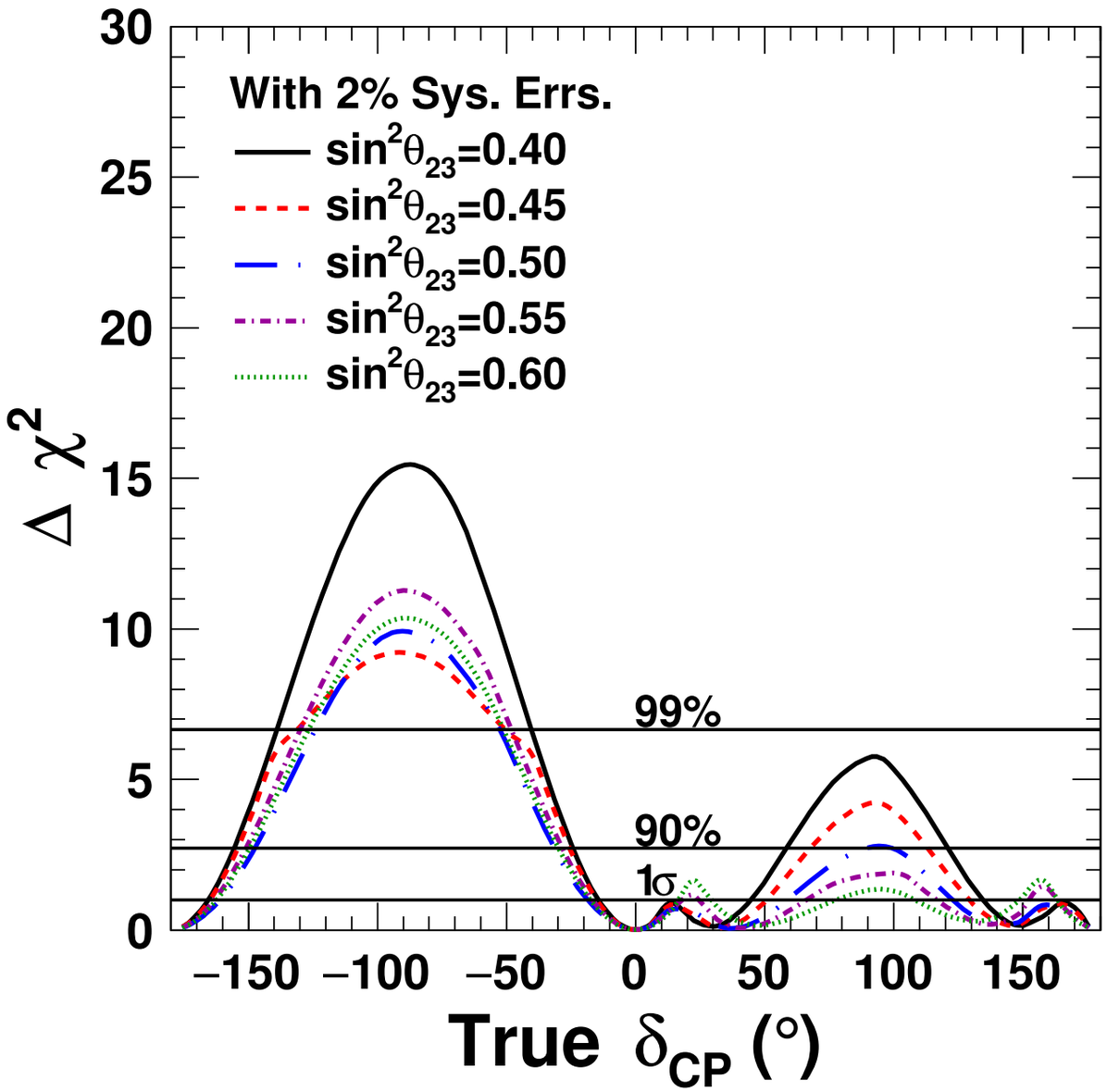
True $\delta_{CP} = -90°$, true MH = NH

δ_{CP} sensitivity vs. true δ_{CP} w/ MH

Known MH



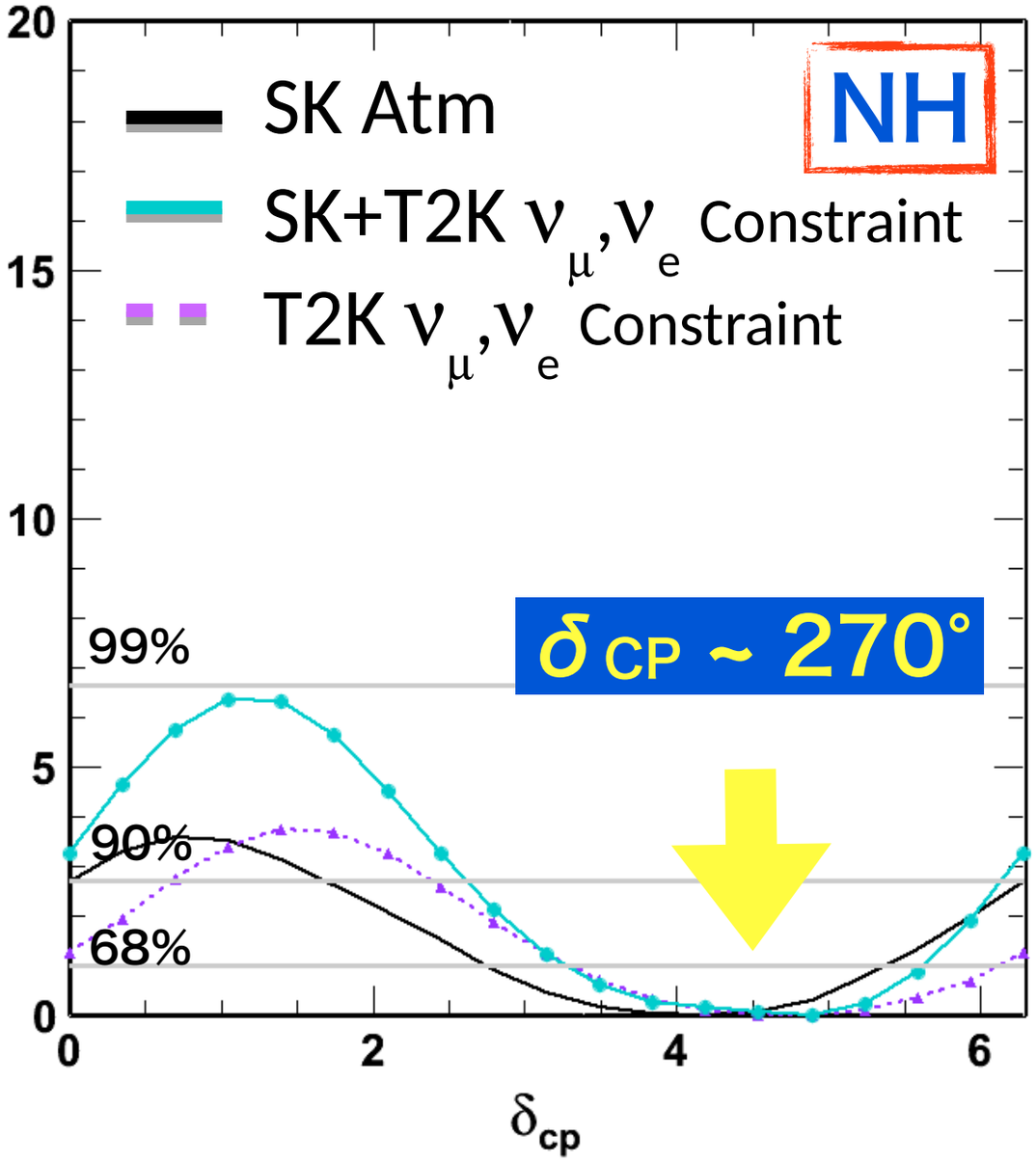
Unknown MH

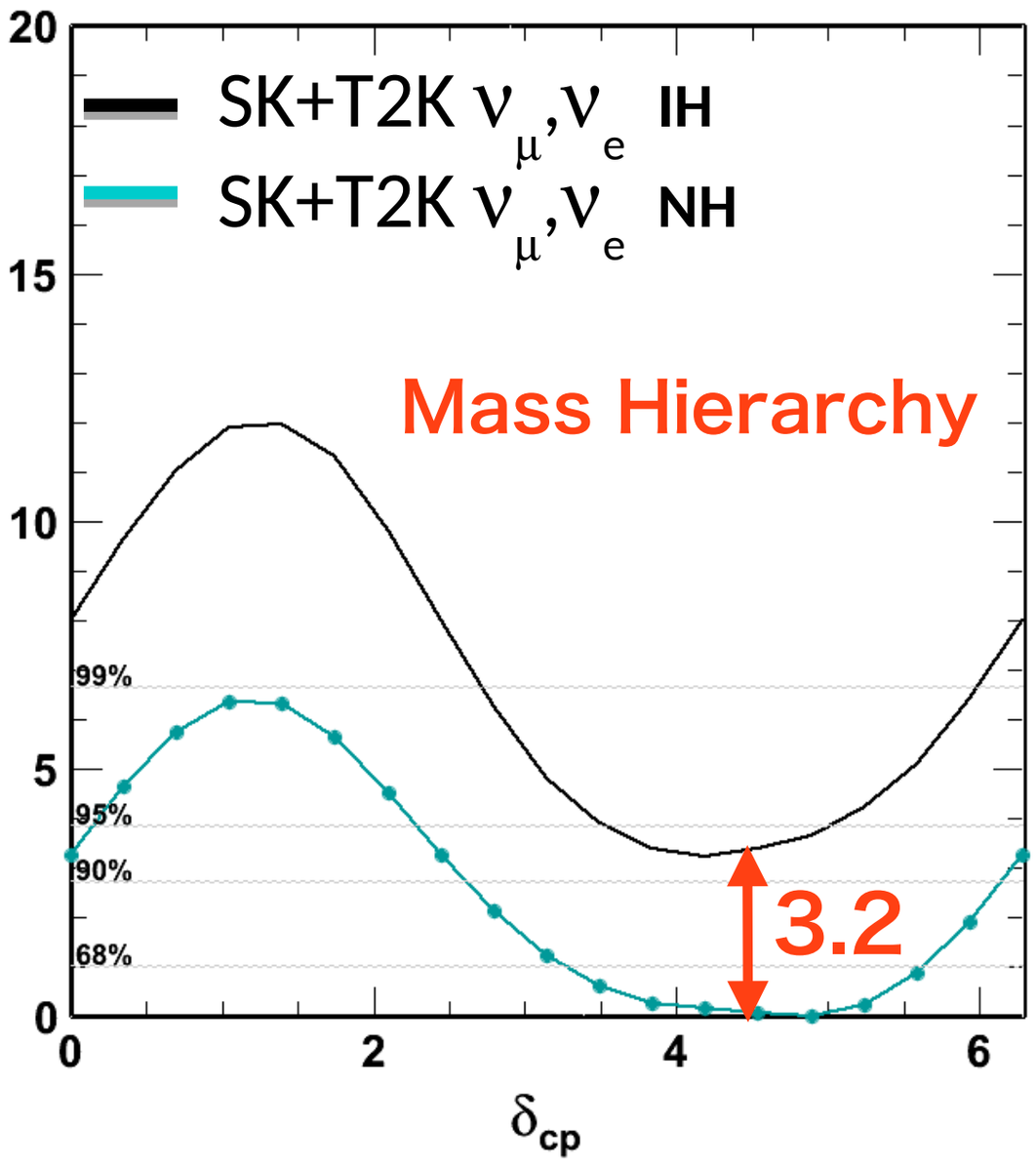


- 99% (3σ) CPV sensitivity for 45% (30%) δ_{CP} region

Current CPV and MH constraint

- Shall we know MH before T2K-II has the final sensitivity (2026)?
  - I think so. T2K and Super-K atm-ν results with reactor θ_{13} put a constraint on CPV and MH. The new NOvA result looks also prefer NH.





$\chi^2_{NH} - \chi^2_{IH} =$ **-3.2** (SK Only -3.0,

T2K-II

- Utilize the high power of J-PARC (**>1MW**) and the T2K beam line with upgrade toward **20E21 POT**.
- Utilize the existing big far detector Super-K (**22.4 kton fiducial**) with upgrade.
- The T2K Near detector can be upgraded for T2K-II (under discussion) to improve the systematics.
- A new intermediate detector could be proposed to improve the systematics (if budget is available)
- Address many physics subjects in addition to standard PMNS CPV.
  - A new source of CPV in neutrinos
  - Determination of oscillation parameters
  - New physics (sterile, Lorentz Vioation, CPT, etc..)
  - Neutrino-Nucleus cross sections

Summary

- We enter the new era to study neutrino CPV by measuring $\nu_\mu \to \nu_e$ and $\overline{\nu}_\mu \to \overline{\nu}_e$.
- T2K-II with 1.3 MW beam can reach 3σ CPV discovery before 2026 when Hyper-K and DUNE/LBNF start.
- T2K-II will provide a positive impact to Hyper-K because the 1.3MW neutrino beam will be ready at the day 1 of Hyper-K (The current Hyper-K LOI is based on the 0.75 kW beam power).