150815
Nufact15
Rio de Janeiro

Future Accelerator-based Neutrino Physics in Asia

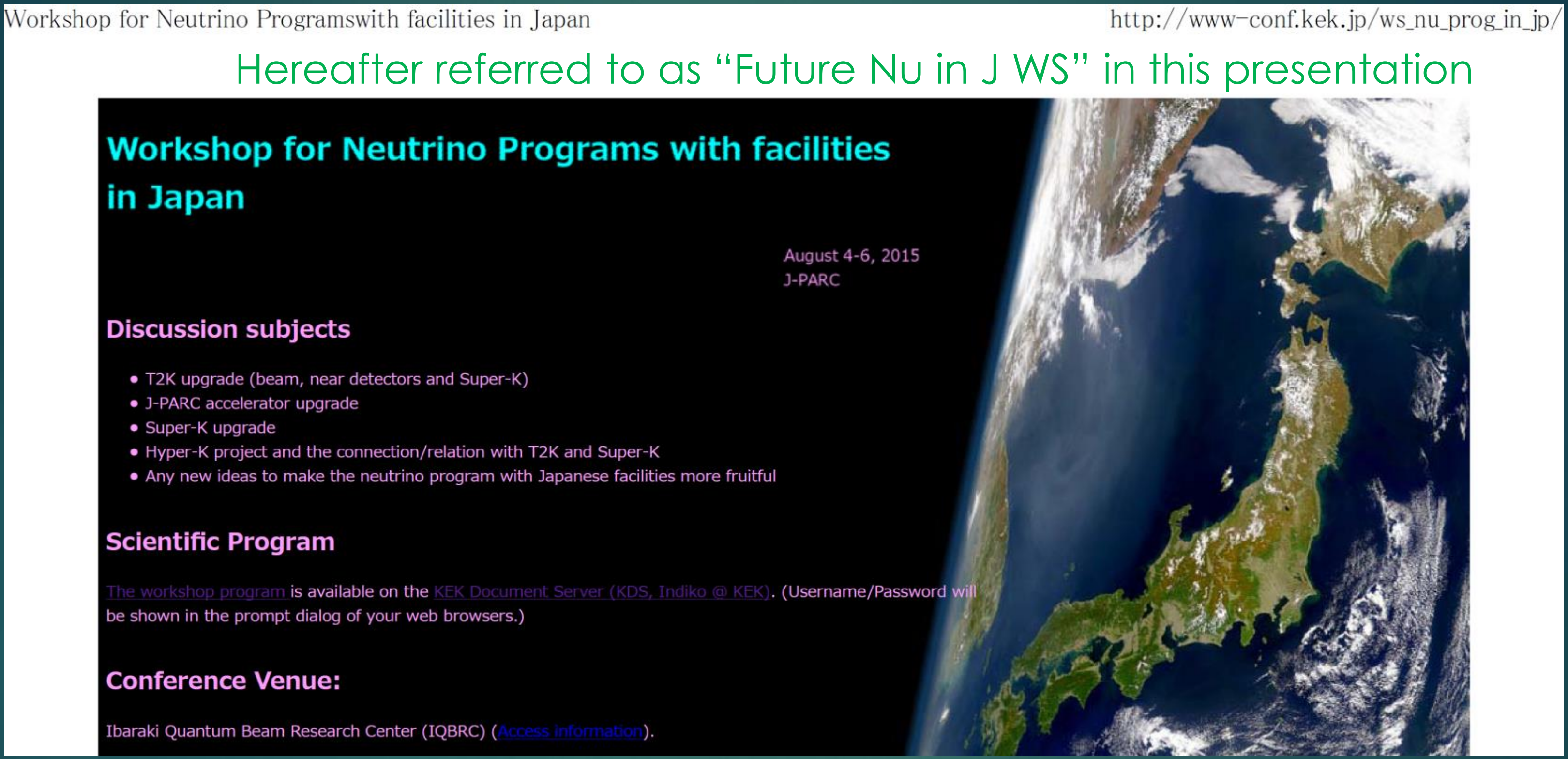
TAKASHI KOBAYASHI
KEK/J-PARC

35+5 min talk

Contents

- Japan-based experiments
  - J-PARC accelerator status and future prospect
  - T2K future
  - HK
  - Extended T2K
- Asian activities and ideas
  - Indian activity
  - Chinese idea
  - Korean idea

Workshop for neutrino programs with facilities in Japan
Aug.4-6, 2015, J-PARC


Workshop for Neutrino Programswith facilities in Japan http://www-conf.kek.jp/ws_nu_prog_in_jp/

Hereafter referred to as “Future Nu in J WS” in this presentation

Workshop for Neutrino Programs with facilities in Japan

August 4-6, 2015
J-PARC

Discussion subjects

- T2K upgrade (beam, near detectors and Super-K)
- J-PARC accelerator upgrade
- Super-K upgrade
- Hyper-K project and the connection/relation with T2K and Super-K
- Any new ideas to make the neutrino program with Japanese facilities more fruitful

Scientific Program

The workshop program is available on the KEK Document Server (KDS, Indiko @ KEK). (Username/Password will be shown in the prompt dialog of your web browsers.)

Conference Venue:

Ibaraki Quantum Beam Research Center (IQBRC) (Access information).

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

- Main goal of my talk on the program in Japan is to digest discussion in this workshop

Accelerator neutrino program in Japan

- Toward understanding of whole picture of neutrino mixings and masses
  - Precision measurements of oscillation → testing 3x3 PMNS picture
  - Determination of CPV phase
  - Contribution to mass hierarchy determination
  - Search for new phenomena
    - Sterile, Lorentz invariance violation, NSI, etc

  To attack big questions in particle physics, such as Quark-Lepton unification, origin of matter dominated universe, etc
- by international collaboration
- Under the global context of coherent/competitive efforts
- using
  - J-PARC proton beam with increasing beam power
  - Super-K → Hyper-K at ~300km

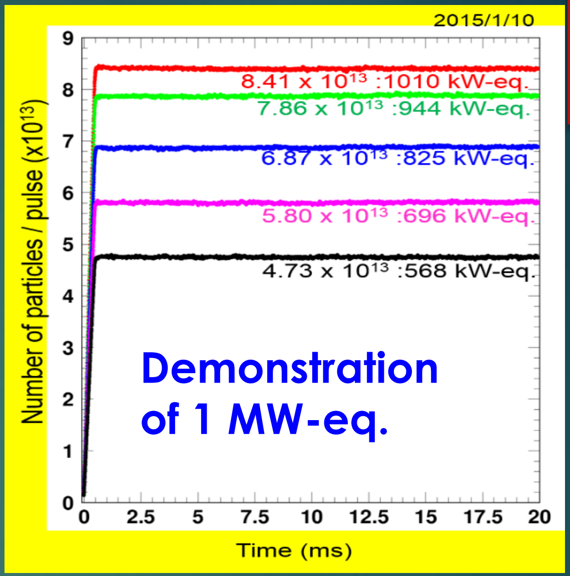
J-PARC accelerator status and prospects


Japan Proton Accelerator Research Complex : J-PARC
J-PARC Facility (KEK/JAEA)
South to North
181MeV Linac ➔400MeV
3 GeV RCS
Neutrino Beams (to Kamioka)
Materials and Life Experimental Facility
Design intensity
RCS for MLF: 1MW
MR for PN : 750kW
30GeV MR
Hadron Exp. Facility
JAEA
KEK
60km
TOKYO
NARITA
CY2007 Beams
JFY2008 Beams
JFY2009 Beams
Bird's eye photo in January of 2008

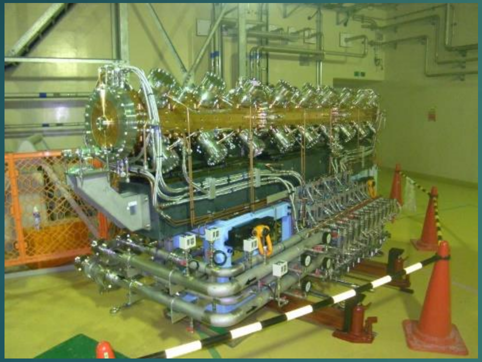
Accelerator status

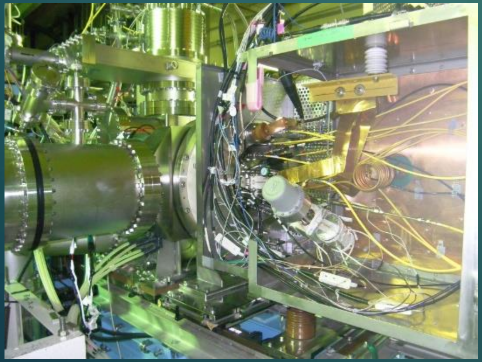
- Recent upgrades
  - LINAC energy is upgraded from 181MeV to design 400MeV in 2013
  - LINAC frontend (Ion source, RFQ) upgraded from 30mA → 50mA in 2014
  - MR inj collimator capacity increased
  - MR RF → introducing FT3L new cores for higher acc grad/higher harmonic.

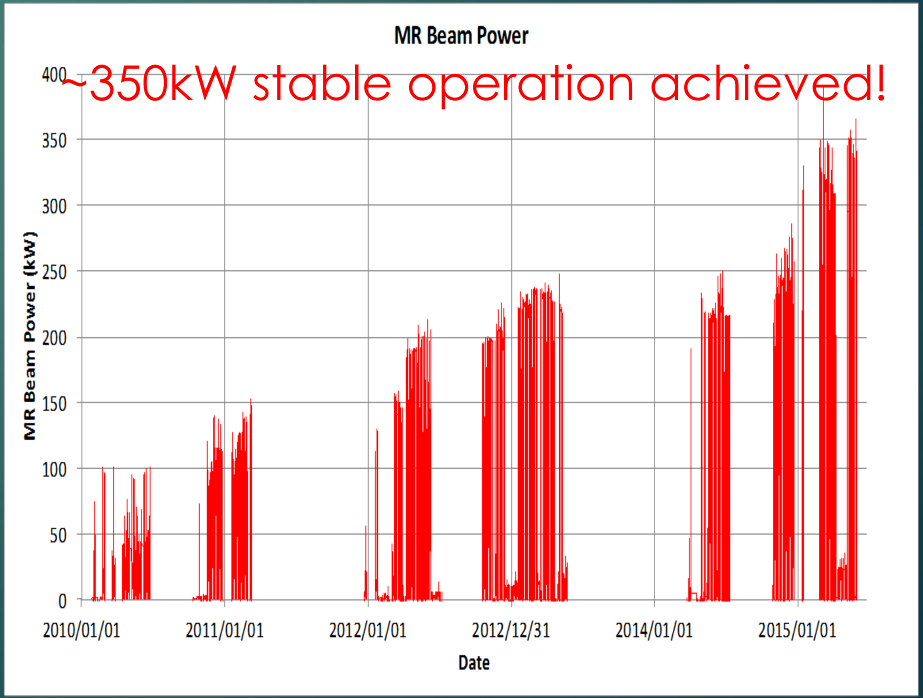
3GeV-RCS



To provide stable 1MW beam for user, reinforcement of the anode power supplies of the rf power amplifiers is being done in 2015 summer shutdown periods.



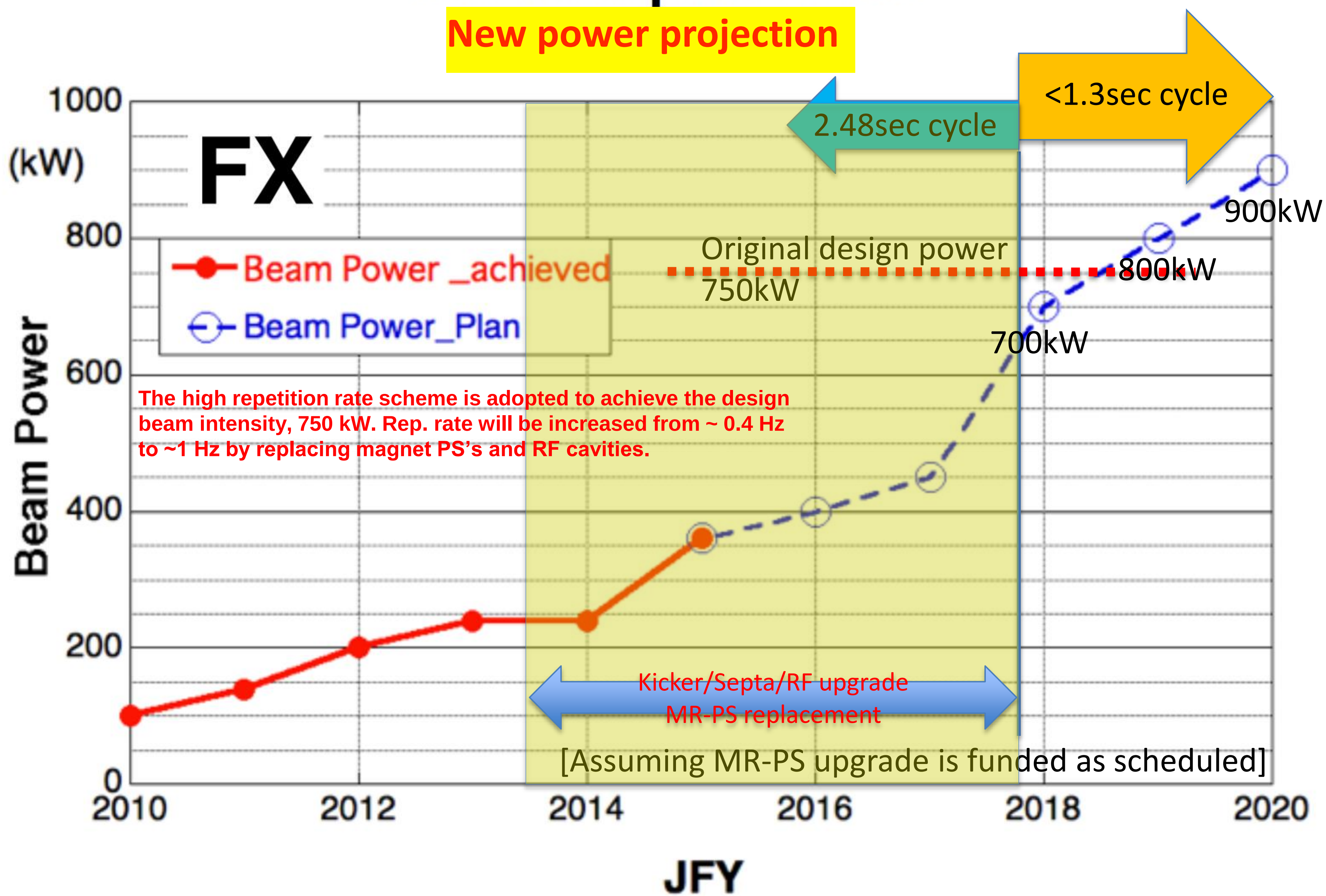




Path toward >750kW

- **Higher #p/bunch**
  - **LINAC upgrade** → Enable RCS operation upto 1MW
    - 400MeV (2013)
    - Frontend (Ion source, RFQ) 30→50mA (2014)
  - **Reduce beam loss in MR**
    - MR RF higher harmonic (2013-2017)
    - BxB/Intra bunch feedback (installed)
    - Injection kicker pulse shape correction (2014-2015)
  - **Increase MR collimator capability**
    - → 3.5kW loss
- **Higher rep late (2.48s → ~1s, x2)**
  - **Replace MR magnet PS** : plan 2016-2018
  - **High gradient RF core** (2013-2017):R&D

Mid-term plan of MR

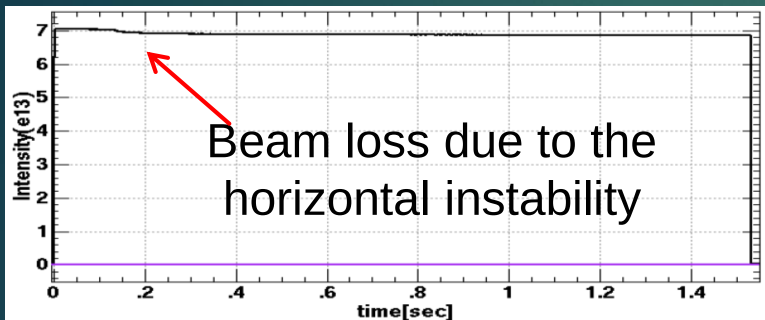


High Intensity beam study in MR

June, 2015
New!

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

High power trial with two bunches



Extracted beam : 6.82e13 ppp (132 kW eq.)

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

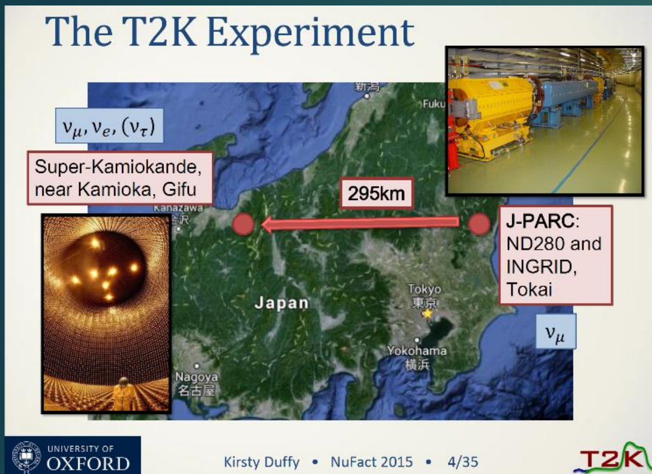
Became possible to aim beyond 750kW

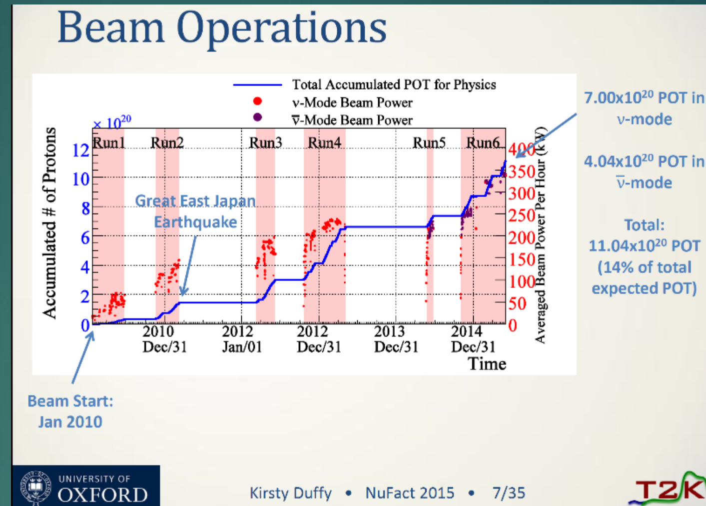
...oss:
Injection kicker improvement, BxB feed back,
2nd harmonic cavity, VHF cavity, etc.

	Bunch number	repetition period (sec)	Beam power (kW)	Beam loss (kW)	Notes
1	2	2.48	132	0.42	measurement
2	8	2.48	530	1.7	estimation
3	8	1.3	1000	3.2	estimation

Present experiment: T2K

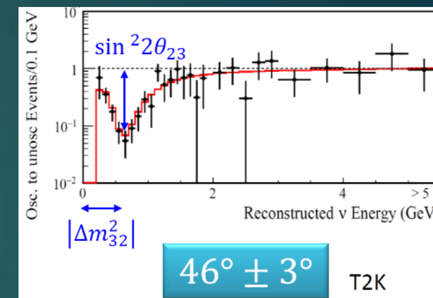
T2K latest achievements

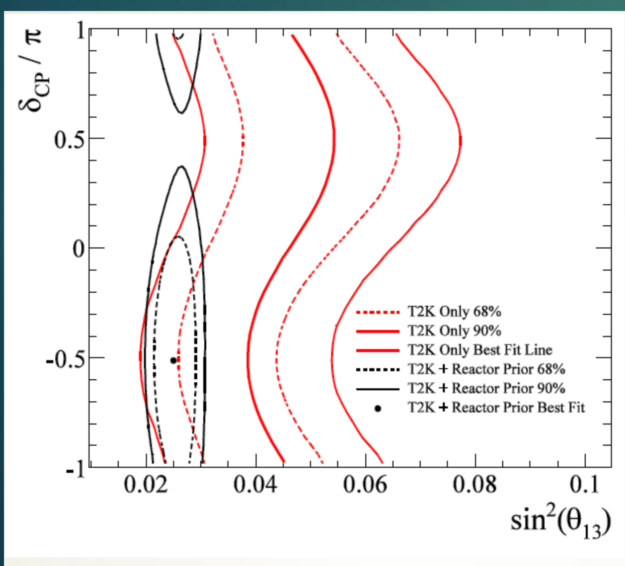




Stable operation at **345kW**

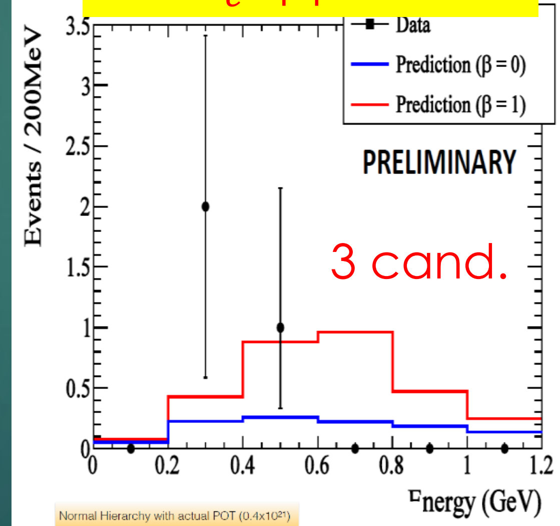
Maximum beam power: **371kW**





Start measuring CPV phase

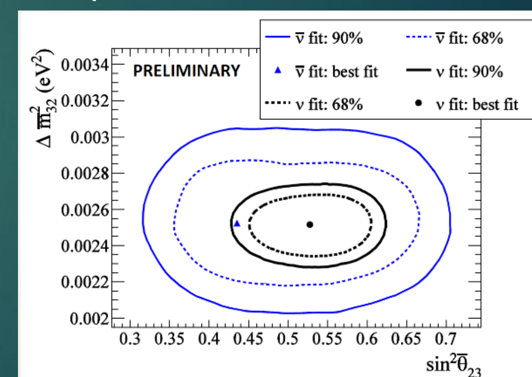
First $\overline{\nu}_e$ app search



Normal Hierarchy with actual POT (0.4x10^21)

Expected events (NH)	$\delta_{CP} = -\pi/2$	$\delta_{CP} = 0$	$\delta_{CP} = +\pi/2$
Signal $\bar{\nu}_\mu \to \bar{\nu}_e$	1.961	2.636	3.288
Background $\nu_\mu \to \nu_e$	0.592	0.505	0.389
Background NC	0.349	0.349	0.349
Background other	0.826	0.826	0.826
Total	3.73	4.32	4.85

$\overline{\nu}_\mu$ disapp. meas.



Best fit values: $\sin^2\overline{\theta}_{23} = 0.46^{+0.14}_{-0.06}$

$\Delta\overline{m}^2_{32} = 2.50^{+0.3}_{-0.2} \times 10^{-3} eV^2$

Start world leading meas.

T2K future

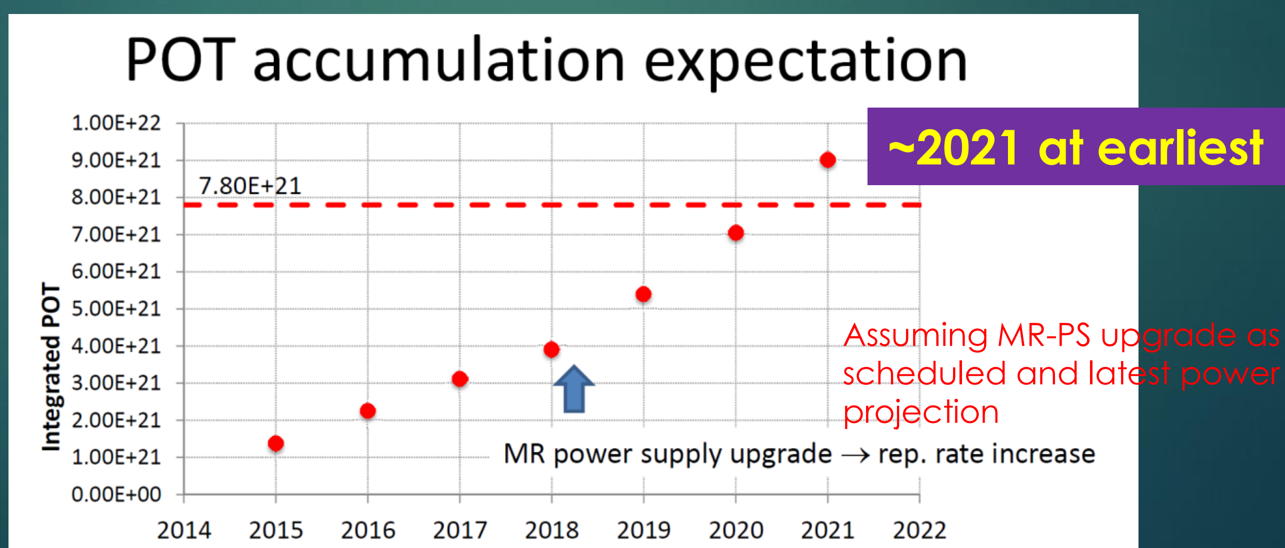
- Will accumulate $\mathbf{7.8 \times 10^{21} \mathit{POT}}$ (750kW x 5 "year") (7xnow)
  - With similar amount of POT for ν and $\bar{\nu}$
- Updated physics goals after ν_e appearance discovery
  - Precision measurements of ν_μ disappearance
    - $\delta(\sin^2\theta_{23})$~±0.05 ~ $\delta(\sin^2 2\theta_{23})$~0.01, $\delta(\Delta m_{23}^2)$~ <10^{-4}eV^2
  - Precision measurements of ν_e appearance
    - Syst err ~ 5% (~10%) for ν ($\bar{\nu}$)
  - **Measurement of CPV phase δ**
  - Contribution to mass hierarchy determination
  - Cross section measurements
  - New physics search (NSI, etc)

PTEP

Prog. Theor. Exp. Phys. **2015**, 043C01 (36 pages)
DOI: 10.1093/ptep/ptv031

Neutrino oscillation physics potential of the T2K experiment

Prog. Theor. Exp. Phys. (2015) 043C01
doi: 10.1093/ptep/ptv031
April 1, 2015



Expected T2K sensitivities

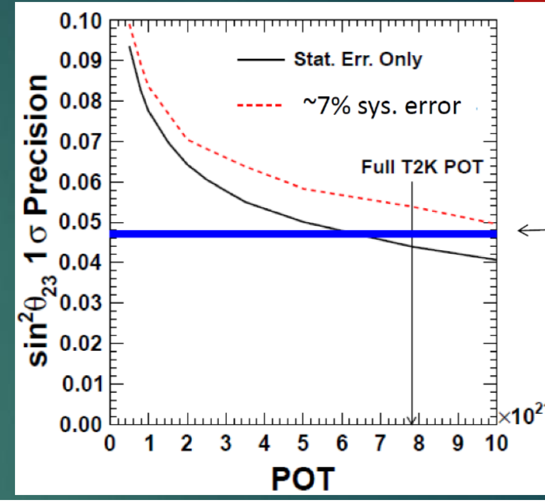
ν_e appearance sample

* 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
$\delta = -90°$	121.4	26.4	19.0	17.2

ν_μ disappearance sample

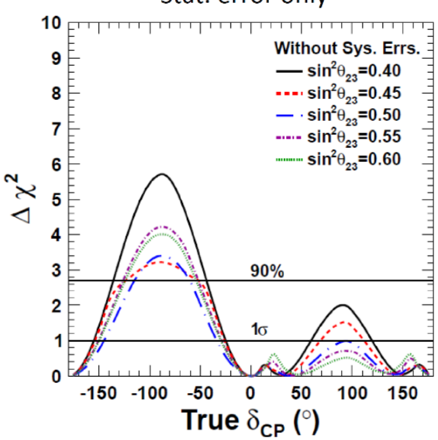
	ν_μ-mode	$\bar{\nu}_\mu$-mode
w/o oscillation	2,648	1,007
w/ oscillation	741	342



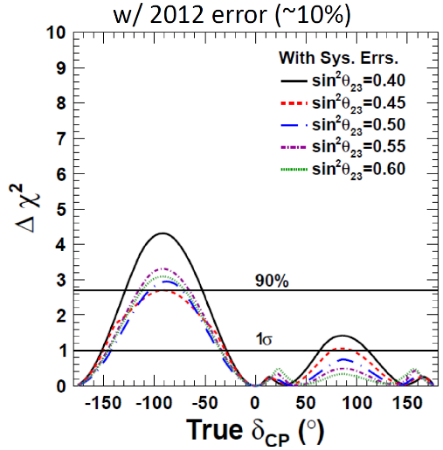
Sensitivity to CP violation at 7.8E21 POT

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

Stat. error only



w/ 2012 error (~10%)

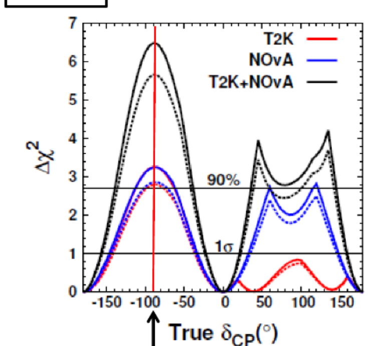


T2K has > 90% C.L. sensitivity if $\delta_{CP} = -90°$

combining w/ NOvA

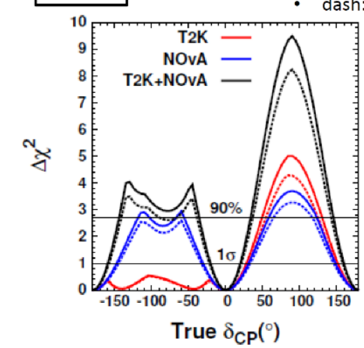
- $\sin^2\theta_{23} = 0.5$
- solid : stat. only
- dash: 5% sys. error

NH case



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

IH case

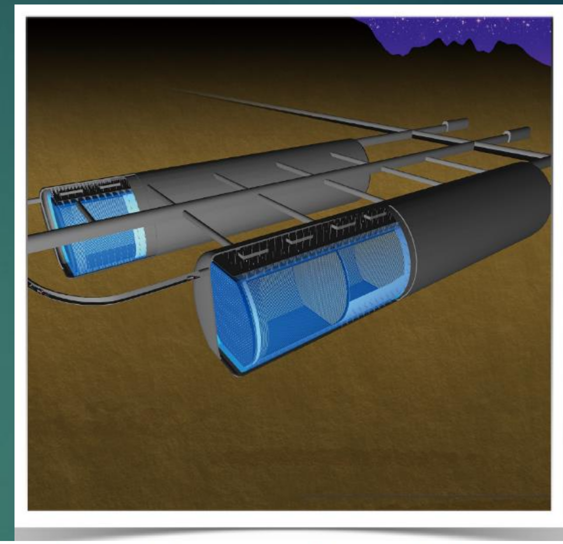


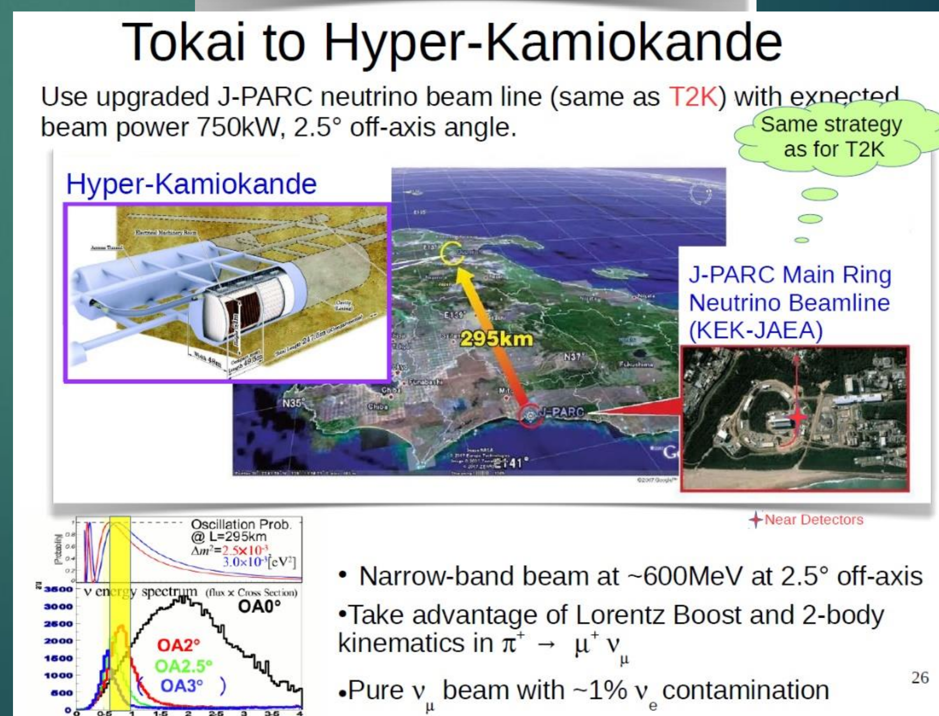
- Both competition and cooperation with NOvA are really important.
- combination w/ SuperK etc. would also enhance the sensitivity

Next generation experiment: J-PARC to Hyper-Kamiokande

Hyper-Kamiokande

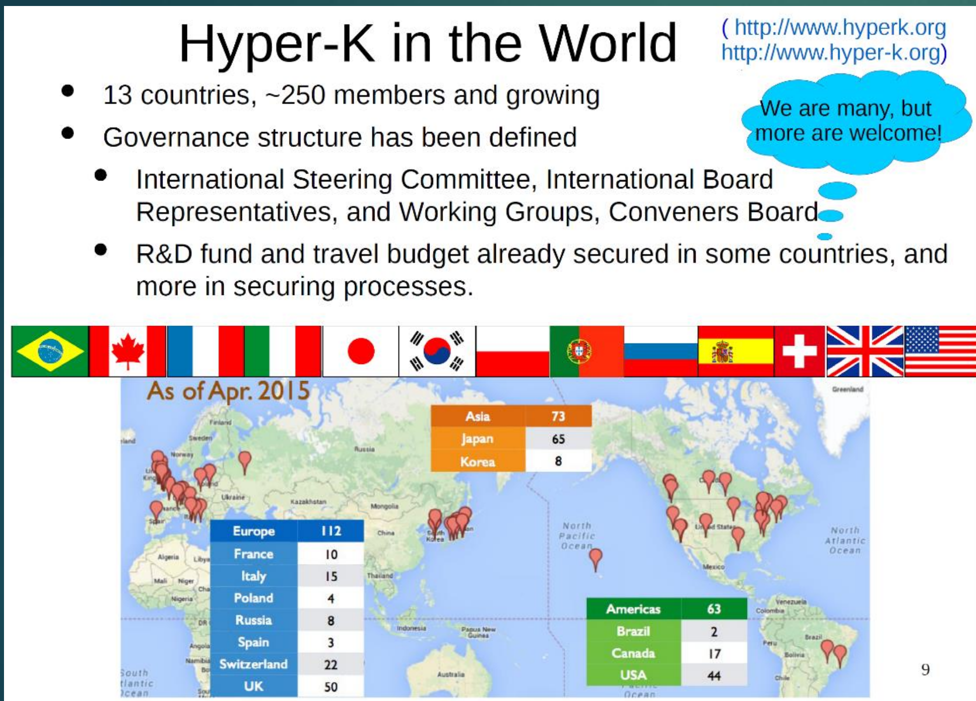
- Next-generation gigantic multi-purpose detector
  - 560kt fiducial mass
  - 20% photo-coverage with 99k 20-inch PMTs
- Physics
  - Neutrino oscillation
    - Accelerator based LBL
    - Atmospheric nu
    - Solar nu
    - ..
  - Proton decay
  - Astrophysics neutrinos
    - Supernova, SRN, dark matter, etc

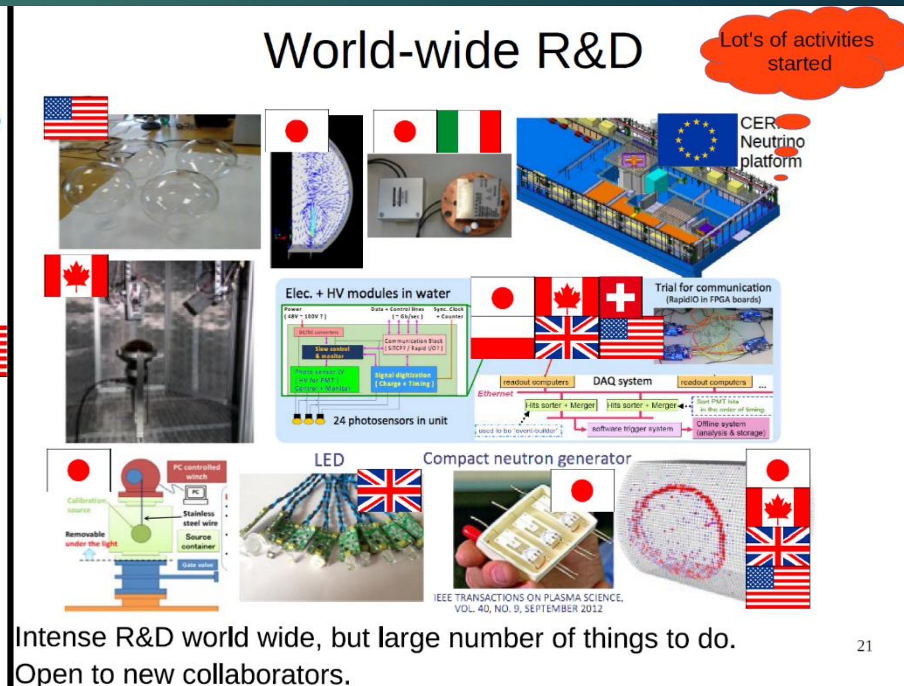




F. Di Lodovico,
Future Nu in J WS

International collaboration on Hyper-K





Recent news

Hyper-K Proto-Collaboration

Inaugural Symposium, Kashiwa, January 31, 2015

KEK-IPNS and UTokyo-ICRR signed a MoU for cooperation on the Hyper-Kamiokande project.

Important moment.
The proto-collaboration is born.

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First Meeting of the proto-collaboration: June 29-July 1, @Kashiwa

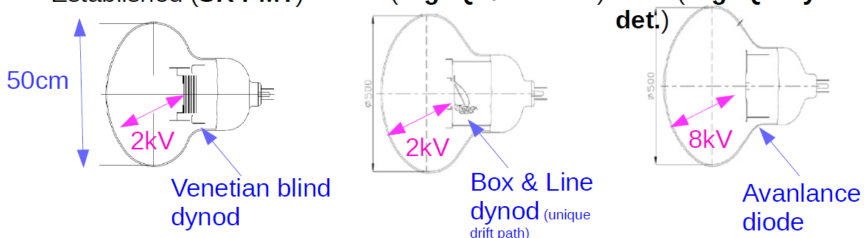
F. Di Lodovico,
Future Nu in J WS

PMT R&D

Photosensors Candidates

R&D going to get better performance and lower costs

Established (**SK PMT**) | R&D (**HighQE/CE PMT**) | R&D (**HighQE hybrid det.**)



	SK PMT	HighQE/CE PMT	HighQE hybrid det.
Quantum Eff. (QE)	22%	30%	30%
Collection Eff. (CE)	80%	93%	95%
Timing resol (FWHM)	5.5 nsec	2.7nsec	1nsec
	Super-K ID PMTs Used for ~20 years →Guaranteed Complex production → Expensive	Under development Better performance Same technology → Lower risk	Under development Far better performance Simple structure →Lower cost New technology →Higher risk

Ongoing tests in EGADS

Photosensors covered by protective case (currently under R&D)

Lower Risk ↔ Higher Performance

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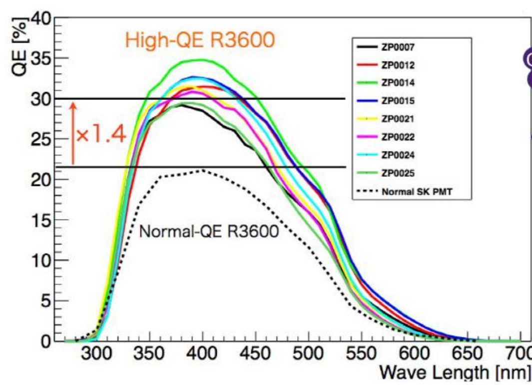
High QE achieved



Great improvement

- High Quantum Efficiency (QE) of ~30% has been achieved ! for 50cm B&L PMT and HPD
- Current studies open to other photo-sensor options as well to achieve a better performance and/or reduced cost

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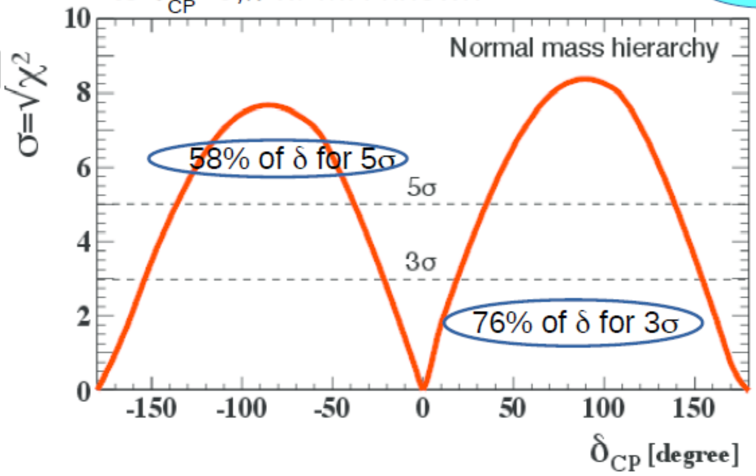
- Great improvement achieved
  - x1.4 higher QE

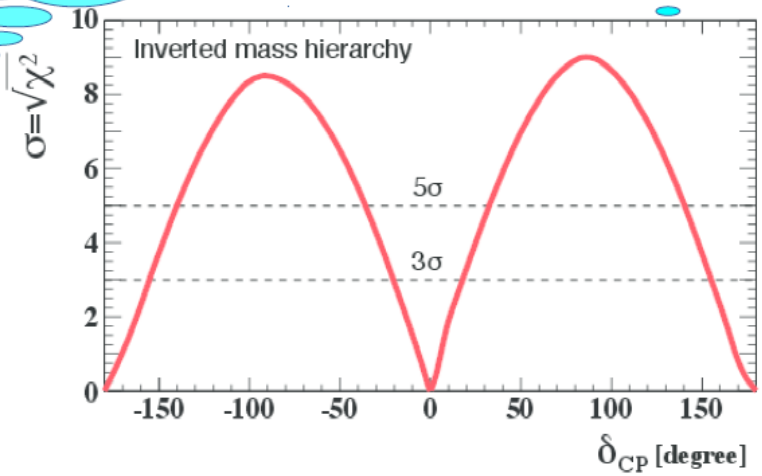
Hyper-K Sensitivity to δ_{CP}

Will improved with updated errors

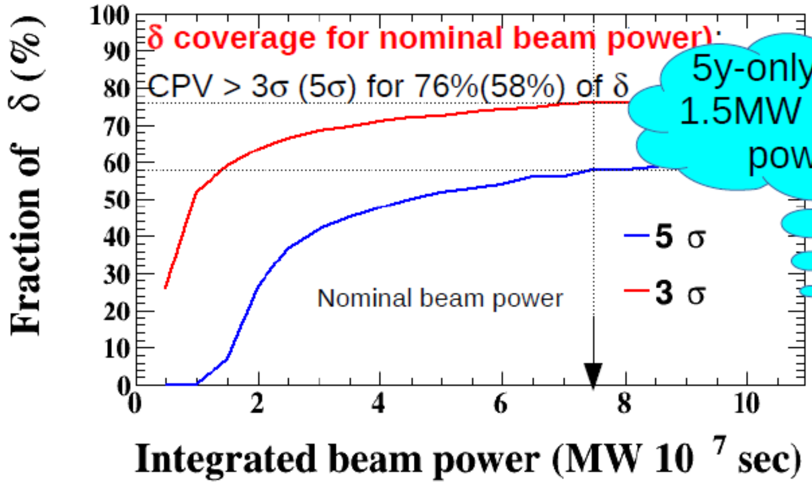
Assume MH is known

CPV discovery sensitivity
to δ_{CP}=0,π w/ MH known



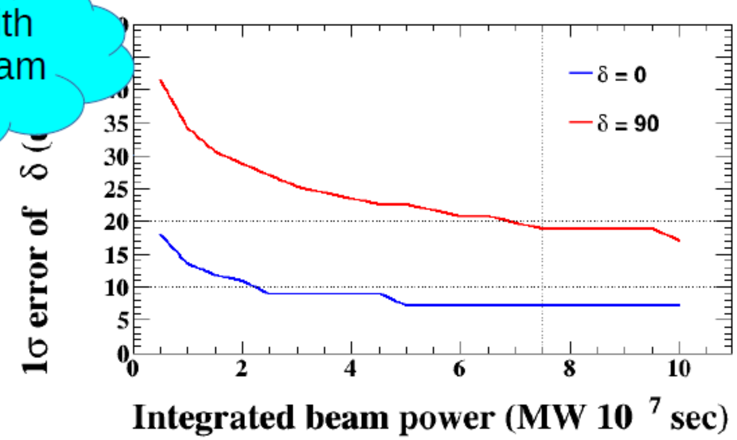


Fractional region of δ(%) for CPV (sin δ ≠0) > 3,5 σ



5y-only with 1.5MW beam power

1σ uncertainty of δ as a function of the beam power: < 19°(6°) for δ = 90°(0°)



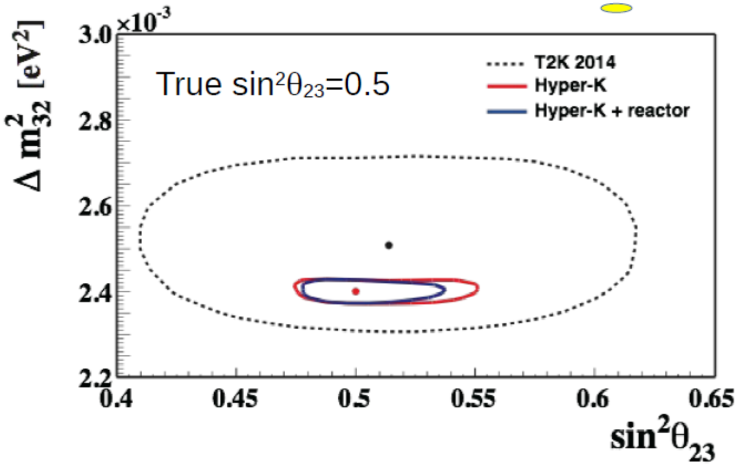
F. Di Lodovico, Future Nu in J WS

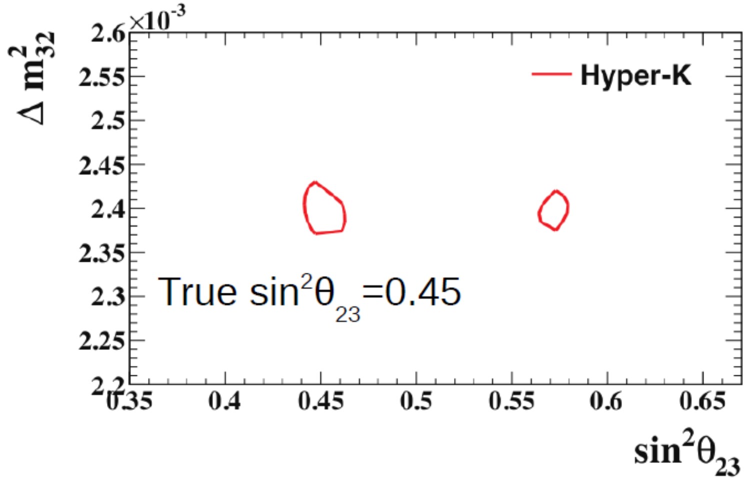
Sensitivity to θ_{23} and Δm^2_{23}

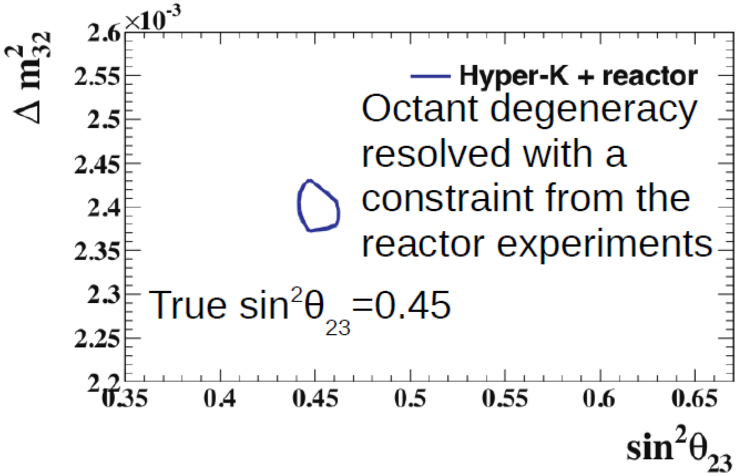
Important combination with reactors

- $\sin^2 2\theta_{23}$ and Δm^2_{23} free parameters as well as $\sin^2 2\theta_{13}$ and δ_{CP} in the fit.
- Octant resolution w/ reactor θ_{13}: ~3σ wrong octact rejection for $\sin^2\theta_{23}$<0.46 or >0.56

True $\sin^2\theta_{23}$	1σ err $\sin^2\theta_{23}$	1σ err Δm^2_{23} (10^{-5}eV^2)
0.45	0.006	1.4
0.50	0.015	1.4
0.55	0.009	1.5





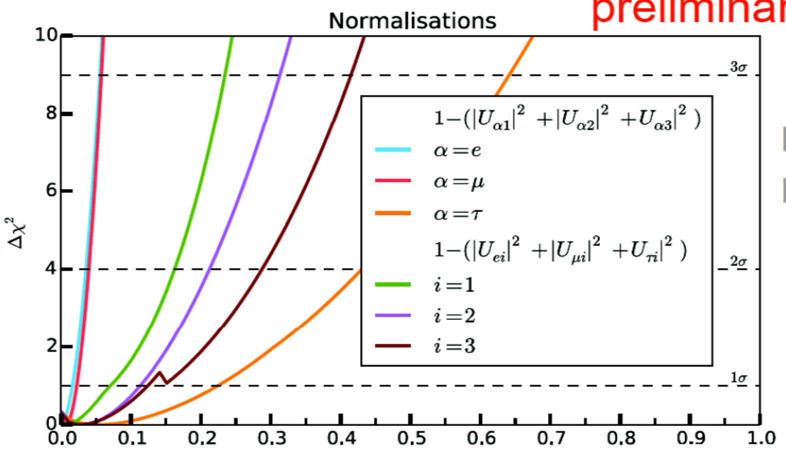


R. Wendell (ICRR)
Future Nu in J WS

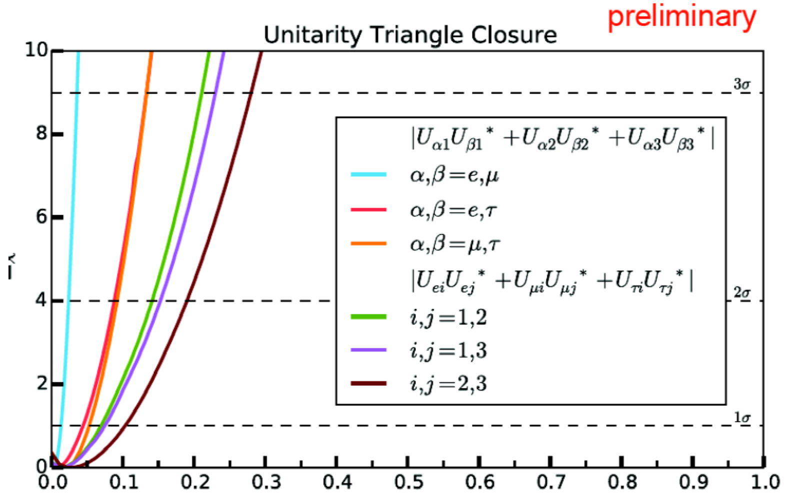
Physics after CPV were found

Global Study of Leptonic Unitarity

Plots from S.Parke@WIN15



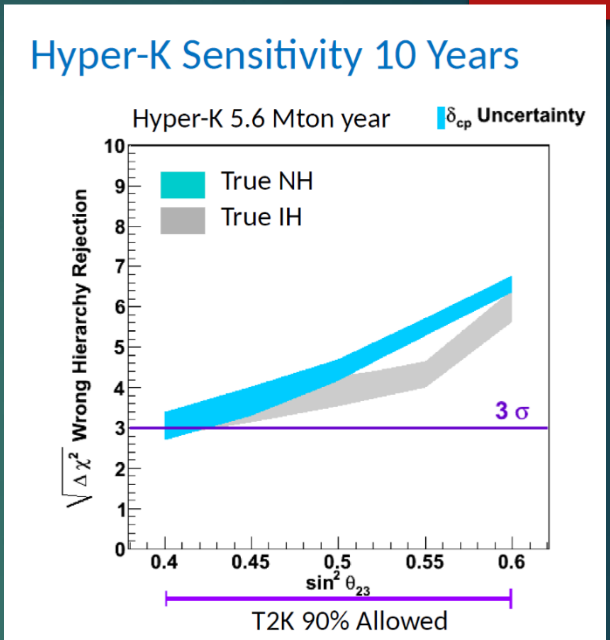
- Hyper-K Beam + Atmospheric measurements:
- Contribute to normalizations
  - α = μ (red line)
  - α = τ (orange line)
  - i = 3 (brown line)

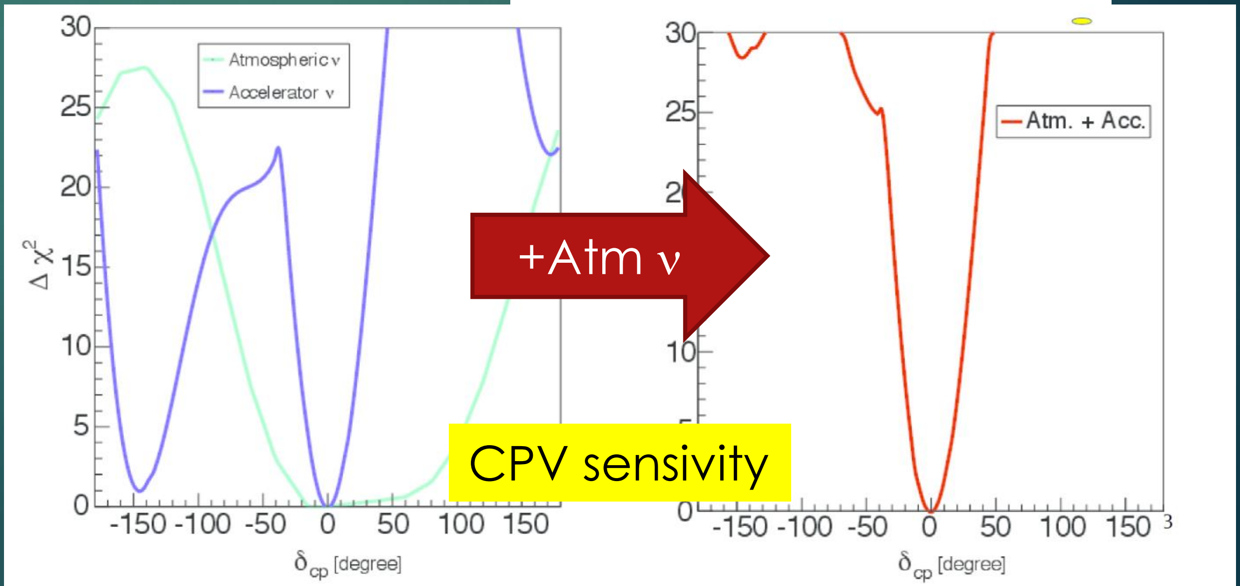


- Contribute to closure of triangles
  - α,β = e,μ (cyan line)
  - α,β = μ,τ (orange line)
  - i,j = 2,3 (brown line)
- Hyper-K can provide high statistics measurements with full systematic correlations to improve (overconstrain) our understanding of these relations

Combination with Atmospheric neutrino

- MH can be determined >3s
- Discrimination of MH can help single out solution of CPV phase δ

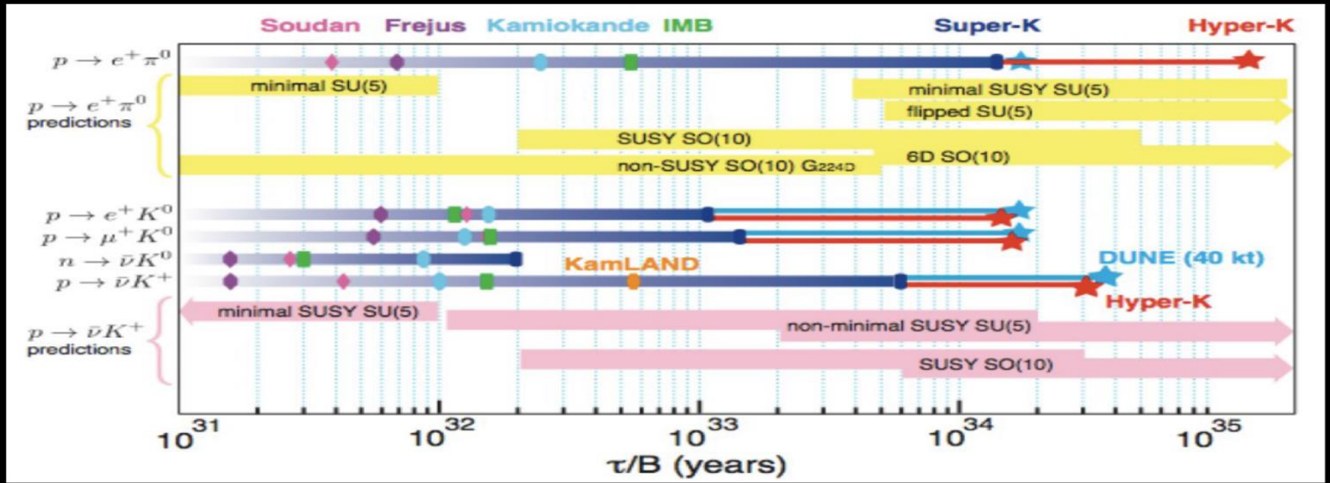




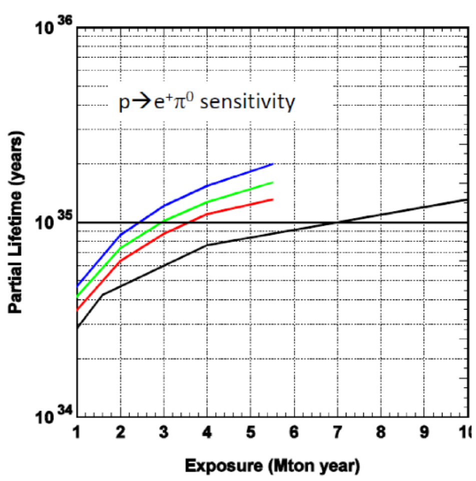
Proton decay

R. Wendell (ICRR)
Future Nu in J WS

Nucleon Decay Physics Potential



Hyper-K's Sensitivity to $p \to e^+\pi^0$

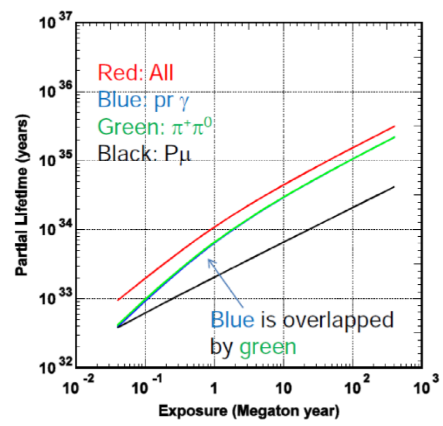


- Baseline Analysis
- Improved Analysis cuts
- BKG Reduced by 50% (n tagging)
- BKG Reduced by 70% (n-tagging)

- Super-Kamiokande has demonstrated neutron tagging via
  - $n + p \to d + \gamma$ (2.2 MeV)
- Hyper-K's tagging depends on detector configuration, Photocoverage, Gd doping etc.

- If no signal is observedlifetime limits $\tau/B > 10^{35}$ years possible with
  - 3.6 Mton×year (red,default)
  - 3.0 Mton×year (green)
  - 2.4 Mton×year (blue)
- Background reduction is an essential component of the Hyper-K nucleon decay program
  - potential for large sensitivity gains exists

Hyper-K's Sensitivity to : $p \to \nu K+$



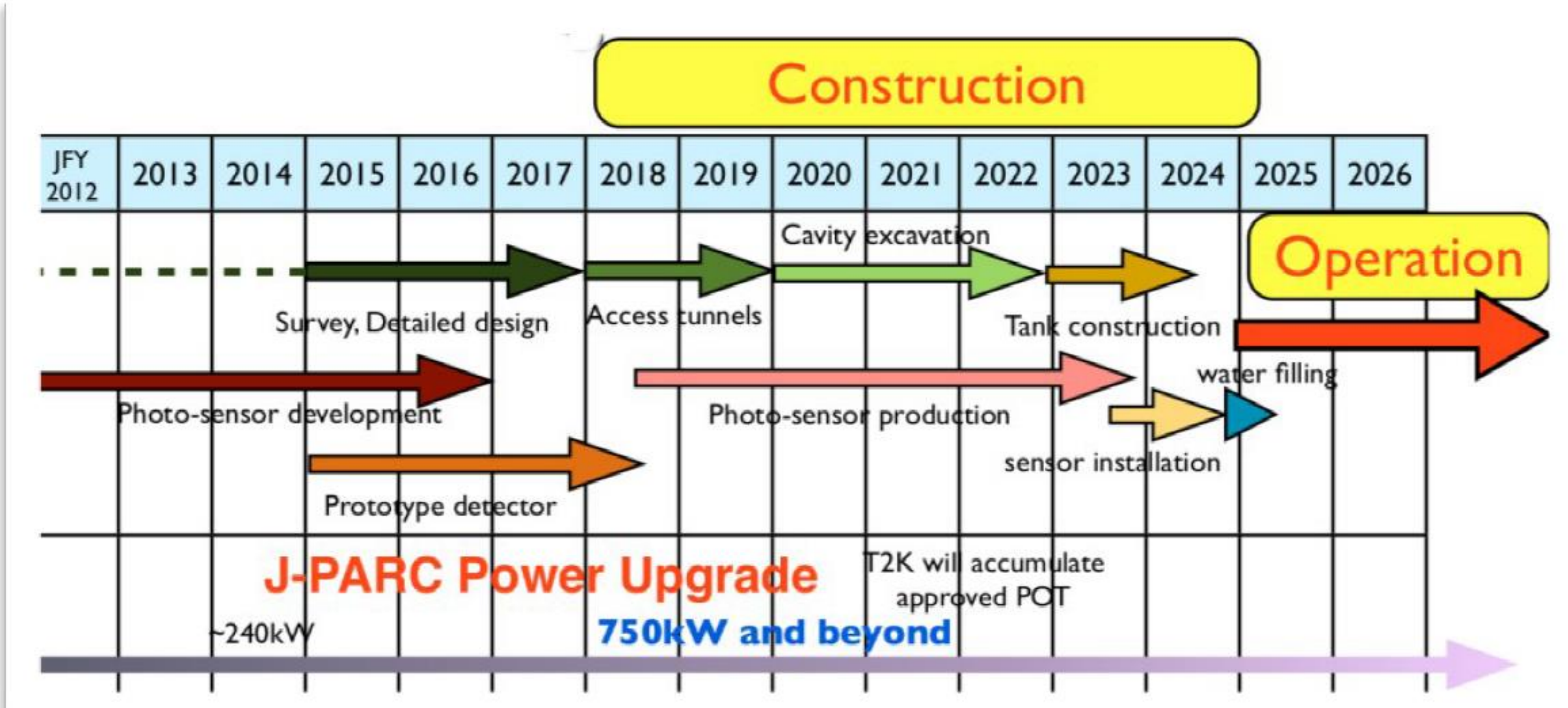
	Hyper-K
Signal ε	7.6 - 37%
BG / Mton yr	1.8 - 2556
10yr. Sens. 90%	**3.2×10^{34}**
SK Limit 90%	7.8×10^{33} preliminary

- Backgrounds from atmospheric neutrino kaon production
  - $\nu + p \to \nu K^+\Lambda + \gamma$ (poorly measured)
  - $\nu + p \to \mu\, p + \gamma$
- Signal efficiency gains possible (likely):
  - Improve γ (faster PMTs)
  - improve π^+ tagging (fitter. improvement)
- Background reduction with n tagging

- Recently Super-K has found two candidates in this mode (BG = 0.87)
- Excellent motivation
  - Reduce backgrounds further!
  - Build a larger detector!

Timeline

The Hyper-Kamiokande Timeline



~2017 Major design decisions finalized
~2018 Construction starts
~2025 Data taking start
> 2025 Discoveries!

Project status and plan

Hyper-K status in Japan

- **Recommendation by HEP community**
  - http://www.jahep.org/office/doc/201202_hecsubc_report.pdf
- **KEK roadmap includes Hyper-K**
  - http://kds.kek.jp/getFile.py/access?sessionId=1&resId=0&materialId=0&confId=11728
- **Cosmic Ray community endorses Hyper-K as a next large-scale project**
- **Science Council of Japan selects Hyper-K as a top priority project in the "Japanese Master Plan of Large Research Projects" (27 chosen out of 192 in all science area).**
  - http://www.scj.go.jp/ja/info/kohyo/pdf/kohyo-22-t188-1.pdf
- It is not in the list of MEXT roadmap 2014. **We seriously challenge the roadmap 2017 for the approval of budget.**

The next action

- Design Report is requested by KEK/ICRR.
  - To be prepared in 2015 toward the budget request. The next processes of the SCJ master-plan and MEXT roadmap will be in 2016-2017.
  - Optimum design, Construction cost&period, Beam & Near detector, International responsibilities
  - The international review will proceed under KEK/ICRR to promote the project.
- Once the budget is approved, the construction can start in 2018 and the operation will begin in ~2025.

- **It is a critical time to promote the project.**
- **Open for new Collaborators**

T.Nakaya, Apr.2015 @ 2nd International Meeting for Large Neutrino Infrastructures

New Initiatives: "T2K-extended" Intermediate experiment before HK/DUNE era

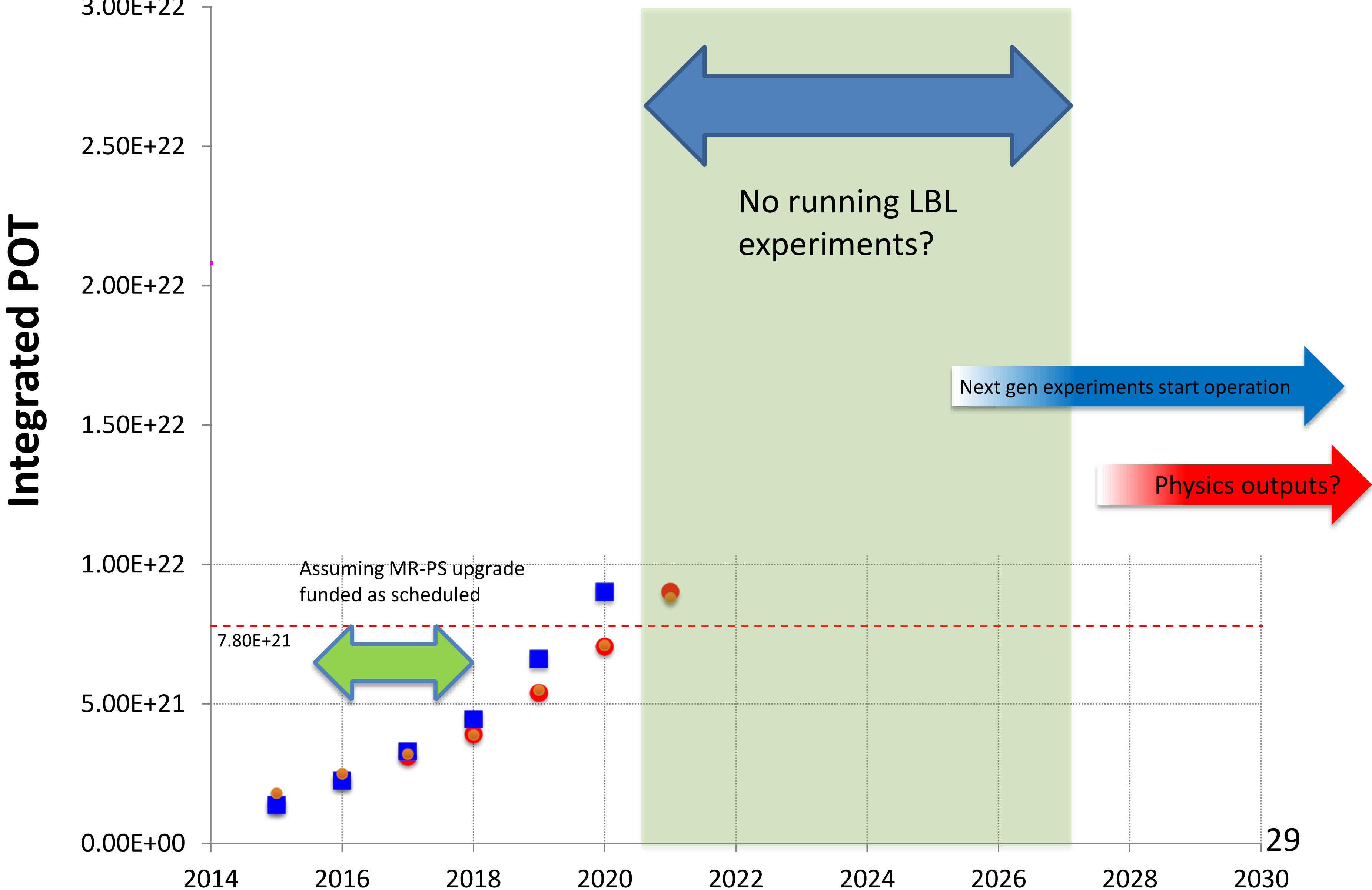
T2K-extended (name not yet defined)

- Neutrino community started to work to propose "extended T2K"
- Interconnect "desert" between T2K/NOVA and DUNE/HK era
- Make full use of present existing facilities with modest upgrades
  - J-PARC MR upgrade → possibility upto ~1.3MW operation
- ~2e22pot by around 2026 before HK/DUNE start operating
- Another ~50% increase of effective statistics by
  - Horn current 250kA → 320kA
  - analysis improvements
- Extract best possible/most precise physics outputs
- Provide learning ground for next generation experiment
  - Realize >1MW high power stable beam operation (acc/beamline)
  - Systematic errors down to a few %

Integrated POT projection

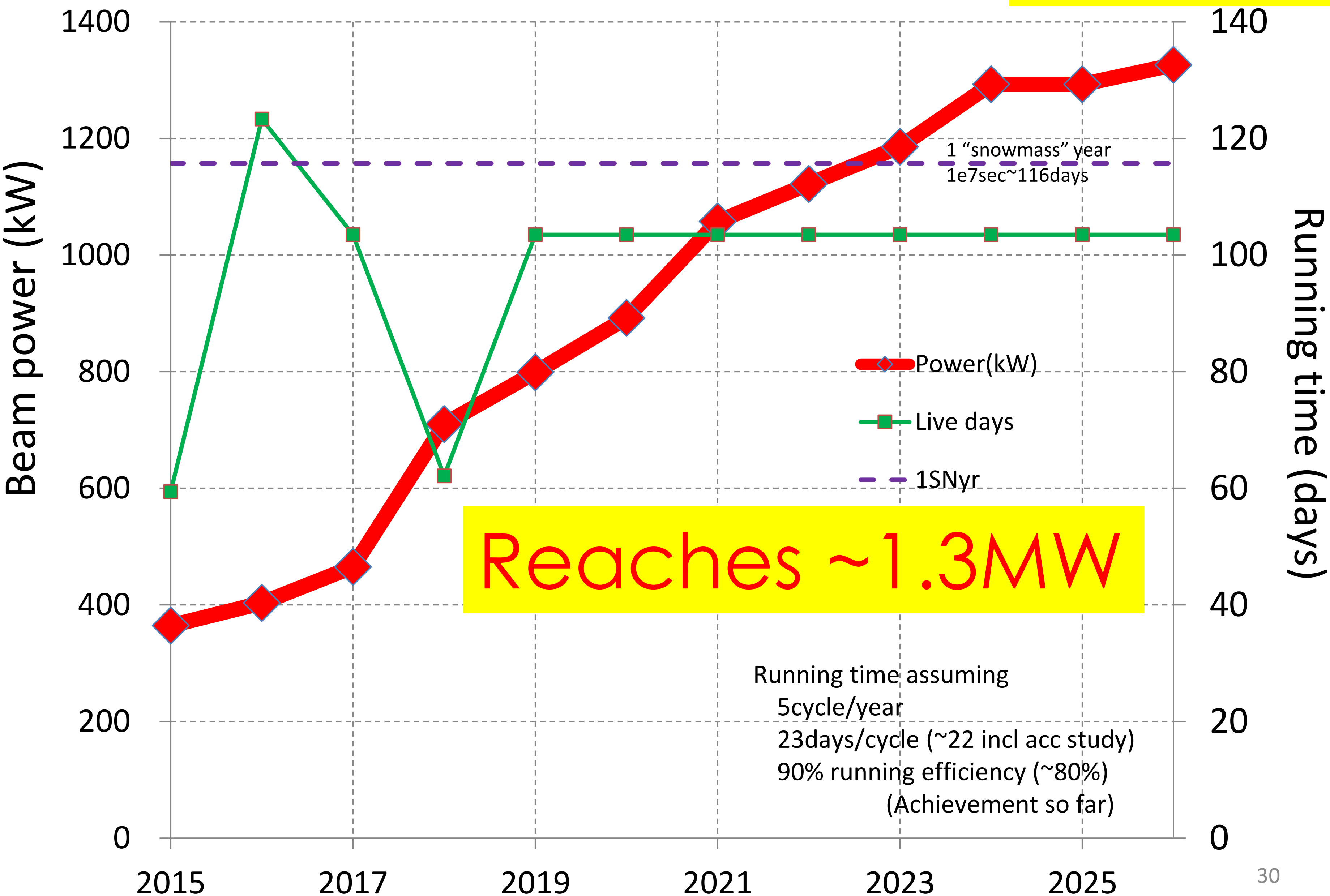
Slide from Future nu in Japan WS

(working assumption)



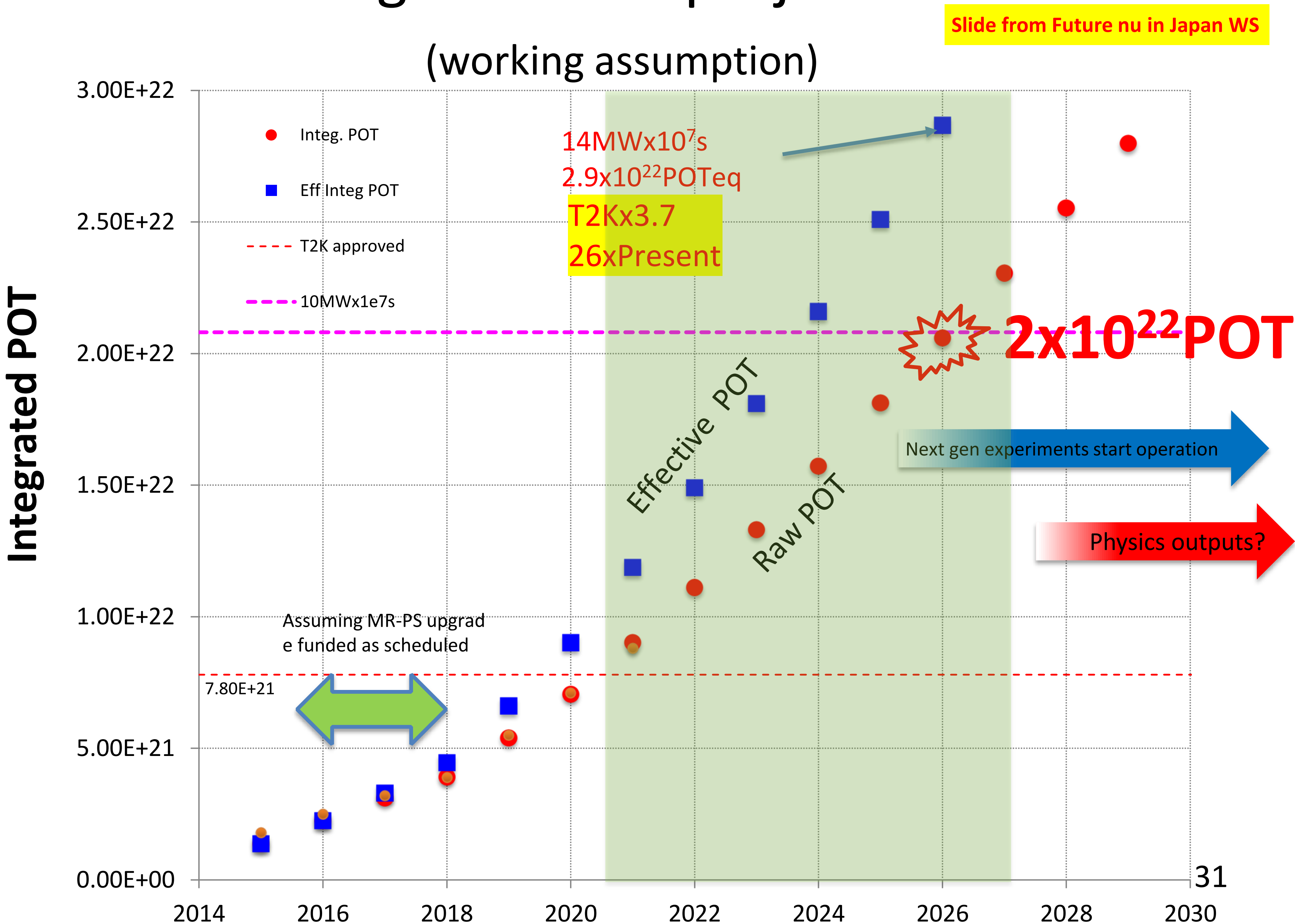
Assumed beam power and running time

Slide from Future nu in Japan WS



Integrated POT projection

(working assumption)



Possible improvements from analysis side

T2K-SK Status and Outlook

Mike Wilking

Workshop for Neutrino Programs with Facilities in Japan

August 4th, 2015

Expanding the Selection

- CP violation sensitivity is limited by ν_e statistics
  - Current ν_e selection efficiency is **66%** (assuming 2 m fiducial volume cut)
- Cuts with the most efficiency loss:
  - Single-ring (86.7%)
  - Zero Michels (89.1%)
  - E_{rec} < 1250 MeV (95.9%)
  - fiTQun π^0 cut (92.0%)
- Further Improvements
  - Expanding the fiducial volume
    - ~30% of SK ID volume is not used
  - Improved reconstruction (fiTQun)
    - Better PID, ring-counting, etc.

T2K-SK ν_e Selection

	MC total	$\nu_\mu + \bar{\nu}_\mu$ CC	$\nu_e + \bar{\nu}_e$ CC	$\nu + \bar{\nu}$ NC	$\nu_\mu \to \nu_e$ CC
interactions in FV	656.83	325.67	15.97	288.11	27.07
FCFV	372.35	247.75	15.36	83.02	26.22
(1) single ring	198.44	142.44	9.82	23.46	22.72
(2) electron-like	54.17	5.63	9.74	16.35	22.45
(3) $E_{vis} > 100$ MeV	49.36	3.66	9.68	13.99	22.04
(4) no Michel election	40.03	0.69	7.87	11.84	19.63
(5) $E_\nu^{rec} < 1250$ MeV	31.76	0.21	3.73	8.99	18.82
(6) not π^0-like	21.59	0.07	3.24	0.96	17.32

264/399 events expected for 10^{22} POT

(assuming $\sin^2 2\theta_{13} = 0.1$, $\sin^2\theta_{23} = 0.5$, $|\Delta m^2_{32}| = 2.4 \times 10^{-3}$ eV^2, $\delta_{CP} = 0$, $\Delta m^2_{32} > 0$)

- In total we should be able to aim at around +50% increase in effective statistics

Summary

- T2K-SK ν_e statistics increase of 40% to 60% may be possible (my rough guess)
  - CCπ^+ with below Cherenkov pions (~13%)
  - Multi-ring events (CCπ^+, CCπ^0, etc.) (up to 20%)
  - Looser and better π^0 and E_{rec} cuts (~5%)
  - Enlarge the fiducial volume (10-15%)
- Purity may also suffer somewhat

Expected # of events

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

* bkg includes wrong-sign

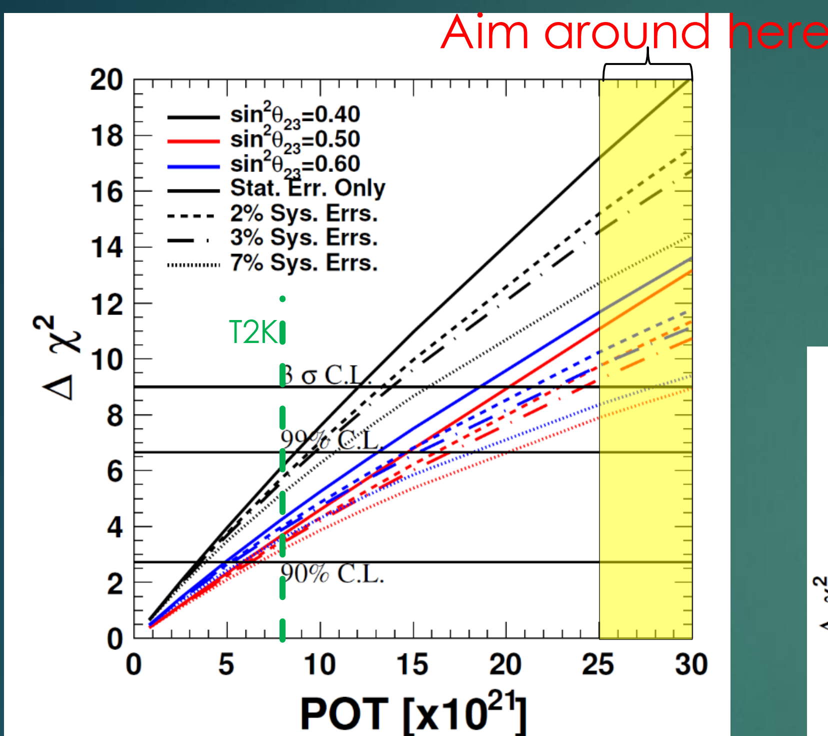
		ν_μ-mode	$\bar{\nu}_\mu$-mode
7.8E21 POT	w/o oscillation	2,648	1,007
	w/ oscillation	741	342
25E21 POT	w/o oscillation	8,519	3,228
	w/ oscillation	2,375	1,096

50% ν- + 50% $\bar{\nu}$-mode

- Assuming same horn current and analysis with present T2K yet

CP sensitivity & precision

Megan Friend (KEK)
Future Nu in J WS

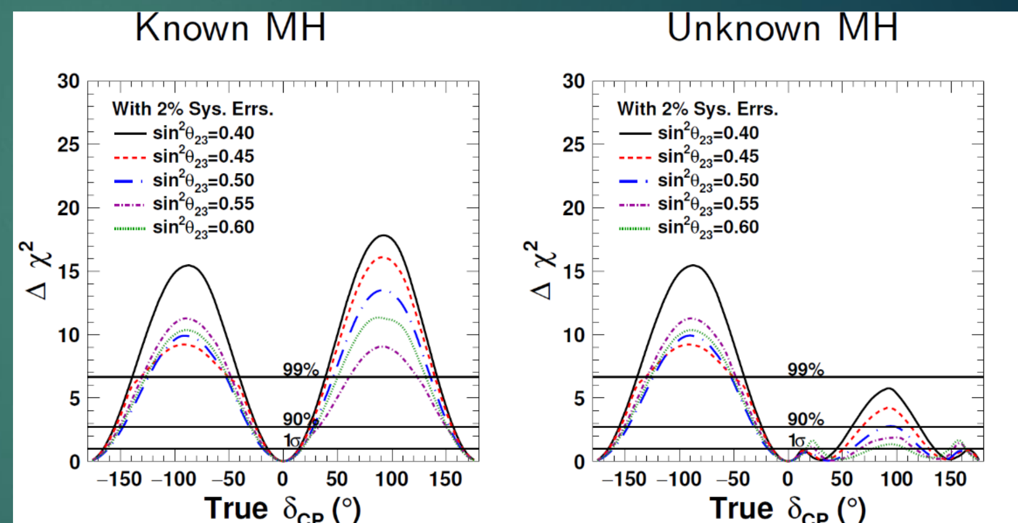


50% ν- + 50% $\bar{\nu}$-mode
True $\delta_{CP} = -90°$, true MH = NH

>3σ possible

for max CPV

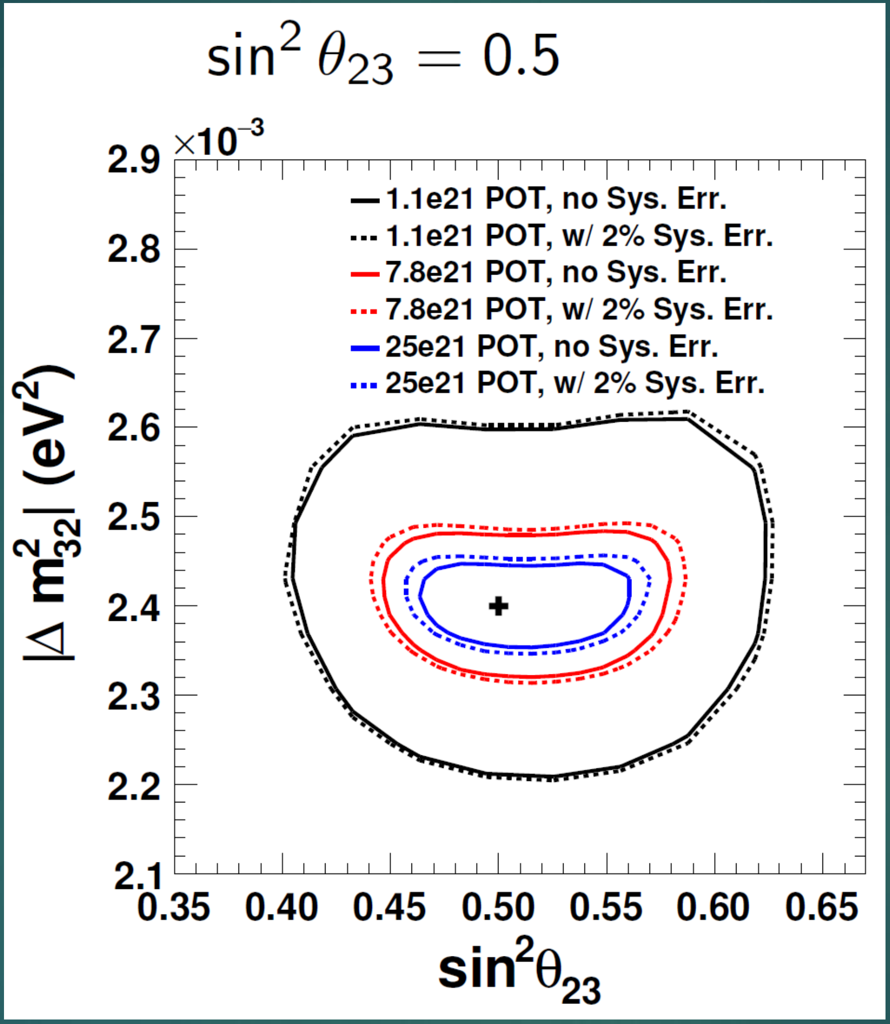
Need to control syst error <~a few %



δ_{CP} Precision

- NH (known), $\delta_{CP} = -90°$, $\sin^2\theta_{23} = 0.5$
- 25×10^{21} POT : $\sigma \sim 36°$(no sys. err.), $\sim 45°$(w/ 2% sys. err.)
- 7.8×10^{21} POT : $\sigma \sim 63°$

Precision of disappearance measurements



- Measurement at 25×10^{21} POT : $\theta_{23} = 45 \pm 1.9^\circ$
  - Current best measurement is $46 \pm 3^\circ$ by T2K

T2K-extended: Plan

- In Future Nu in J WS, agreed to write LoI → Proposal to J-PARC PAC
  - Next PAC is Jan 2016
- There are lots of rooms for new ideas and contributions
  - Accelerator/beam power upgrade
  - Detector upgrade
  - Analysis upgrade
- Your ideas and participations are highly welcome

Keys for the future

- Statistics
  - Integrated beam power
    - Realization of high power: 350kW(realized)→750kW→1.3MW(→MultiMW?)
      - Accelerator
      - Beam line
    - Realization of stable operation = Availability
  - Improvement of analysis
  - Realization of Hyper-K
- Systematics
  - Flux extrapolation
    - “NA61”-type experiment indispensable
    - Support for such measurements important
  - Cross sections

Beam line

J-PARC High Intensity Neutrino Beam

T. Sekiguchi (KEK)
on behalf of T2K Beam Group

Design Philosophy of Neutrino Beamline

- **Tolerance for high power beam**
  - All beamline components designed for 750 kW beam
  - Equipments that cannot be replaceable after irradiation are designed for 3 or 4 MW beam.
- **Remote maintenance**
  - Secondary beamline equipments are highly irradiated with more than 1 Sv/h.
  - Beamline components inside Target Station can be replaceable remotely.

10 Year Term Plan of Beam Power Improvement

- **Design beam power = 750 kW**
  - Will be achieved in 2018
  - Beam power over 750 kW is recently being considered.
- **Aim for 1.3 MW beam by 2026**
  - Proton intensity = **3.2×10^{14} protons/pulse**.
  - Repetition cycle = **1.16 sec.** with new MR power supplies.
- **Can our beamline accommodate to 1.3 MW beam?**

Beam Power	# of protons/pulse	Rep. rate
350 kW (achieved)	1.8×10^{14}	2.48 sec.
750 kW (proposed) [original plan]	2.0×10^{14} [3.3×10^{14}]	1.30 sec. [2.10 sec.]
1.3 MW (proposed)	3.2×10^{14}	1.16 sec.

Prospect for Hardware Upgrade

- **Cooling capacity**
  - Apparatuses themselves can withstand 1.3 MW beam.
  - Improvement of flow rate both for water and helium circulations is needed.
    - Replacement with larger pumps
    - Replacement with larger-size plumbing
    - ⇒ These will be feasible but need 1 year for modification.
- **Radiation**
  - Radioactive air
    - Reinforcement of air-tightness ⇒ 1.3 MW can be manageable.
  - Radioactive water disposal
    - Enlargement of dilution tank
      - Modification of existing tank ⇒ ~1.3MW
      - New facility building for water disposal ⇒ 2MW
        - 2 years for construction (no beam stop needed)

Horn Operation Improvement

- **Operation status**
  - 250 kA operation for physics data taking since 2010.
    - Mainly due to refurbishment of old K2K PS (rated 250 kA).
  - Currently, operated with 2.48 s cycle.
    - 1.3 s for 750 kW (not operated with the existing PS)
- **3 PS configuration for 320 kA and 1 Hz operation**
  - New power supply developed (2 PS's already produced).
  - Also, low impedance striplines newly developed.
- **Timeline**
  - Production of the last PS, transformers, part of striplines
  - Aim to start 320 kA operation from summer 2017.

Sekiguchi (KEK)
In NuFact15

Yes, we can

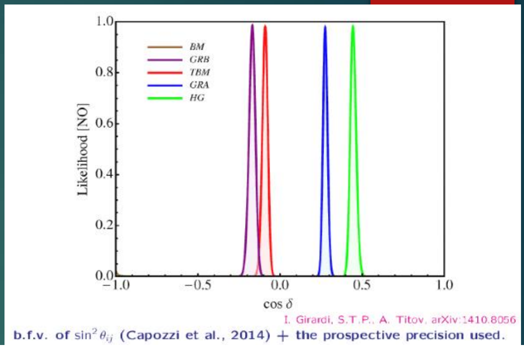
Improved Acceptable Beam Power

Conponent	Limiting factor	Acceptable value
Target	Thermal shock	3.3×10
	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

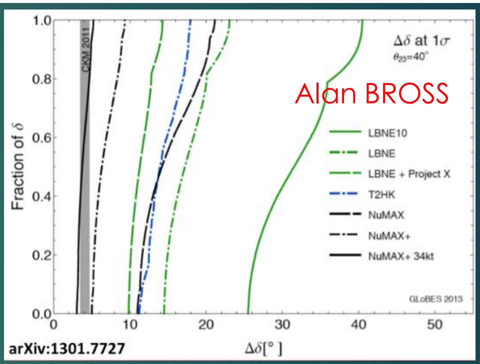
- After appropriate upgrade

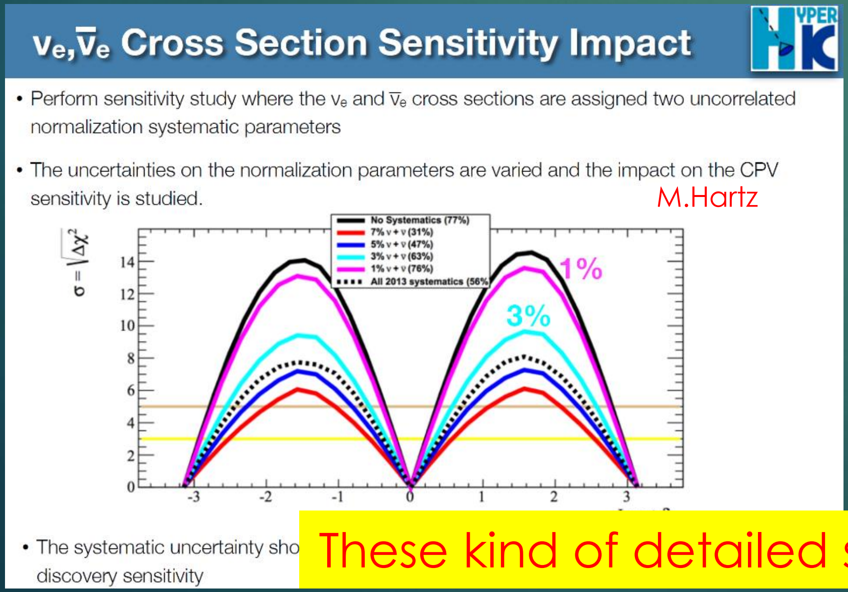
Systematics: Cross sections

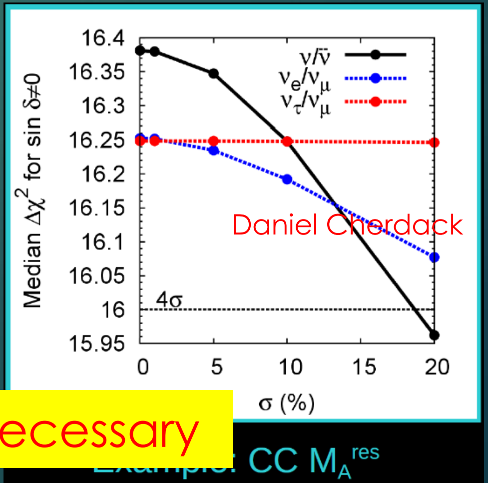
- (Needless to say,..) We need to know to what precision we need to know what(systematic error sources) to know what(physics) to what precision
- To what precision can we achieve with present setup?
- If it is not sufficient to realize physics goal, then we need to build new thing
  - Upgrading near detector
  - New type of detector: nuPRISM, TITUS
  - nuSTORM (somewhere in the world)
- **Incremental approach is important**



S. T. Petcov, Flavors of New Physics, KEK Tokai Campus, 09/03/2015







These kind of detailed studies are necessary

CP asymmetry (1st order approx.)

$$A_{CP} \equiv \frac{P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e)}{P(\nu_\mu \to \nu_e) + P(\bar{\nu}_\mu \to \bar{\nu}_e)} = A'\left\{1 + \frac{2\bar{P}'^2}{P'^2 - \bar{P}'^2}(\delta_\sigma + \delta_\varepsilon)\right\}$$

$$A' \equiv \frac{P' - \bar{P}'}{P' + \bar{P}'},$$

$$\delta_\sigma \equiv \frac{\bar{r}_\sigma}{r_\sigma} - 1, \quad \delta_\varepsilon \equiv \frac{\bar{r}_\varepsilon}{r_\varepsilon} - 1 \qquad \left(r_\sigma = \sigma_e / \sigma_\mu,\ r_\varepsilon = \varepsilon_e / \varepsilon_\mu\right)$$

$$P'_{\mu \to e}(E_{true}) \equiv \frac{N_e(E_{true})}{N_\mu^{\exp}(E_{true})}$$

← FD ν_e obs. E_ν-unfoled

← FD ν_μ unosc. exp'ed normalized by ND ν_μ meas

- Ratio of e/μ cross-section ratio & e/μ effi ciency ratio enter

Minamino (Kyoto)
M.Hartz(KavliIPMU/TRIUMF)
K.Mahn (MSU)
In NuFact15

Where we are & Where we go

Current T2K systematic errors

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%

There are on-going efforts to reduce this nucleus-dependent errors with water target measurements in T2K near detectors.

* 2014 errors don't include the effect of multi-nucleon bound state at the neutrino interaction.

- Need to aim at a few % level
- Cannot achieve in "1day", need learning process
- "T2K-extended" can provide important opportunity

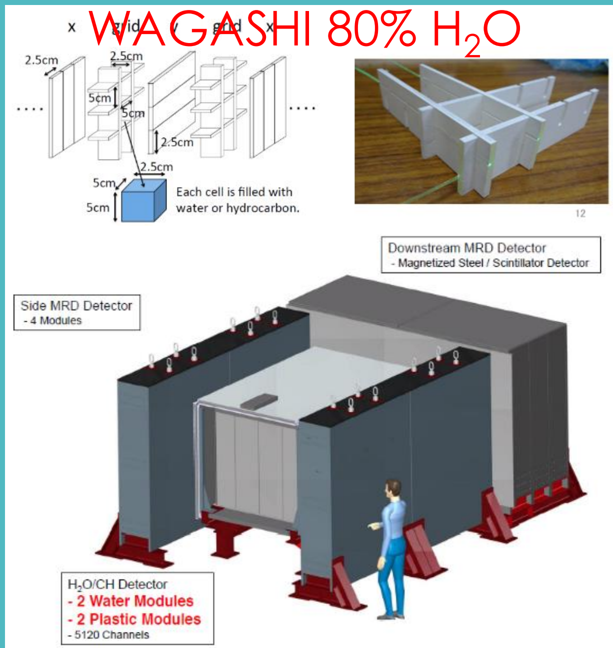
PTEP 2015, 053C02

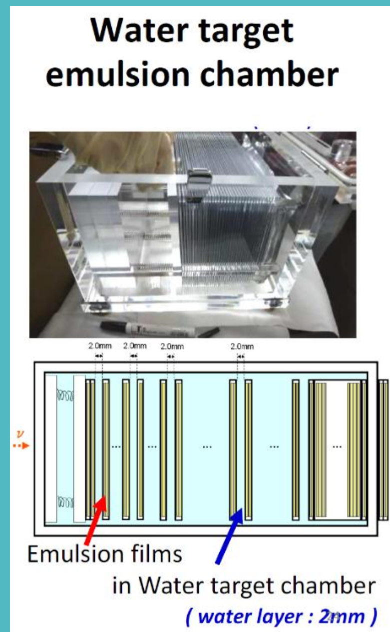
Table 9. Uncertainties (in %) for the expected number of events at Hyper-K from the systematic uncertainties assumed in this study. ND: near detector.

		Flux & ND-constrained cross section	ND-independent cross section	Far detector	Total
ν mode	Appearance	3.0	1.2	0.7	3.3
	Disappearance	2.8	1.5	1.0	3.3
$\bar{\nu}$ mode	Appearance	5.6	2.0	1.7	6.2
	Disappearance	4.2	1.4	1.1	4.5

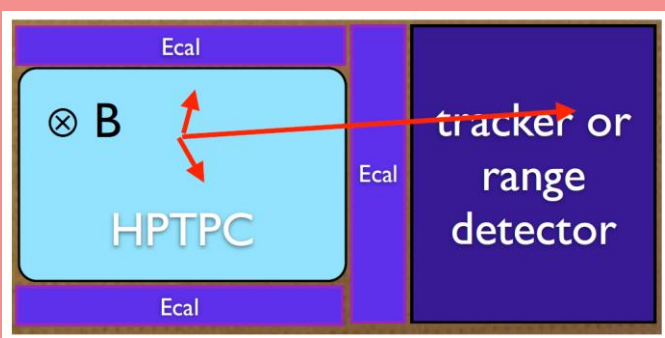
Ideas of new detector

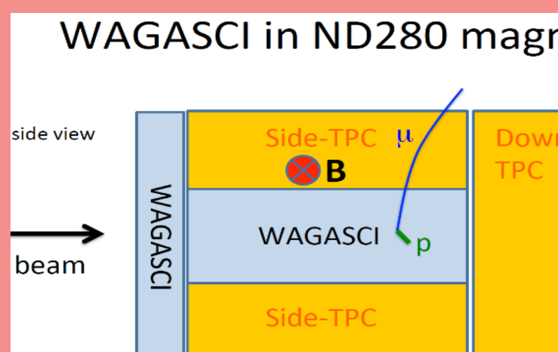
Already on-going projects



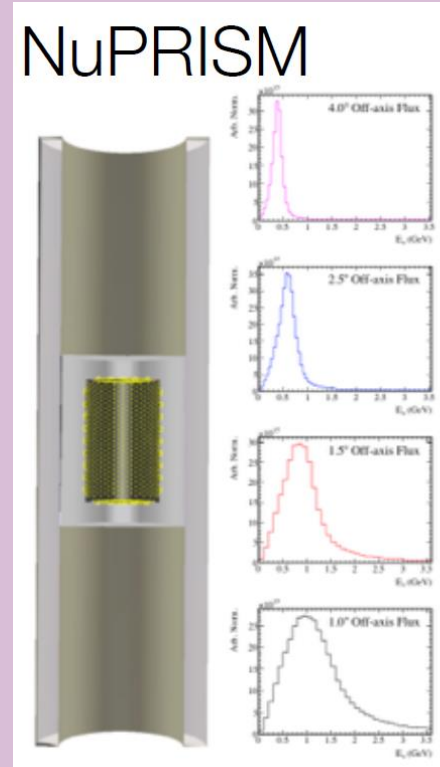


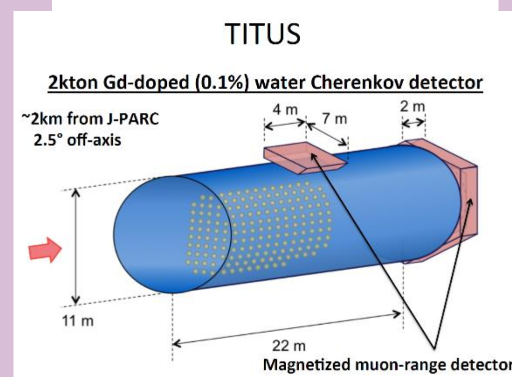
Ideas to upgrade present ND in UA1 mag





Ideas of new detectors





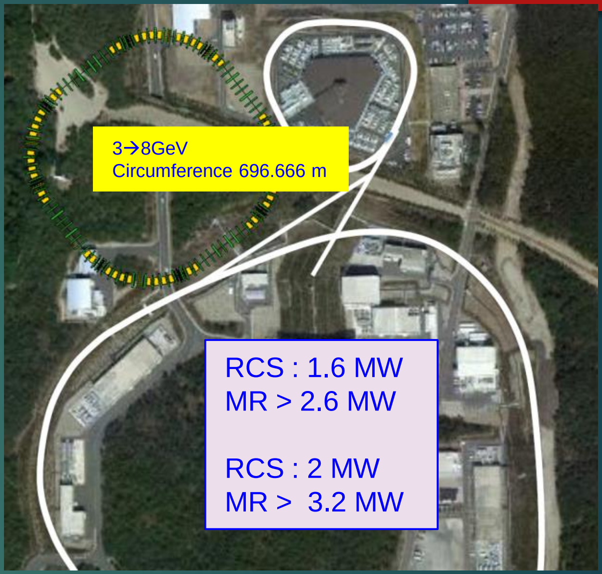
Ideas of new detector

Draw your favorite detector

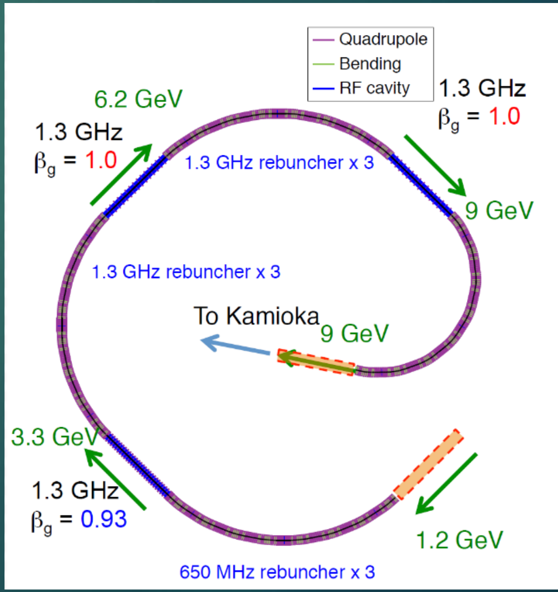
- Your participation for the discussions and for the projects are welcome!

Ideas for even higher power

- Second booster in J-PARC
  - Introduce new 8GeV booster for MR injection to "eliminate" space charge effect at injection
  - Upto 3.2MW when RCS is 2MW



- "Circular" Linear accelerator
  - Utilize TRISTAN/KEKB tunnel at Tsukuba campus
  - 9GeV, 100mA, 1%duty = 9MW

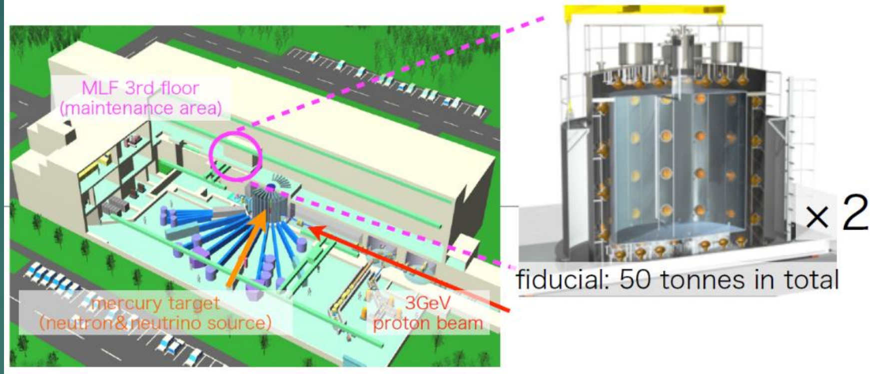


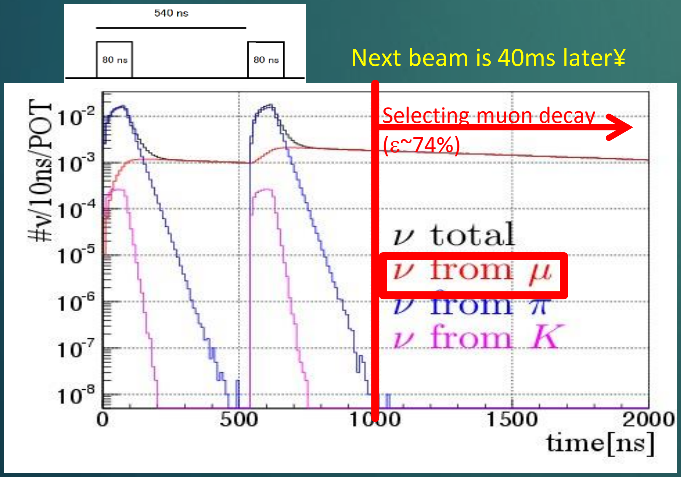
Non-LBL experiments

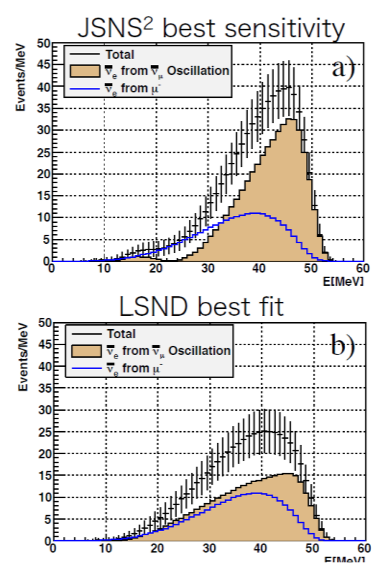
J-PARC E56: JSNS² at MLF

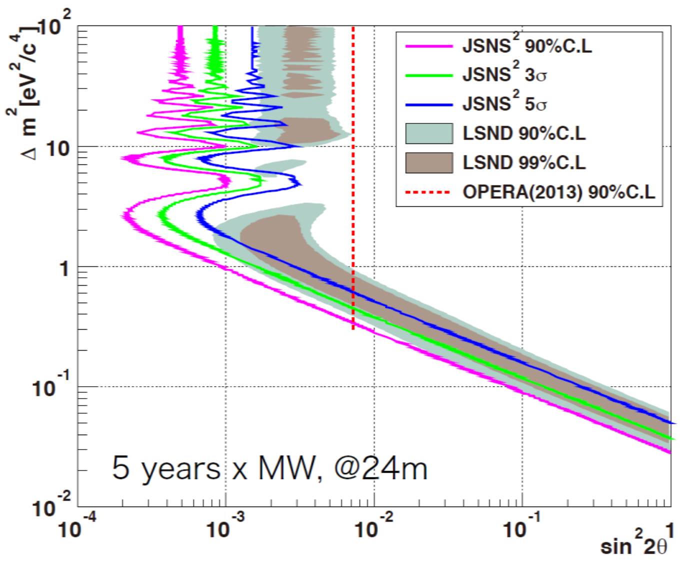
M. Harada *et al*, arXiv:1310.1437 [physics.ins-det]

- aims to measure the neutrino oscillation with sterile neutrino $(\mu^+ \rightarrow \bar{\nu}_\mu \rightarrow \bar{\nu}_e)$
- **Stage-1 status granted**
- Experimental setup
  - baseline: 24m
  - Fiducial volume: 50 tonnes
  - Energy resolution σE : 15%/√E [MeV]
  - Delayed coincidence method: neutrons are observed as γs from Gd-capture
  - PID(γ/n) capability by Cherenkov and/or Pulse Shape Discrimination (PSD)
- Advantage: Low duty beam from scinchrotron









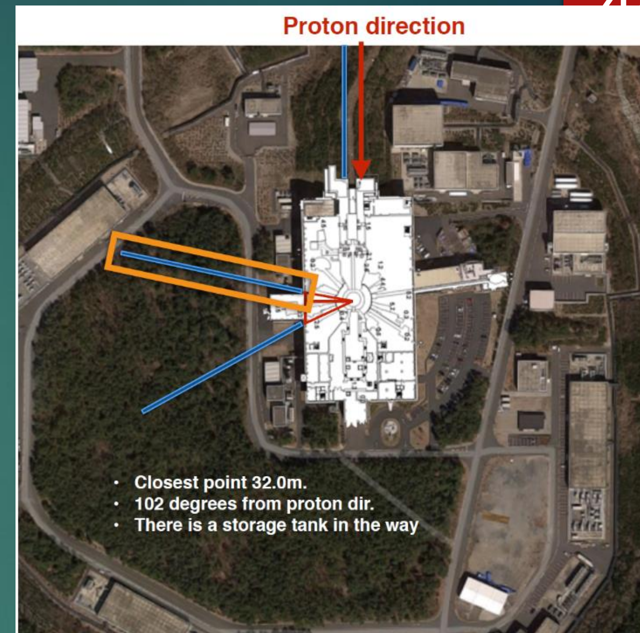
Another new idea: KPIPE

Searching for the Sterile Wave:
A ν_μ-disappearance search using Kaon decay-at-rest

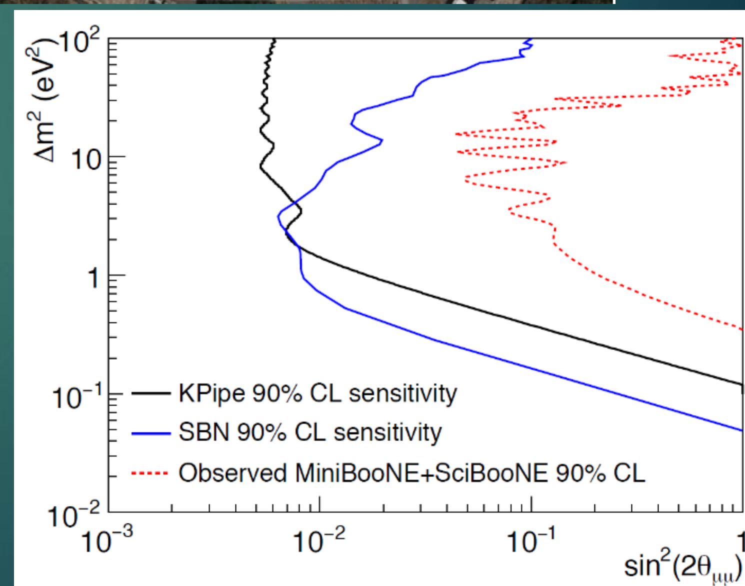
T. Wongjirad, S. Axani, G. Collin, J. Conrad, M. Shaevitz, J. Spitz

Workshop for Neutrino Programs with Facilities in Japan
August 5th, 2015

- "KPipe" is a proposal for a short-baseline muon neutrino disappearance experiment at the J-PARC MLF that uses neutrinos from Kaon Decay at Rest (KDAR)



A (BIG) pipe, 3 m diameter and 120 m long, filled with liquid scintillator



No proposal/LoI submitted to PAC yet

Asian activities and ideas

- Indian participation to US projects
  - Beside INO
- Chinese idea for future neutrino beam "MOMENT"
- Possibility of neutrino beam from J-PARC to Korea

Indian participation to US projects

Raj Gandhi

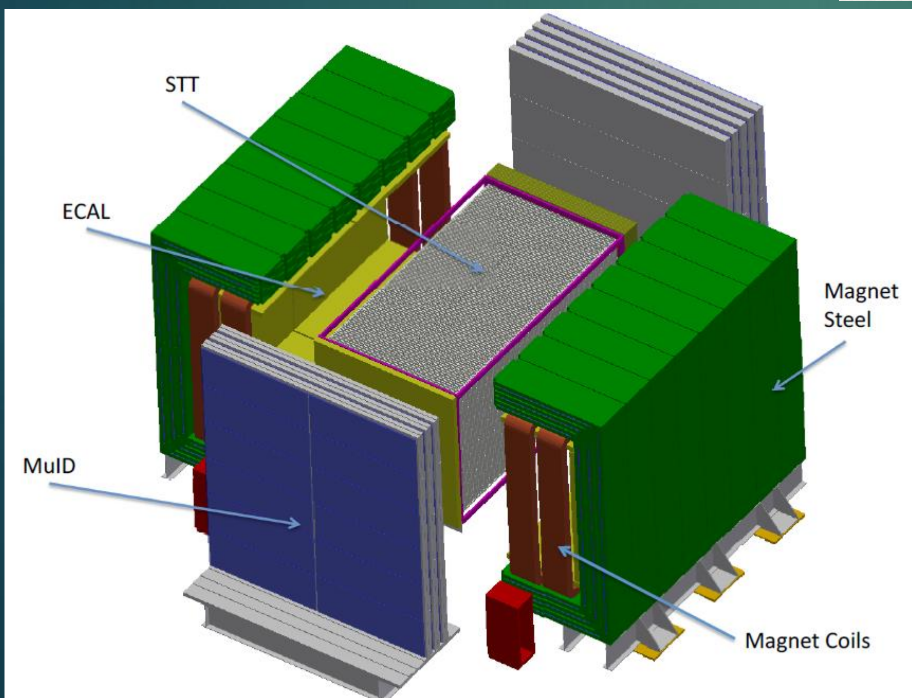
Proposal from India to build DUNE near Detector

There is an Indian proposal to build the near detector for DUNE. The proposed conceptual design has been accepted by the collaboration as the Reference Design for the DUNE-ND, and has undergone extensive technical reviews both on the US and Indian side.

a) Measurements which will reduce systematic uncertainties in LBL FD oscillation analyses and will allow FD to reach full physics potential.

b) Precision measurements of parameters in SM neutrino interactions (Cross-section measurements in 0.5 to 20 GeV energy region, Weinberg angle, Sum rules, structure functions....

c) Search for new physics(Heavy Neutrinos, Sub-GeV Dark matter...



Milorad POPOVIC (FNAL), NuFact15

Charge Item: #1
Mishra

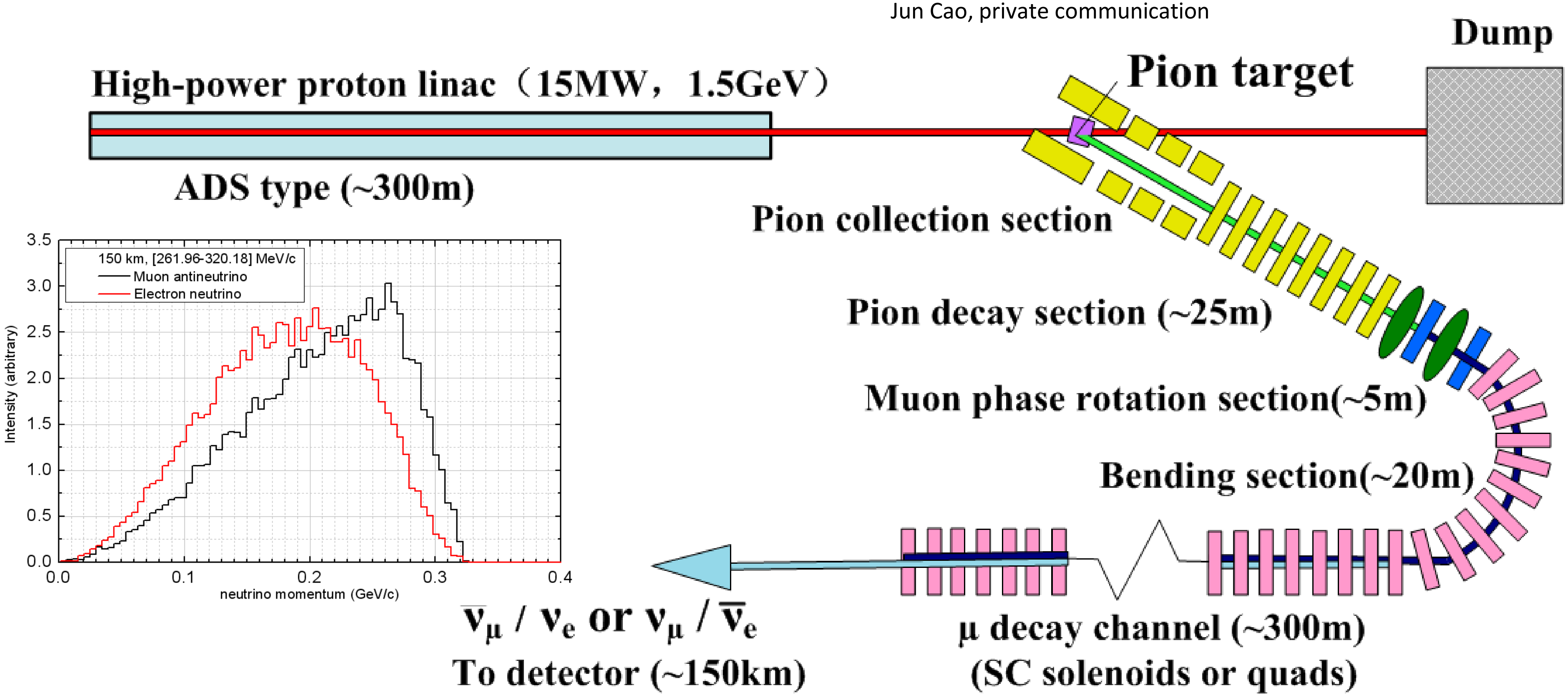
International Partners/India

- Indian Institutions-Fermilab Collaboration (IIFC) created in fall 2007
  - Signatories: Fermilab, BARC (Mumbai), IUAC (Delhi), RRCAT (Indore), VECC (Kolkata)
  - Encompasses R&D on
    - Superconducting accelerating modules
    - HLRF and LLRF
    - Cryogenics
    - Instrumentation
    - Magnets
- U.S. DOE-Indian DAE Implementing Agreement “for Cooperation in the Area of Accelerator and Detector Research & Development for Discovery Science” signed July 2011
- Annex I to the DOE-DAE Implementing Agreement signed in January 2015
  - Enables significant Indian contribution to PIP-II R&D and construction
  - Up to \$200M (direct) authorized under the 12th and 13th Indian Plans
    - \$60/140M
  - Calls for joint DOE-DAE evaluation of R&D accomplishments in 2018, prior to initiation of 13th plan.
- Pitamber Singh (BARC) participating in this meeting as an official observer

19 S. Holmes | Intro to PIP-II 6/16/2015 Fermilab PIP-II

MOMENT: A New Idea on ν Beam

Jingyu TANG and several talks in NuFact15,
Jun Cao, private communication



- Neutrinos from muon decay
- Proton LINAC for ADS ~15 MW
- Energy: 300 MeV/150 km
- Phys. Rev. STAB **17**, 090101 (2014)

Neutrinos after the target/ collection/decay similar to NuFact: ~ 10^{21} ν/year

MOMENT Status

- MOMENT is a new nu beam aiming at the next generation experiment, after DUNE and T2HK.
- It depends on
  - R&D Progress of the 15MW ADS proton LINAC
  - What's the physics after DUNE and T2HK?
  - If there is physics, will a neutrino factory be built?

ICFA-neutrino panel:
- Aiming at headline discoveries
- Looking for emerging scenarios

- Working on
  - Optimizing the beamline, considering the suitable detector technology
  - Critical R&D such as targetry, Super-conducting Magnets

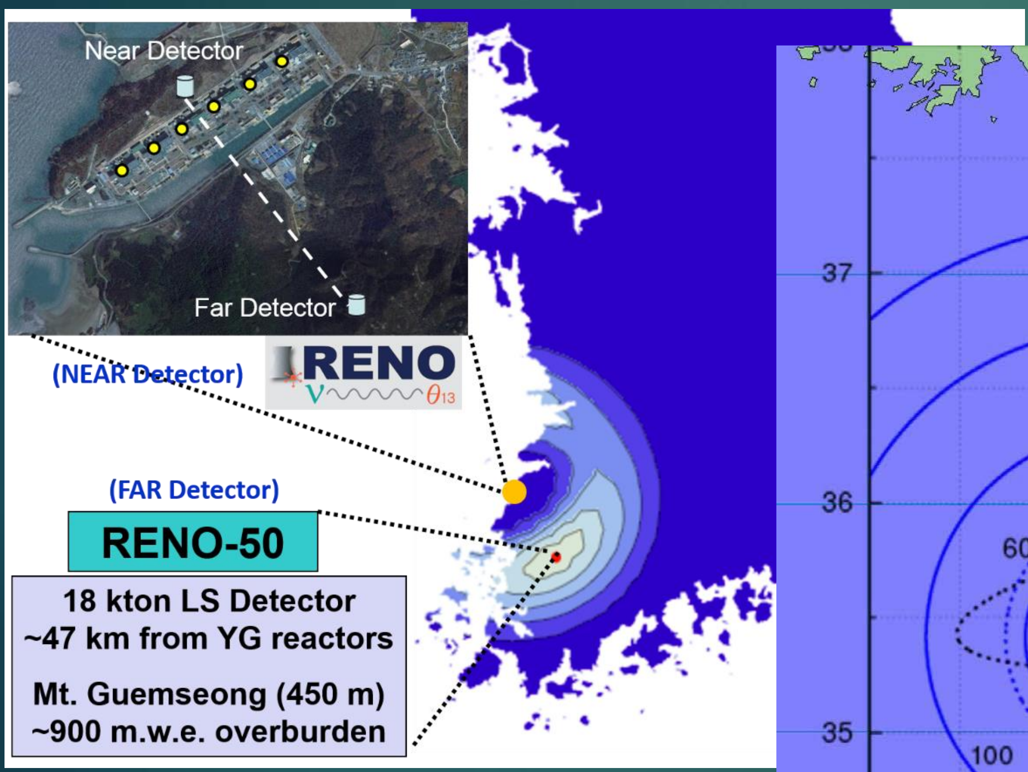
Possibility of beam from J-PARC to Korea

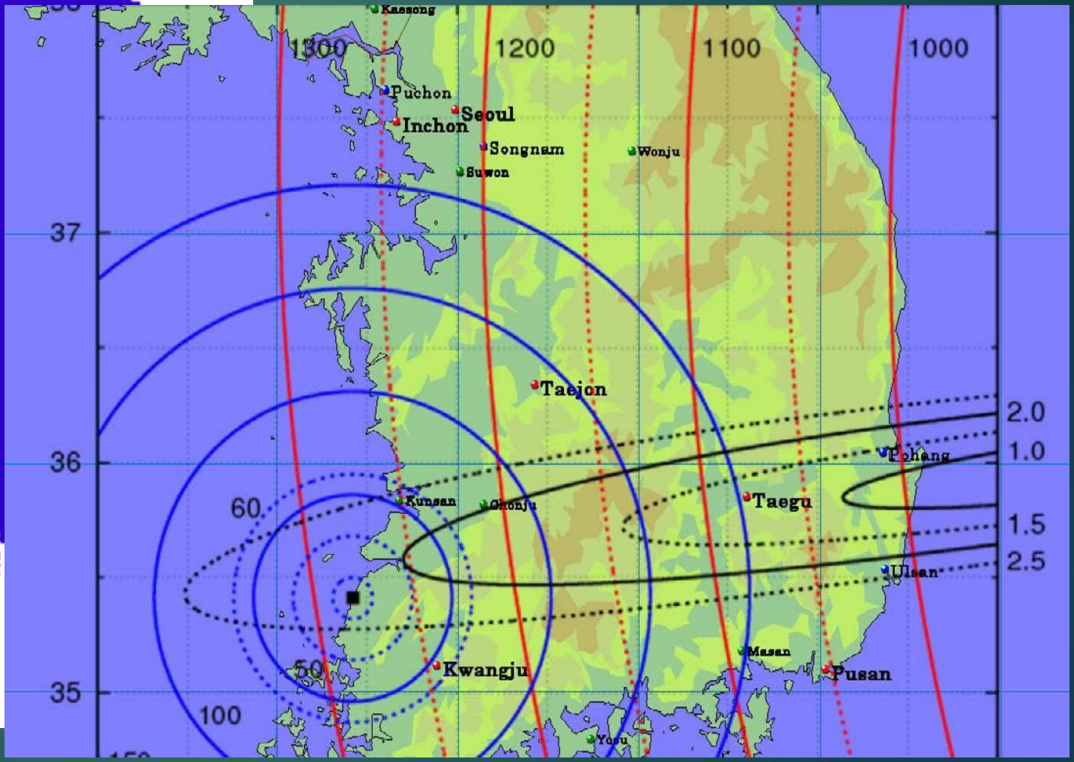
Kaoru Hagiwara, Naotoshi Okamura, Ken-ichi Senda, Phys.Rev. D76 (2007) 093002

Kaoru Hagiwara, Naotoshi Okamura, Ken-ichi Senda, JHEP 1109 (2011) 082

Yoshitaro TAKAESU, NuFact15 Poster

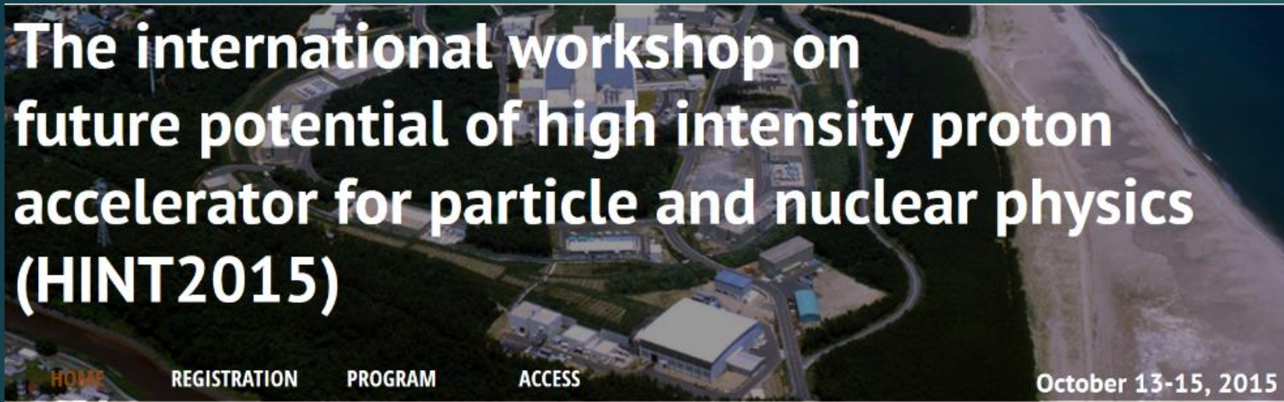
~ 1,300 km baseline of 1.0-2.5 degree off-axis (i.e. second oscillation maximum)





Summary

- Japanese accelerator-based experiments
  - J-PARC accelerators
    - RCS demonstrated 1MW beam
    - MR achieved ~350kW, aim 700~900kW(2018~2020) → ~1.3MW(by ~2026)
    - Multi-MW ideas: 2nd booster/9MW linac at Tsukuba
  - LBL
    - T2K upto approved 7.8×10^{21}POT by around 2021 at earliest
    - "T2K-extened": Aim to search CPV >3σ with ~2×10^{22}POT &~50% improvements in experiments by ~2026
      - Good smooth connection from T2K to Hyper-K, good entry point for new groups
      - **Plan to submit LoI/Proposal to PAC soon**. Your ideas and participation are highly welcome
    - J-PARC → Hyper-Kamiokande: aim to start construction ~2018, operation ~2025
      - Your ideas and participation are highly welcome
  - Non-LBL
    - JSNS^2 @ J-PARC MLF search for sterile neutrino: Stage-1 granted
    - New ideas are emerging
- Asian activities and ideas
  - Indian participation to US projects
  - Chinese idea for future neutrino beam "MOMENT"
  - Possibility of neutrino beam from J-PARC to Korea
- **Incremental (~staging) approaches are important**
  - CPV (maximal?), Cross section meas. ~8%→5%→a few%, nuFact R&D with physics objectives



ABOUT THIS WORKSHOP

The international workshop on future potential of high intensity proton accelerator for particle and nuclear physics (HINT2015) will be held at J-PARC, Tokai-Village, Ibaraki, Japan from 13th to 15th October, 2015. This workshop follows the workshop held in December 2012 at J-PARC on "Future direction of Proton Intensity Frontier".

The workshop will focus on future prospects of high intensity proton accelerators and beams toward Multi-MW beam power and, new frontier of particle and nuclear physics enabled by the high intensity beams.

First bulletin

TOPICS

There will be sessions covering the following topics;

- Present status and future plan of world high intensity proton accelerators
- Technical challenges to realize Multi-MW accelerators
- Technical challenges to realize Multi-MW beam facilities
- Neutrino physics with high intensity beam
- Kaon particle physics with high intensity beam
- Muon particle physics with high intensity beam
- Hypernuclear physics with high intensity beam
- Hadron physics with high intensity beam
- Neutron physics with high intensity beam

Oct13-15
@J-PARC

HINT2015 J-PARC
Search

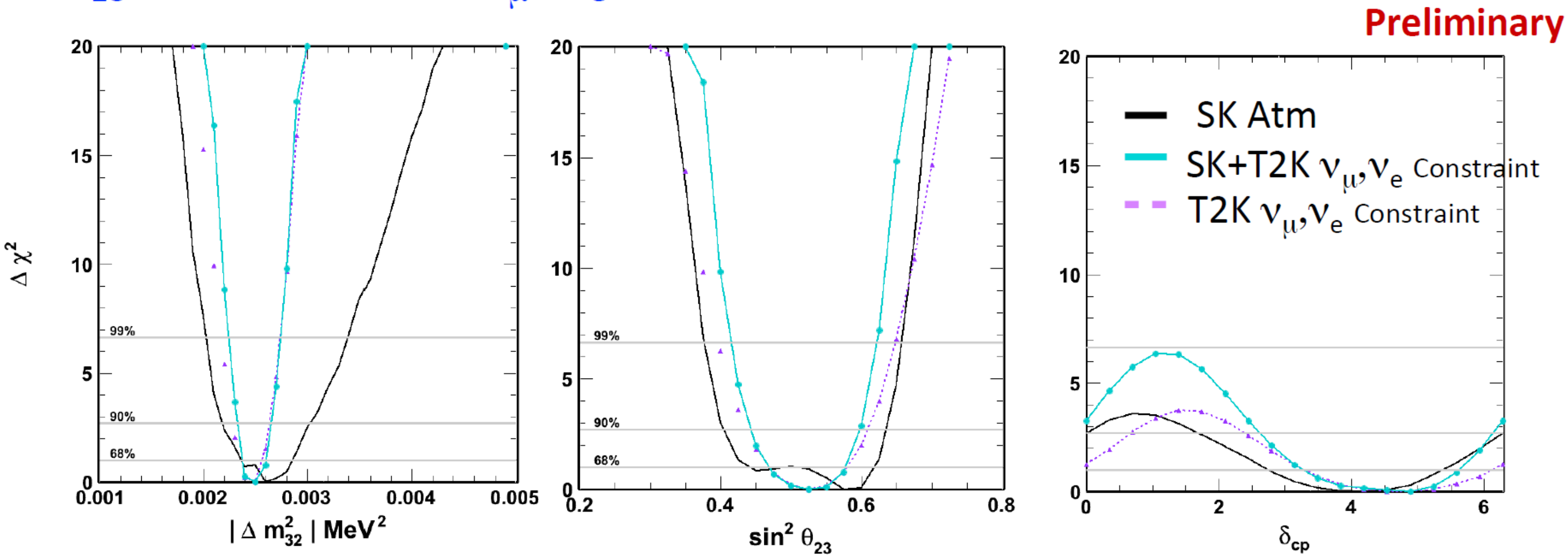
Registration: Sept.13
Poster registration extended to Aug.31

Backup

SK+T2K results

Kameda(ICRR, U.Tokyo)
Aug.11

θ_{13} **Fixed** SK + T2K ν_μ, ν_e , Normal Hierarchy



Fit (517 dof)	$\chi 2$	δ_{cp}	θ_{23}	Δm_{23} ($x10^{-3}$)
SK + T2K (NH)	651.53	4.887	0.525	2.5
SK + T2K (IH)	654.73	4.189	0.550	2.4

- $\chi^2_{NH} - \chi^2_{IH}$ = **-3.2** (-3.0 SK only)
- **CP** Conservation ($\sin\delta_{cp} = 0$) allowed at (at least) 90% C.L. for both hierarchies

CP measurement

Observables

$$N_e(E_{rec}) = N_{obs}(E_{rec}) - N_{BG}(E_{true})$$
$$= \int dE_{true} \Phi_\mu(E_{true}) \cdot P_{\mu\to e}(E_{true}) \cdot \sigma_e(E_{true}) \cdot \varepsilon_e(E_{true}) \cdot r_e(E_{true}, E_{rec})$$

μ flux **cross sec.** **det.eff** **det.responce**

unfold det. responce

$$N_e(E_{true}) = \Phi_\mu(E_{true}) \cdot P_{\mu\to e}(E_{true}) \cdot \sigma_e(E_{true}) \cdot \varepsilon_e(E_{true})$$

Divide by exp'ed # of ν_μ events w/o oscillation

$$P'_{\mu\to e}(E_{true}) \equiv \frac{N_e(E_{true})}{N_\mu^{\exp}(E_{true})} = \frac{N_e(E_{true})}{\Phi_\mu^{\exp} \cdot \sigma_\mu \cdot \varepsilon_\mu} = \frac{N_e(E_{true})}{\Phi_\mu^{\exp} \cdot \sigma_e \cdot \varepsilon_e} \times \frac{\sigma_e}{\sigma_\mu} \cdot \frac{\varepsilon_e}{\varepsilon_\mu}$$

r_σ r_ε

$$= P_{\mu\to e}(E_{true}) \cdot r_\sigma(E_{true}) \cdot r_\varepsilon(E_{true})$$

CP Asymmetry

$$A_{CP} \equiv \frac{P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e)}{P(\nu_\mu \to \nu_e) + P(\bar{\nu}_\mu \to \bar{\nu}_e)} = \frac{P' \big/ r_\sigma r_\varepsilon - \bar{P}' \big/ \bar{r}_\sigma \bar{r}_\varepsilon}{P' \big/ r_\sigma r_\varepsilon + \bar{P}' \big/ \bar{r}_\sigma \bar{r}_\varepsilon}$$

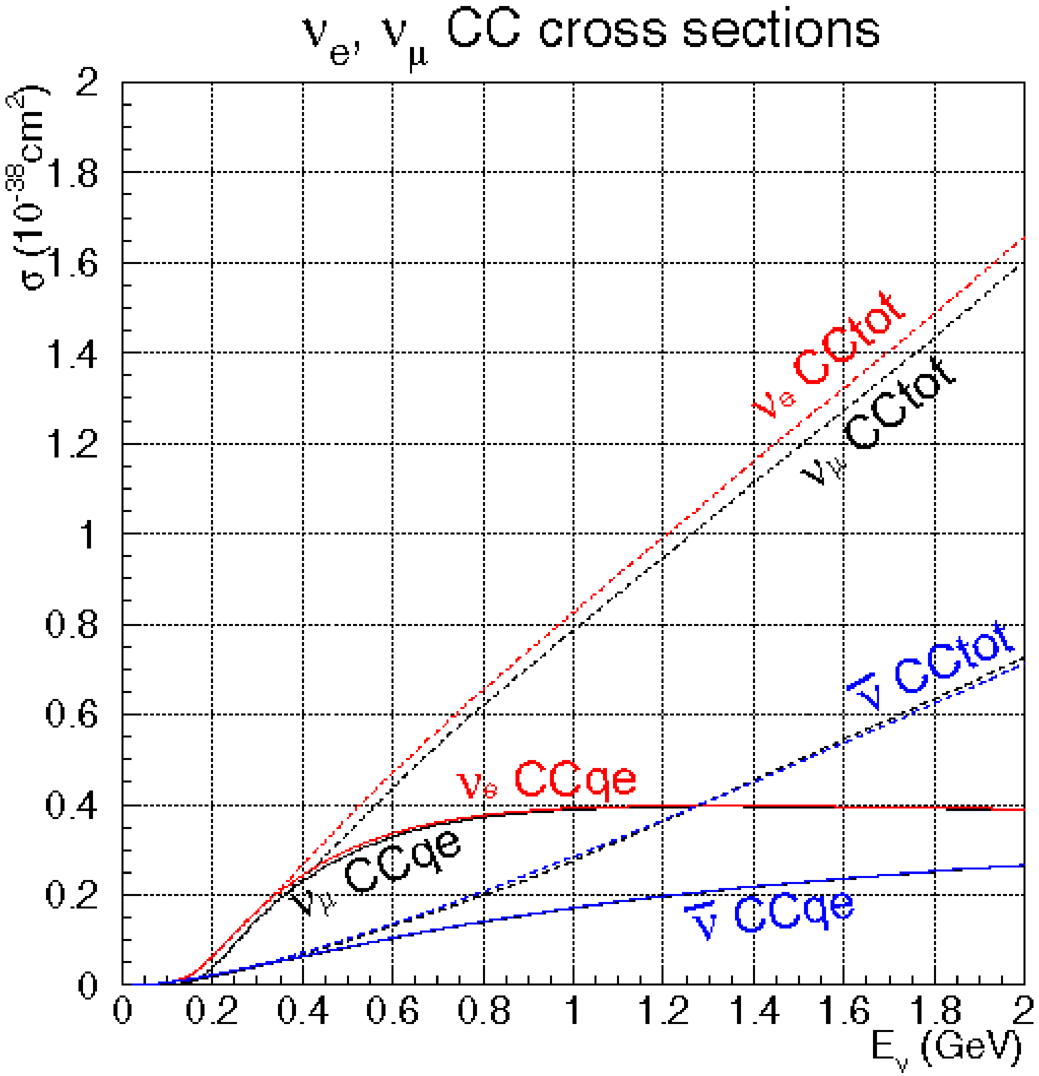
$$= A' \left\{ 1 + \frac{2\bar{P}'^2}{P'^2 - \bar{P}'^2} \left(\delta_\sigma + \delta_\varepsilon \right) \right\}$$

where

$$A' \equiv \frac{P' - \bar{P}'}{P' + \bar{P}'}, \quad \delta_\sigma \equiv \frac{\bar{r}_\sigma - r_\sigma}{r_\sigma}, \quad \delta_\varepsilon \equiv \frac{\bar{r}_\varepsilon - r_\varepsilon}{r_\varepsilon} \qquad \left(r_\sigma = \sigma_e \big/ \sigma_\mu ,\ r_\varepsilon = \varepsilon_e \big/ \varepsilon_\mu \right)$$

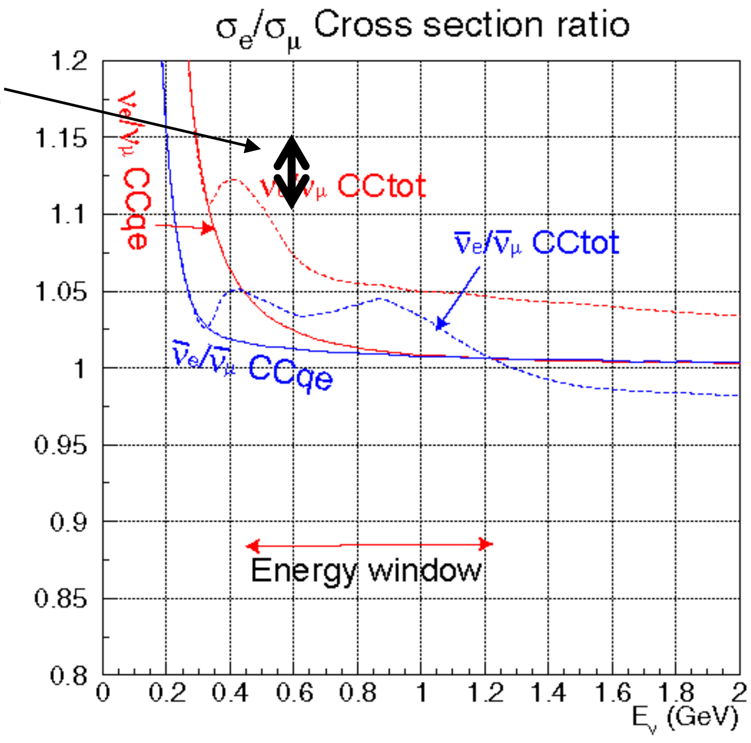
Only differences of e/μ cross section ratios and efficiency ratios

Cross sections



Cross section difference

~5%

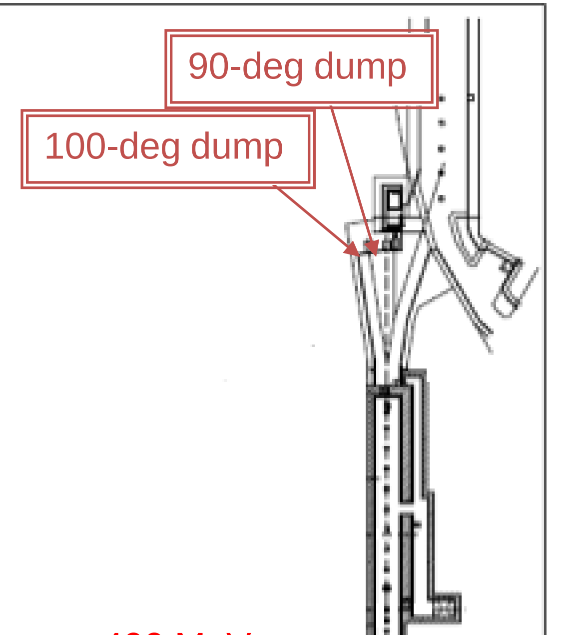


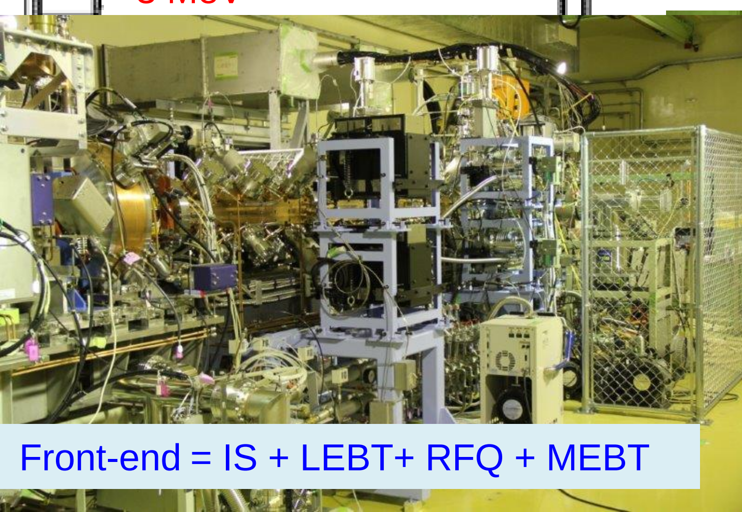
CCqe ratio diff
1~5% @ energy window

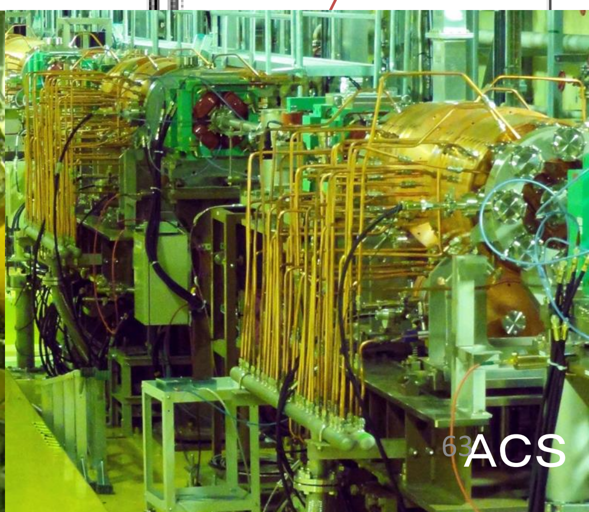
J-PARC accelerator

Linac

- **Particle:** H^-
- **Energy:** 400 MeV
- **Peak current:** 30 mA (~ June 2014)
  50 mA by replacing front-end in 2014
- **Repetition:** 25 Hz
- **Pulse width:** 0.5 msec

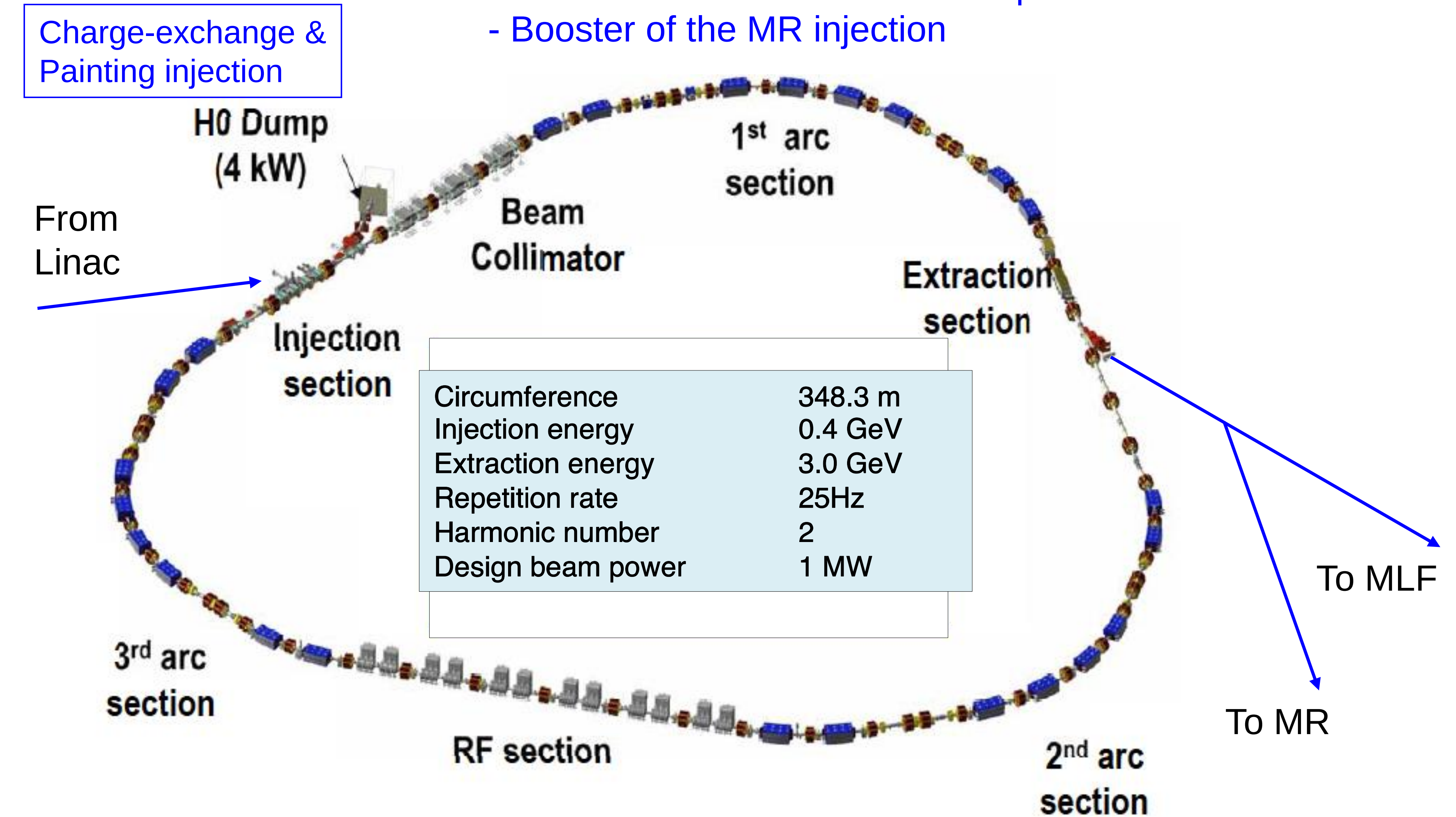






RCS (Rapid Cycling Synchrotron)

Two purposes of the RCS:
- Proton driver for neutron/muon production in MLF
- Booster of the MR injection

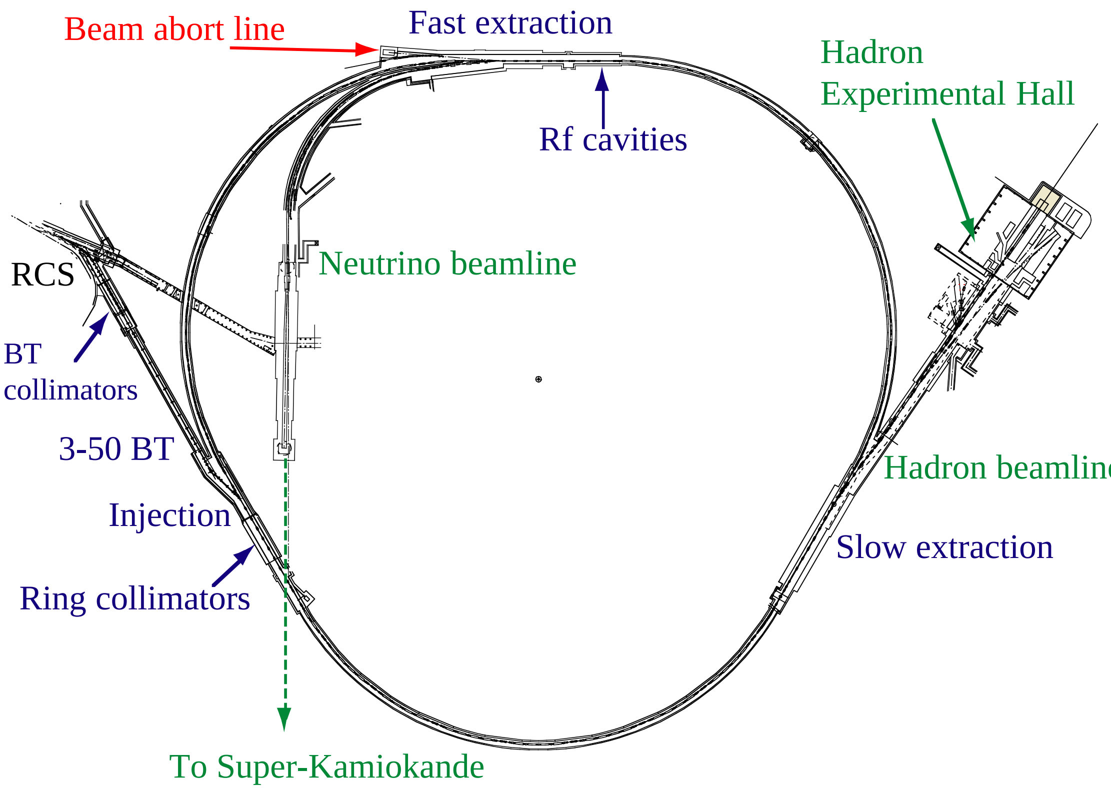


Circumference	348.3 m
Injection energy	0.4 GeV
Extraction energy	3.0 GeV
Repetition rate	25Hz
Harmonic number	2
Design beam power	1 MW

Main parameters of MR

Circumference	**1567.5 m**
Cycle time	**6 s for SX**
	2.48 s for FX
Injection energy	**3 GeV**
Extraction energy	**30 GeV**
Superperiodicity	**3**
h	**9**
Number of bunches	**8**
Rf frequency	**1.67 - 1.72 MHz**
Transition γ	**j 31.7 (typical)**

Physical Aperture	
3-50 BT Collimator	**54-65 π.mm.mrad**
3-50 BT physical ap.	**> 120 π.mm.mrad**
Ring Collimator	**54-65 π.mm.mrad**
Ring physical ap.	**> 81 π.mm.mrad**



Three dispersion free straight sections of 116-m long:
- Injection and collimator systems
- Slow extraction (SX)
to Hadron experimental Hall
-MA loaded rf cavities and Fast extraction(FX) (beam is extracted inside/outside of the ring)
outside: Beam abort line
inside: Neutrino beamline (intense ν beam is send to SK)

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 and RF cavities.

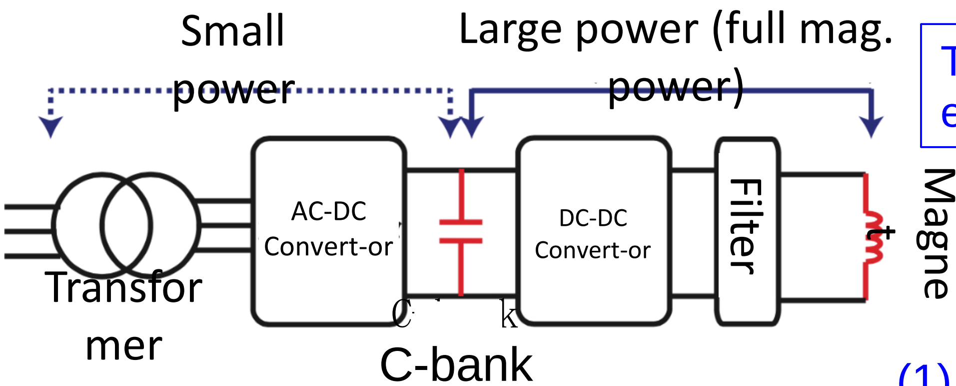
SX: Parts of stainless steel ducts are replaced with titanium ducts to reduce residual radiation dose. The beam power will be gradually increased toward 100 kW watching the residual activity.

JFY	2014	2015	2016	2017	2018	2019	2020
	Li. current upgrade		New PS buildings			New	
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 Higher rep rate	1.3 s	1.2 s
High gradient rf system **2nd harmonic rf system** **VHF cavity**	Manufacture, installation/test R&D	 R&D, manufacture, installation/test					
Ring collimators		Add.collimators	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					

[Assuming MR-PS upgrade is funded as scheduled]

New power supplies for 1 Hz operation

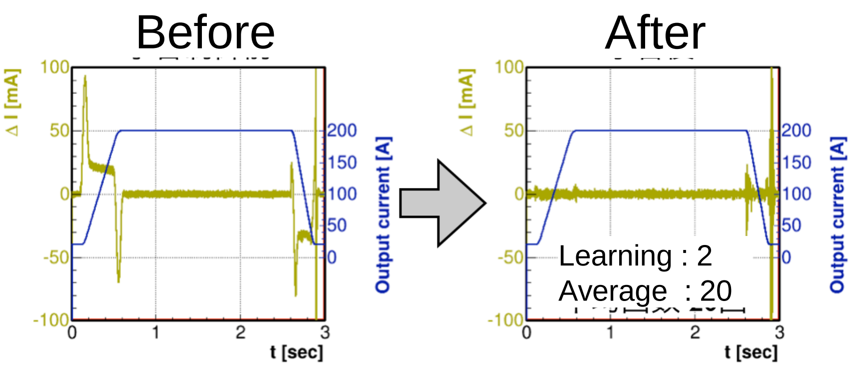
Large scale PS for bending magnets and quad. magnets in arc setions



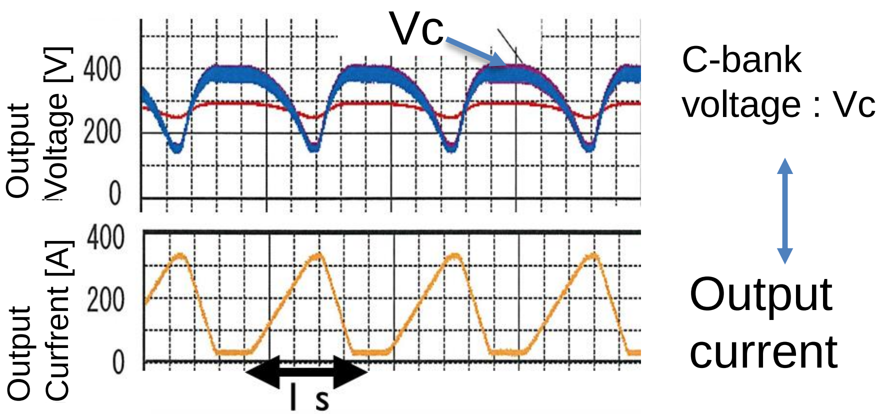
Two large converters and large capacitance for energy recovery, symmetric power module circuit

Repetition rate < 1.3sec, Ripple ~10^{-6}

(1) Proof of principle by a desk-top PS (2012)
(2) R&D of the small prototype PS (2013)
(3) R&D of the middle prototype PS (2014)



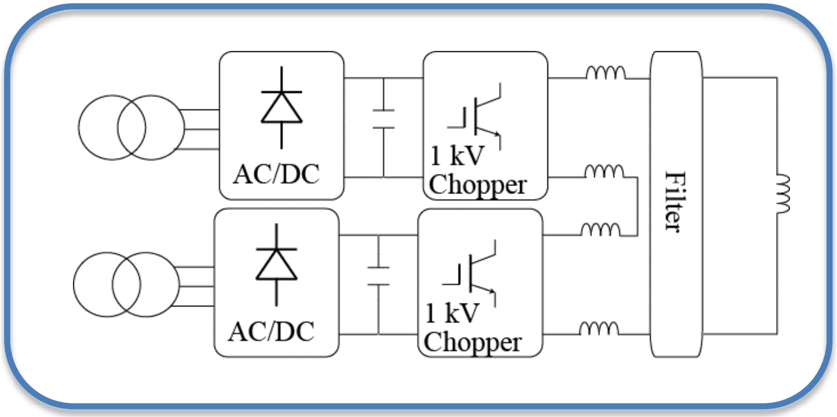
Self-learning control system



Power recovery by C-bank

R&D of new power supplies for 1 Hz operation (cont'd)

***Small scale PS** for Quad. Magnets in straight section and sextupole magnets*

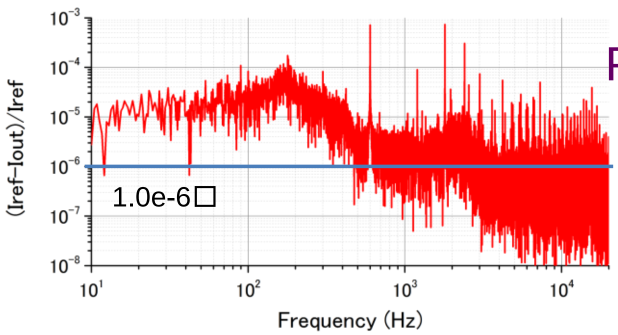


Diode rectifiers, two 1kV choppers are connected in series, symmetric power module circuit

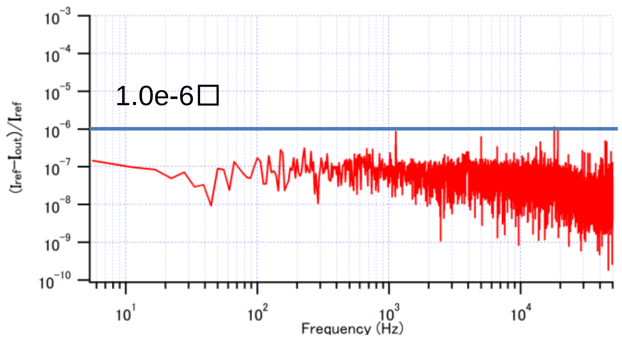
It is possible to build with the combination of existing products.

The model PS system was tested using the real sextupole magnet network.

Current ripple at 30 GeV



Present IGBT-PS



The new PS

Mass production will start in JFY2016 if the budget request is approved by the government.

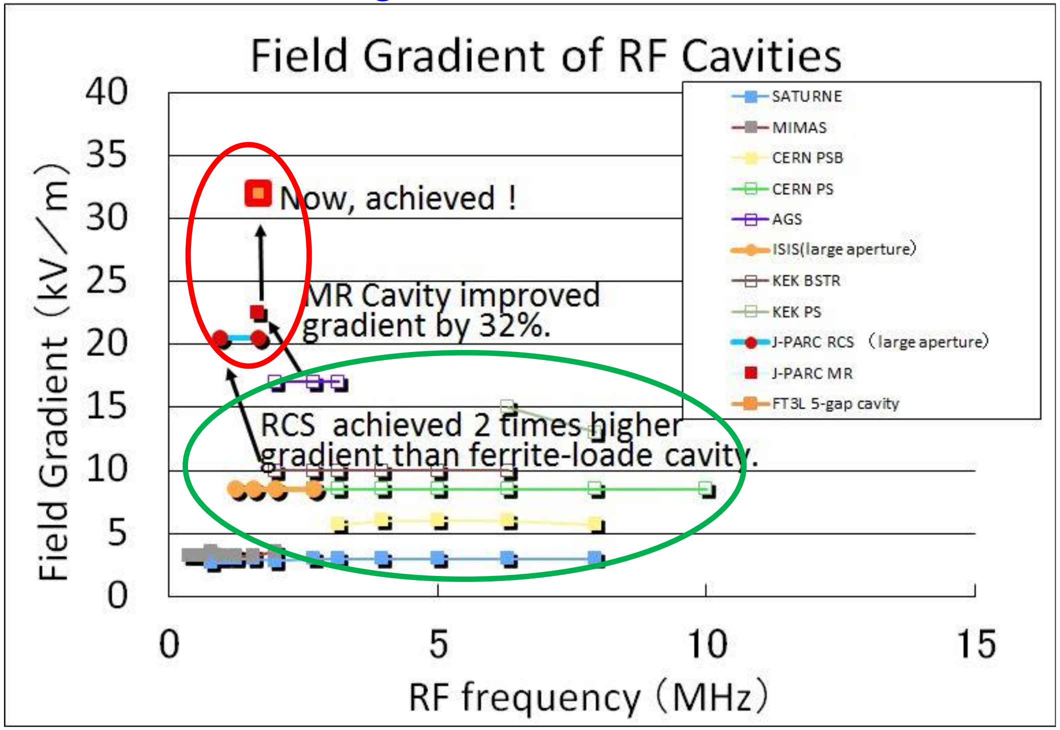
Plan of PS mass production

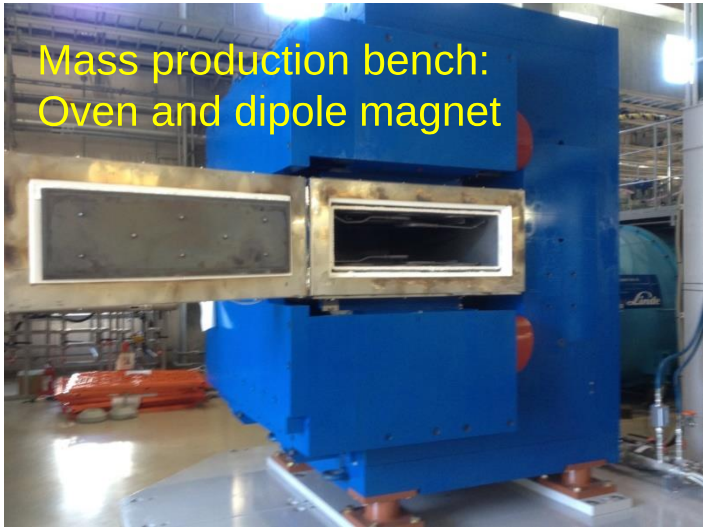
JFY	2015	2016	2017	2018
New buildings for new power supplies		D4,D5,D6		
Large PS (10) (B (6), Q (4))			B (3) Q (2)	B (3) Q (2)
Middle PS (1) (Q(1))	Leading PS for mass-production			
Small PS (9) (Q (6), S (3))		Q (6)	S (3)	
Cooling water system		D4,D5,D6		
Installation & tuning				

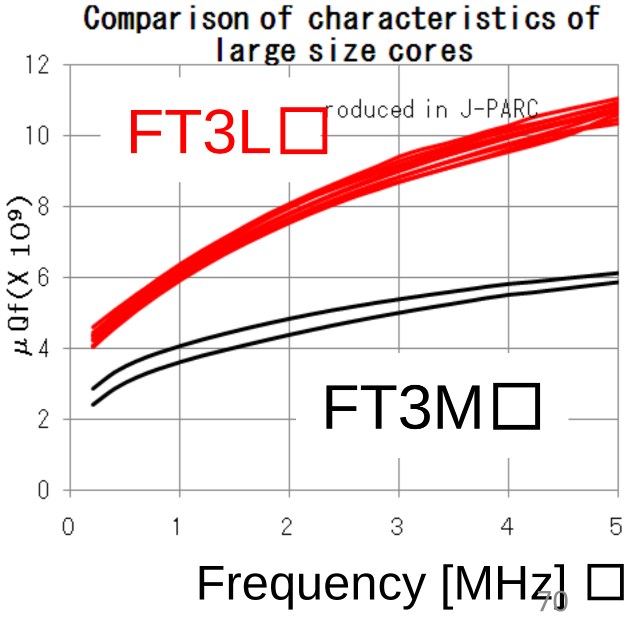
High impedance rf system

A new type of the magnetic alloy (MA) core, FT3L(made by Hitachi Metal), is adopted to increase shunt impedance of the rf cavity. The core is processed by annealing with magnetic field.

Comparison of field gradient of rf cavities for hadron rings.





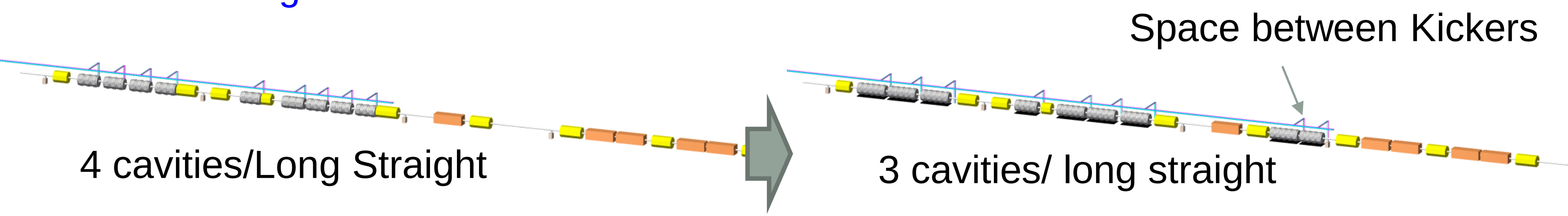


Performance of cavities depends on core materials: ferrite and MA.

J-PARC already achieved very high field gradient.

RF system for high repetition operation

Configuration of rf cavities



Before Replacement

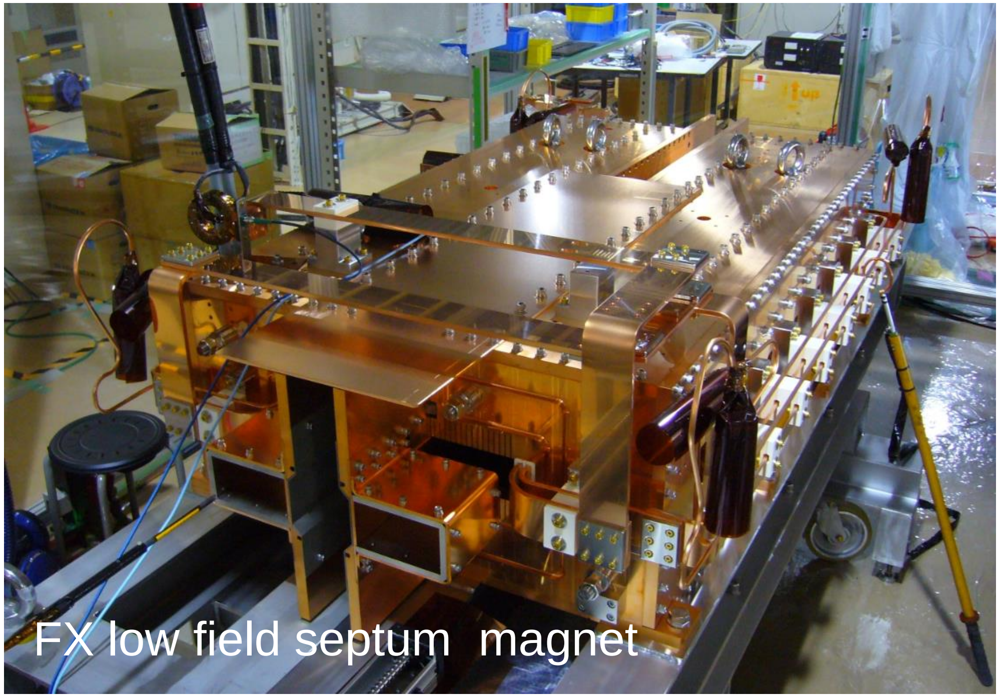
After Replacement

	2013	2014	2015	2016	2017	2018
	Li 400 MeV	*Li 50mA*				*MR 1.3-sec operation*
Present FT3M cavities	*9*	*8*	*4*	*0*	*0*	*0*
New FT3L Cavities	*0*	*1*	*5*	*9*	*9*	*9*
New FT3L 2nd cavity	*0*	*0*	*0*	*0*	*2*	*2*
Available voltage	*315 kV*	*355 kV*	*485 kV*	*602 kV*	*602 kV*	*602 kV*
(2nd Harmonic)	*(35 kV)*	*(70 kV)*	*(70 kV)*	*(70 kV)*	*(70 kV)*	*80 kV*
Number of cavity cells	*27*	*29*	*36*	*43*	*43*	*43+8(2nd)*

Required voltage: 280 kV(~2017), 540 kV(2018~)

Injection and FX septum systems

New injection septum magnet I and FX low field septum for high repetition rate operation have been manufactured and tested.



New injection septum:

- Stable (low vibration)
- Small leakage field ~ 10^{-4}
  (the current septum : 4×10^{-3})

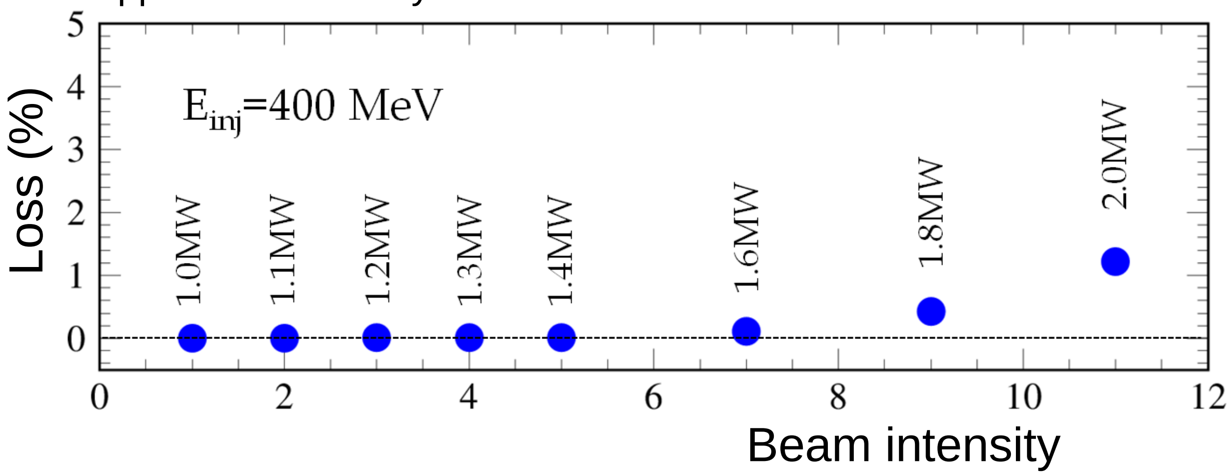
Eddy current type is adopted to the new FX low field septum

- Small Power Consumption (possible at low cooling capacity)
- Small Leakage Field ～10^{-4}
  (the current type septum： 10^{-3})
- Stable (low vibration)
- Thin Septum Thickness ～7 mm
  (the current septum：9.5mm)

They will be installed in the 2015 summer shutdown.

Feasibility of the RCS

Injection beam parameters:
Energy : 400 MeV
Peak current : 50 mA~100 mA
Pulse length: 0.5 ms
Chopper-beam on duty : 0.53



RCS intensity	Loss	Loss power at 25 Hz
1.0 MW	~0.3%	400 W
1.1 MW	~0.3%	440W
1.2 MW	~0.3%	480 W
1.3 MW	~0.3%	520 W
1.4 MW	~0.3%	560 W
1.6 MW	~0.5%	1067 W
1.8 MW	~0.7%	1680 W
2.0 MW	~1.5%	4000 W

RCS collimator limit ~4 kW
→ RCS has a feasibility to operate 2 MW

- Linac 100 mA/0.5 ms (50 mA/1.0 ms) operation is required.
  R&D of ion source / long pulse operation of linac
- The rf system should be replaced to compensate a heavy beam loading.
- The collimator capability should be upgraded to get a margin for the beam loss.
- Activation downstream of the charge exchange foils should be reduced.

….

Future proton driver for long-baseline neutrino experiment

The maximum beam intensity is limited by the physical aperture of the MR.

The scenarios for achieving much larger beam power than the design specification for neutrino experiment are now discussed.

1. Booster ring for the MR (emittance damping ring)

    The BR with an extraction energy ~ 8 GeV, is constructed between the RCS and the MR

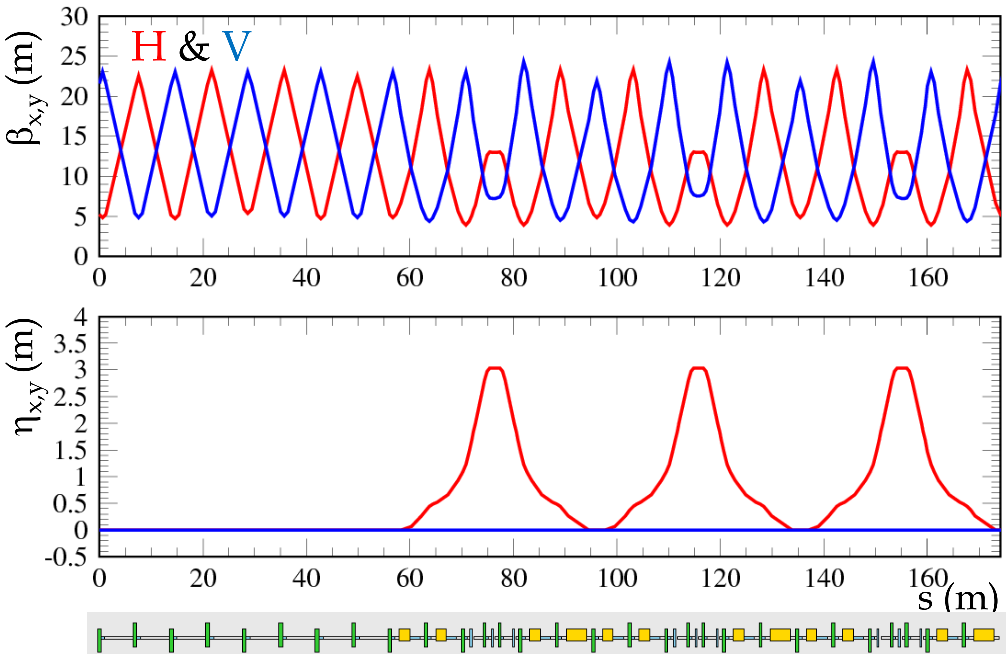
2. New proton linac for neutrino beam production

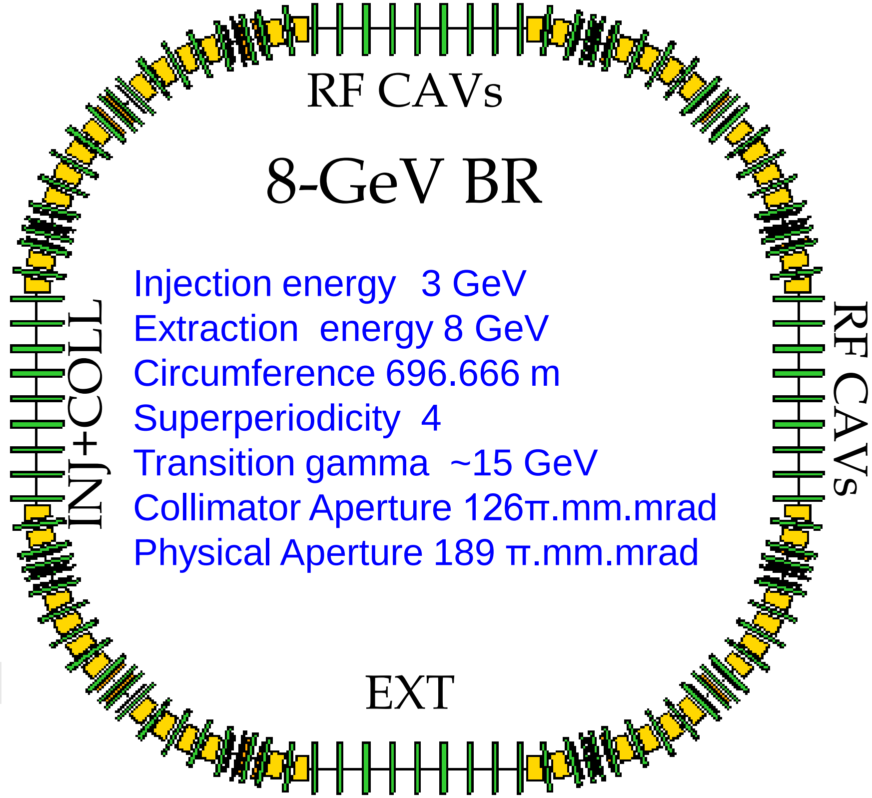
    (Construction site may not be the Tokai campus)

    - Linac with an beam energy > 9 GeV
    - The MR is operated only for the SX users

The 8-GeV booster ring

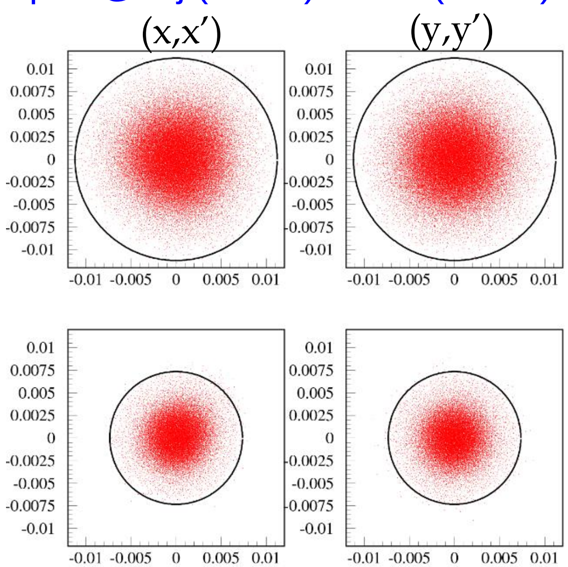
Beta & Dispersion for 1-superperiod





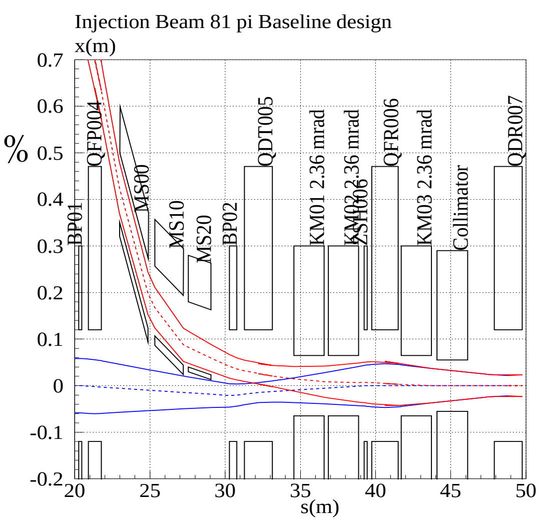
Injection energy 3 GeV
Extraction energy 8 GeV
Circumference 696.666 m
Superperiodicity 4
Transition gamma ~15 GeV
Collimator Aperture 126π.mm.mrad
Physical Aperture 189 π.mm.mrad

Phase plot @ inj.(3GeV) & extr.(8GeV)



@ 3GeV
ε>125.5π ~0.04%

@ 8GeV
ε>54π ~0.06%



8 GeV injection in the MR using new septa&kickers

RCS : 1.6 MW
MR > 2.6 MW

RCS : 2 MW
MR > 3.2 MW

Outline of the Proton Driver using ILC Cavity

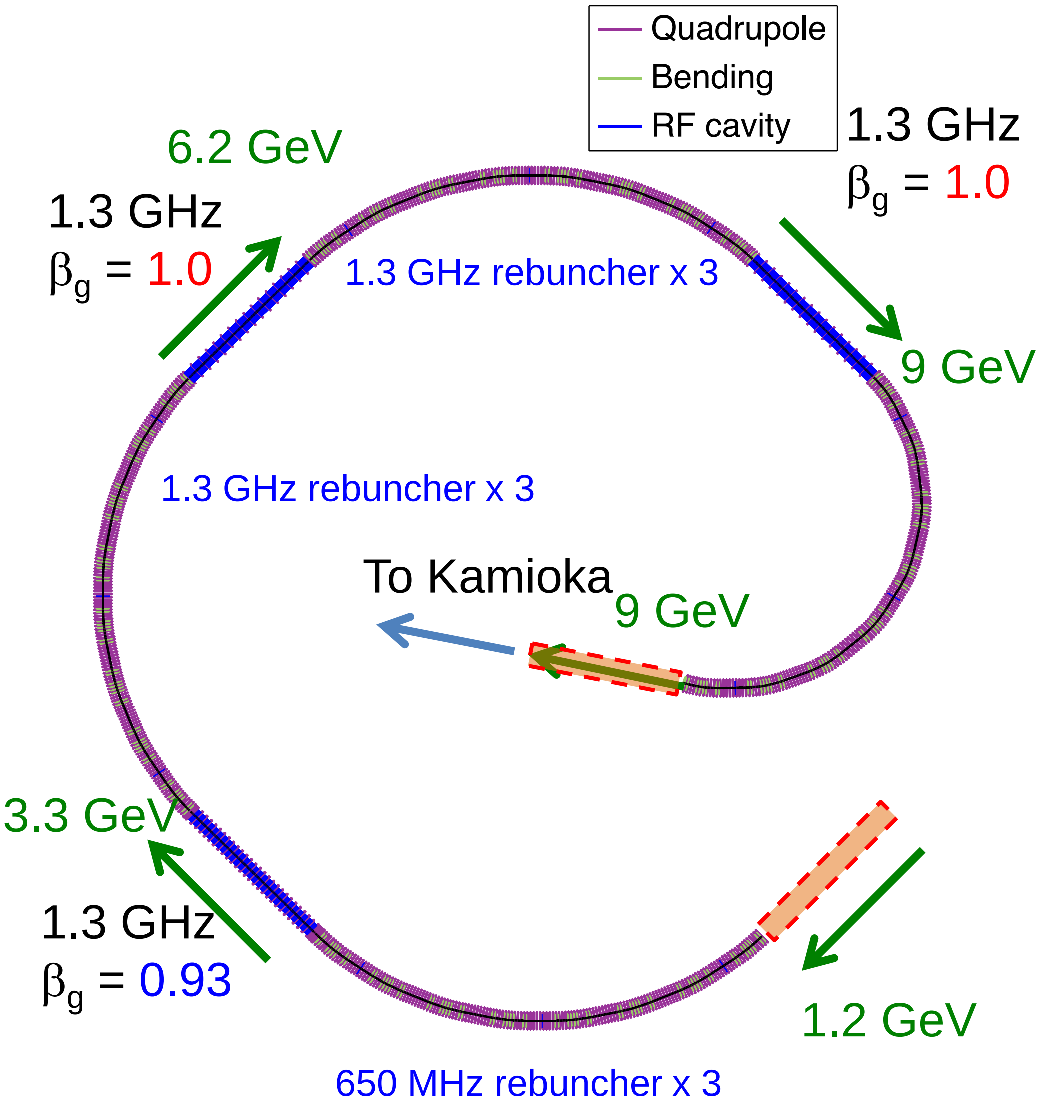
- Outline of acceleration :
    - 1.2 GeV in 1st straight.
    - 3.3 GeV in 2nd straight.
    - +2.9 GeV in 3rd and 4th straight.
      3.3 + 2.9 x 2 = 9.0 GeV

- Peak current : 100 mA (pulse)
- Beam duty : 1 %

- Beam power :
9000 MeV x 0.1 A x 1 % = **9 MW**

- β_g of SC cavities :
    - 2nd straight : β_g = **0.93**
    - 3rd and 4th straight: β_g = **1.0**

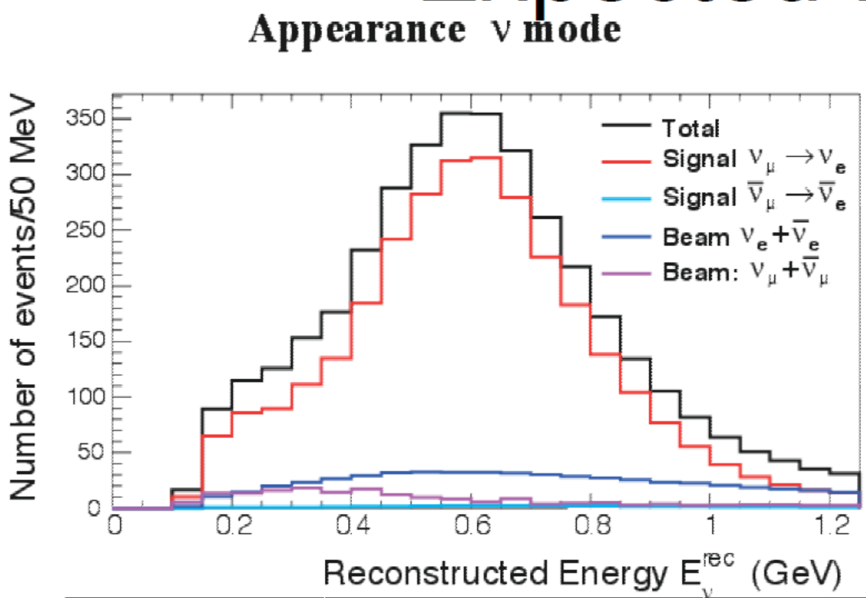
- Normalized RMS emittance
    - Transverse : 0.30 π･mm･mrad
    - Longitudinal : 0.37 π･MeV･deg

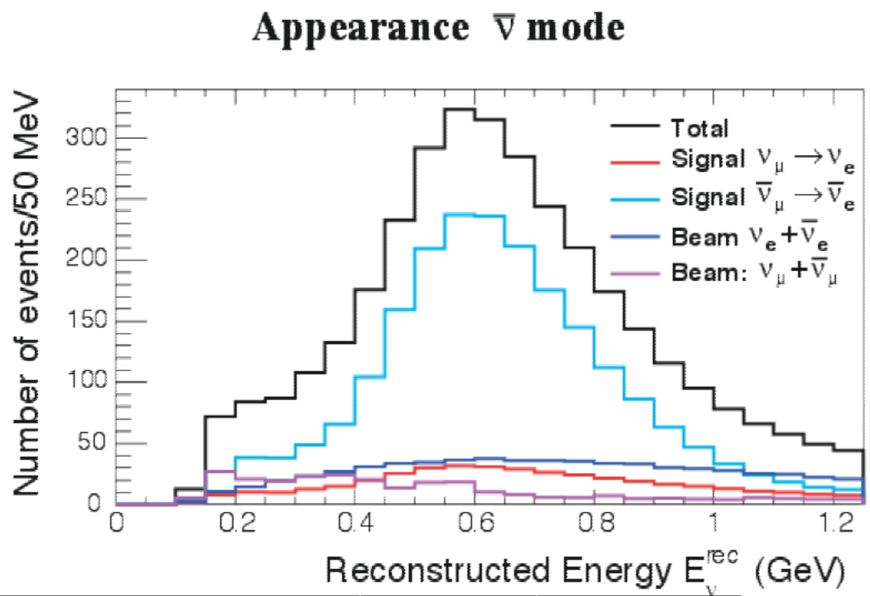


Hyper-Kamiokande

F. Di Lodovico,
Future Nu in J WS

Expected Events





Appearance	Signal		Background					Total
	$\nu_\mu \to \nu_e$	$\bar{\nu}_\mu \to \bar{\nu}_e$	ν_μ	$\bar{\nu}_\mu$	ν_e	$\bar{\nu}_e$	NC	
ν mode	3016	28	11	0	503	20	172	3750
$\bar{\nu}$ mode	396	2110	4	5	222	265	265	3397

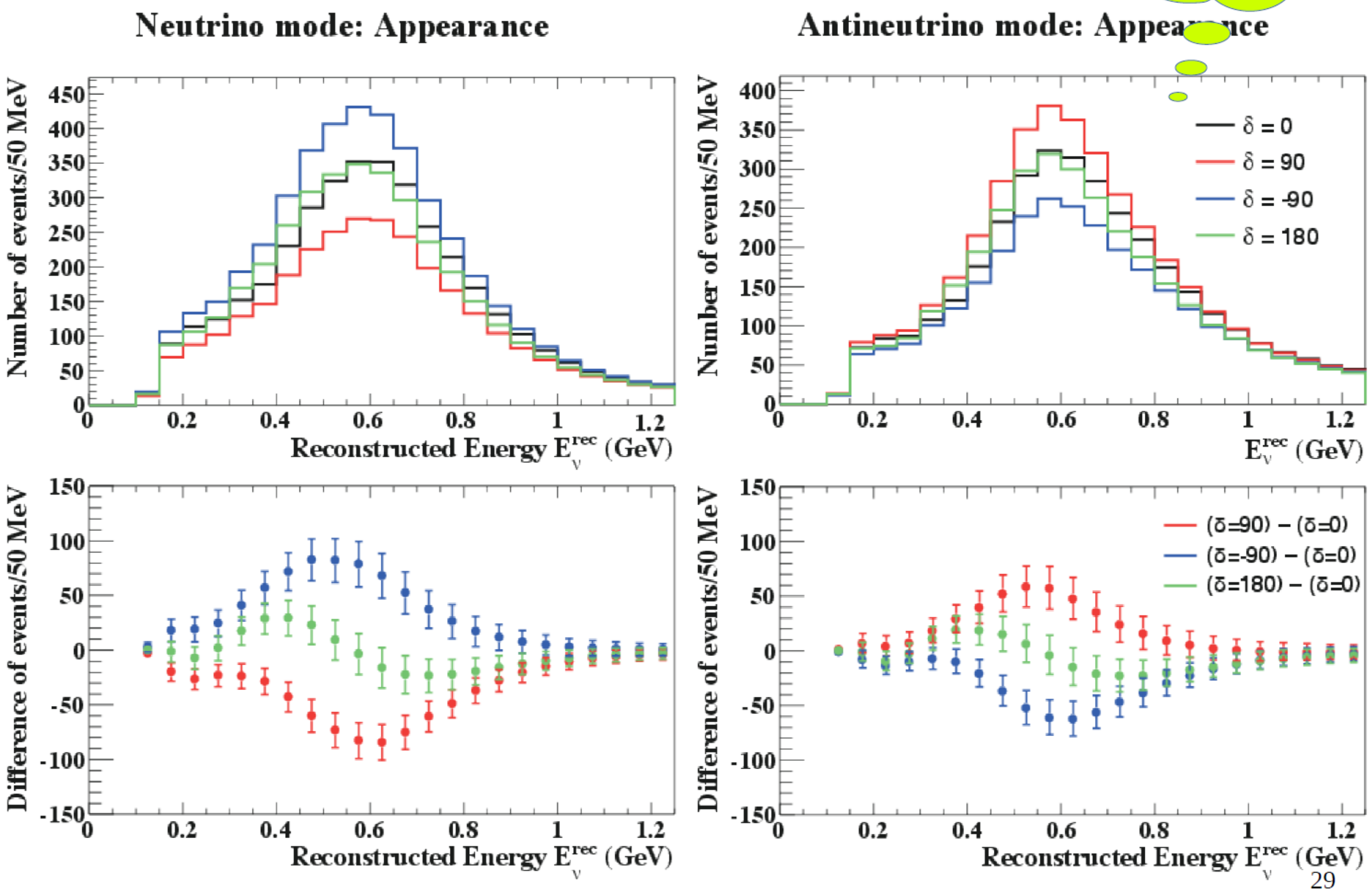
Disappearance	ν_μ	$\bar{\nu}_\mu$	ν_e	$\bar{\nu}_e$	NC	$\nu_\mu \to \nu_e$	Total
ν mode	17225	1088	11	1	999	49	19372
$\bar{\nu}$ mode	10066	15597	7	7	1281	6	26964

Large statistics

Large expected number of events. NH, $\sin^2 2\theta_{13} = 0{,}1$ and $\delta_{CP} = 0$

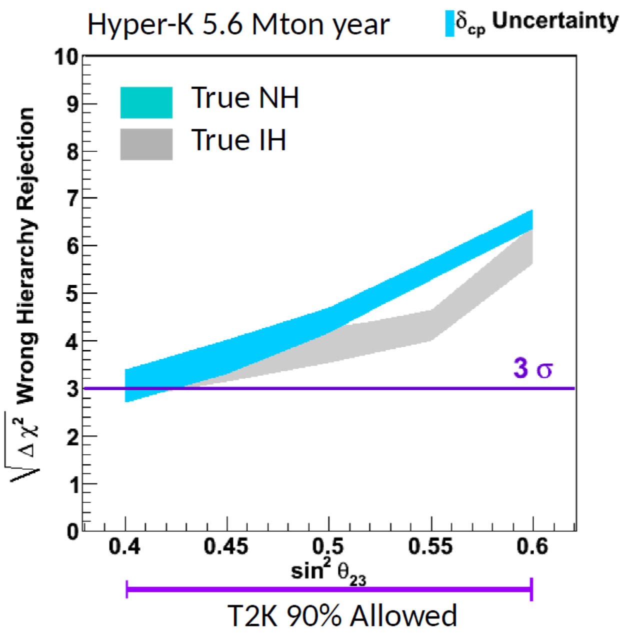
Expected Events

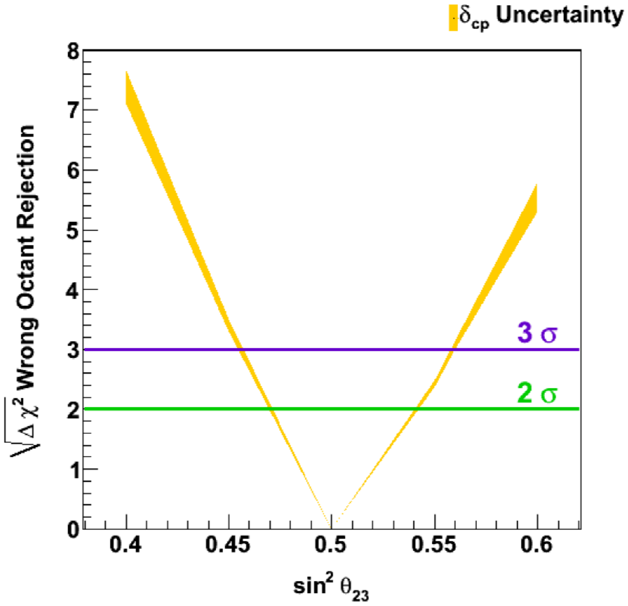
Also shape relevant for CPV



Sensitivity on MH and octant from HK Atm-nu measurements

Hyper-K Sensitivity 10 Years





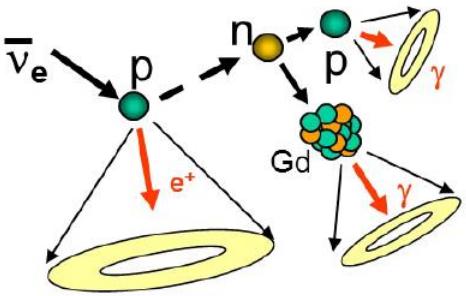
- Expect better than ~3σ sensitivity to the mass hierarchy using atmospheric neutrinos alone
- 3σ Octant determination possible if $\sin^2 2\theta_{23} < 0.99$

Gadolinium Option

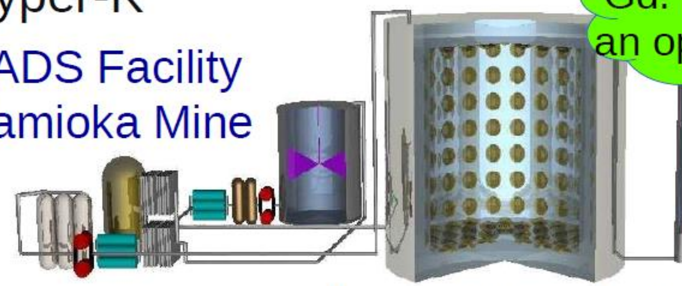
Beacom and Vagins, *Phys. Rev. Lett.*, 93:171101, 2004 [226 citations]

- Gd-doping proposed in 2004 mainly to greatly enhance supernova neutrino detection.
- It can help also other physics
  - Beam physics → distinguish ν and $\bar{\nu}$; CCQE and other ν-interactions
  - Proton decays → reduce background
- R&D programme started with EGADS (200ton scale model of Super-K)
- Now finishing → Super-K will run with the Gd-doping
- Considered as possible option for Hyper-K

SK will have Gd. It could be an option for HK



EGADS Facility in Kamioka Mine



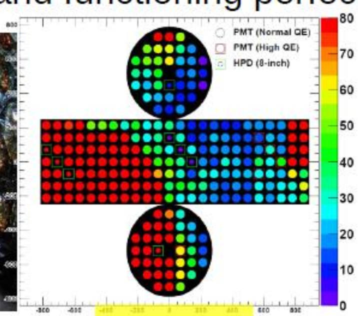
April 2015: fully loaded (0.2%) with Gd sulfate, and functioning perfectly.

EGADS:

12/2009

11/2011

8/2013



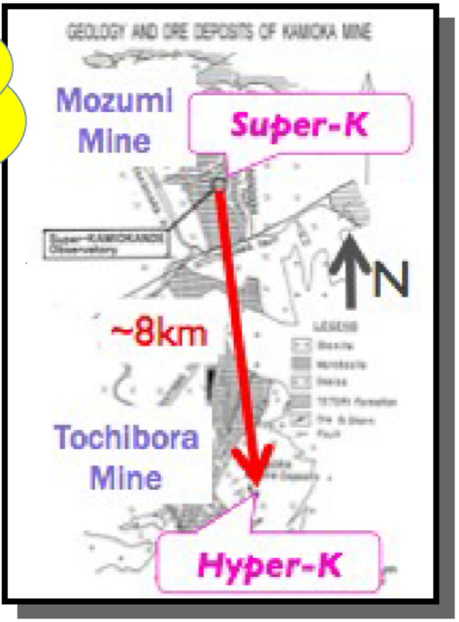
6/2015

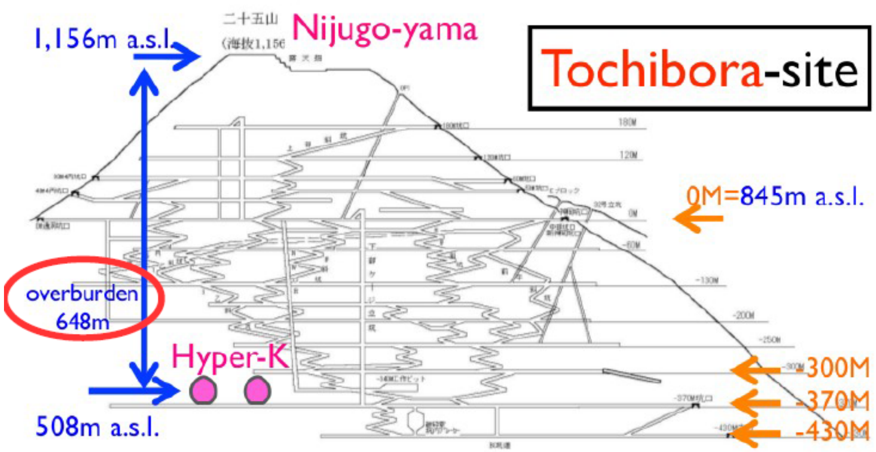
Site(s) and Cavern(s)

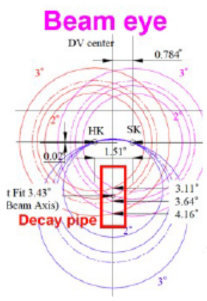
Two sites are being investigated:

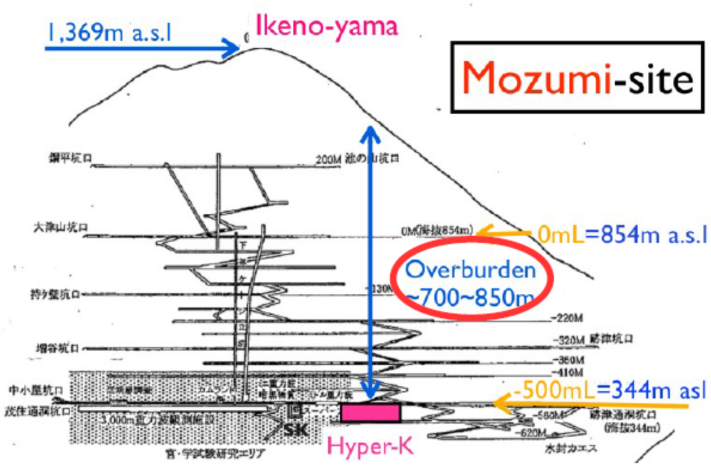
- Tochibora mine:
  - ~8km South from Super-K
  - Identical baseline (295km) and off-axis angle (2.5º) to Super-Kamiokande
- Mozumi mine (same as Super-K)
  - Deeper than Tochibora
- Rock quality in the two sites similar
- Confirmed HK cavern can be built w/ existing techniques

Two options but nominal case is Tochibora.









Hyper-K Sensitivity to δ_{CP}

Errors being re-evaluated

- Based on experience and prospects of T2K.
- Three main categories of systematic uncertainties:
  - Flux and cross section uncertainties constrained by the fit to current ND.
  - Cross section uncertainties not constrained by the fit to current ND data: errors reduced as more categories of samples are added to ND fit.
  - Uncertainties on the far detector reduced as most of them are estimated by using atmospheric neutrinos as a control sample (larger stat at Hyper-K).

Errors (%) on the expected number of events				
	ν mode		$\bar{\nu}$ mode	
	ν_e	ν_μ	ν_e	ν_μ
Flux & Near Detector (ND)	3.0	2.8	5.6	4.2
ND-independ. xsect	1.2	1.5	2.0	1.4
Far Detector	0.7	1.0	1.7	1.1
Total	3.3	3.3	6.2	4.5

- Planning to update errors and thus sensitivities based on the discussions on the T2K upgrade.

“Other” Beam Physics

Apart from the mixing parameters, there is a rich landscape of physics topics:

- Cross section measurements – mainly at the near detector suite.
- Consistency checks of three flavour framework (e.g. PMNS unitarity), combination with other LBN and atmospheric experiments, etc.
- Physics that goes beyond the three flavour paradigm, examples:
  - Non-standard interactions → deviations from the three-flavor mixing model
  - Lorentz and CPT violation → sidereal neutrino oscillations
  - New long-distance potentials arising from discrete symmetries
  - Sterile neutrino states that mix with the three known active neutrino states

Studies currently under way to estimate the sensitivity

Comment on Leptonic Unitarity

500 km/GeV

15,000 km/GeV

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

flavor states

Mass Eigenstates

If the PMNS matrix is unitary we expect these relations (for l = e, μ, τ)

Normalization $$N_l \equiv \sum_{i=1,2,3} |U_{li}|^2 = 1$$

Triangle $$T_{lm} \equiv \sum_{i=1,2,3} U_{li} U^*_{mi} = 0$$

- The pieces of the matrix that can be probed depend on L and E of neutrino source
  - Hyper-K will have both “fixed” L/E (beam) and “varying” L/E (atmospheric ν)
- Computations assume that the U_{pmns} is unitary, but this can be tested
  - Models of new physics (SeeSaw, SUSY) predict U_{pmns} is piece of a larger matrix
- For LBL νμ disappearance: $|U_{\mu 3}|^2 \left(1 - |U_{\mu 3}|\right) \rightarrow \frac{|U_{\mu 3}|^2 \left(|U_{\mu 1}|^2 + |U_{\mu 2}|^2|\right)}{\sum_i |U_{\mu i}|^2|}$
- Hyper-Kamiokande can probe many elements of this matrix *by itself* with combined beam and atmospheric neutrino measurements

Comment on Leptonic Unitarity

If Unitarity is NOT assumed, then to first order

$$
\left\{
\begin{array}{ll}
\text{LBL } \nu_\mu \to \nu_\mu & |U_{\mu 3}|^2 (|U_{\mu 1}|^2 + |U_{\mu 2}|^2|) \\
\text{LBL } \nu_\mu \to \nu_e & \mathbb{R}\{U_{\mu 3} U_{e3}^* (U_{\mu 1} U_{e2}^* + U_{\mu 3} U_{e2}^*)\} \\
\text{ATM } \nu_\mu \to \nu_\tau & \mathbb{R}\{U_{\mu 3} U_{\tau 3}^* (U_{\mu 1} U_{\tau 2}^* + U_{\mu 3} U_{\tau 2}^*)\} \\
\text{ATM Reson } \nu_\mu \to \nu_e & (r|U_{\mu 3}|^2 - 1) \\
\text{ATM Sub-GeV } \nu_\mu \to \nu_\mu & |U_{\mu 1}|^2 |U_{\mu 2}|^2
\end{array}
\right.
$$

- Typically single oscillation channels are sensitive to multiple parts of the mixing matrix
  - true for any experiment
- However atmospheric neutrino measurements have sufficient breadth in L/E to have some sensitivity to both "1-2" and "2-3" columns of the mixing matrix (in principle)
  - separating $U_{\mu 1}$ and $U_{\mu 2}$ with (1.0~3.0 GeV data)
- To really make progress improvements in detector performance and systematic errors (flux, cross-section) will be essential

$$
\begin{pmatrix}
U_{e1} & U_{e2} & U_{e3} \\
U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\
U_{\tau 1} & U_{\tau 2} & U_{\tau 3}
\end{pmatrix}
$$

$$
\begin{pmatrix}
U_{e1} & U_{e2} & U_{e3} \\
U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\
U_{\tau 1} & U_{\tau 2} & U_{\tau 3}
\end{pmatrix}
$$

Hyper-K's Sensitivity to Other Decay Modes

Mode	Sensitivity (90% CL) [years]	Current limit [years]
$p \rightarrow e^+\pi^0$	13.0×10^{34}	1.7×10^{34}
$p \rightarrow \overline{\nu}K^+$	3.2×10^{34}	0.78×10^{34}
$p \rightarrow \mu^+\pi^0$	9.0×10^{34}	1.1×10^{34}
$p \rightarrow e^+\eta^0$	5.0×10^{34}	0.42×10^{34}
$p \rightarrow \mu^+\eta^0$	3.0×10^{34}	0.13×10^{34}
$p \rightarrow e^+\rho^0$	1.0×10^{34}	0.07×10^{34}
$p \rightarrow \mu^+\rho^0$	0.37×10^{34}	0.02×10^{34}
$p \rightarrow e^+\omega^0$	0.84×10^{34}	0.03×10^{34}
$p \rightarrow \mu^+\omega^0$	0.88×10^{34}	0.08×10^{34}
$n \rightarrow e^+\pi^-$	3.8×10^{34}	0.20×10^{34}
$n \rightarrow \mu^+\pi^-$	2.9×10^{34}	0.10×10^{34}

- Generally speaking, Hyper-K is expected to have an order of magnitude better sensitivity than Super-K to many decay channels

- For background dominated modes, like $p \rightarrow e^+X$, $\mu^+\nu\nu$, $\nu\pi^+$ etc., the improvement is roughly a factor of 4 or 5

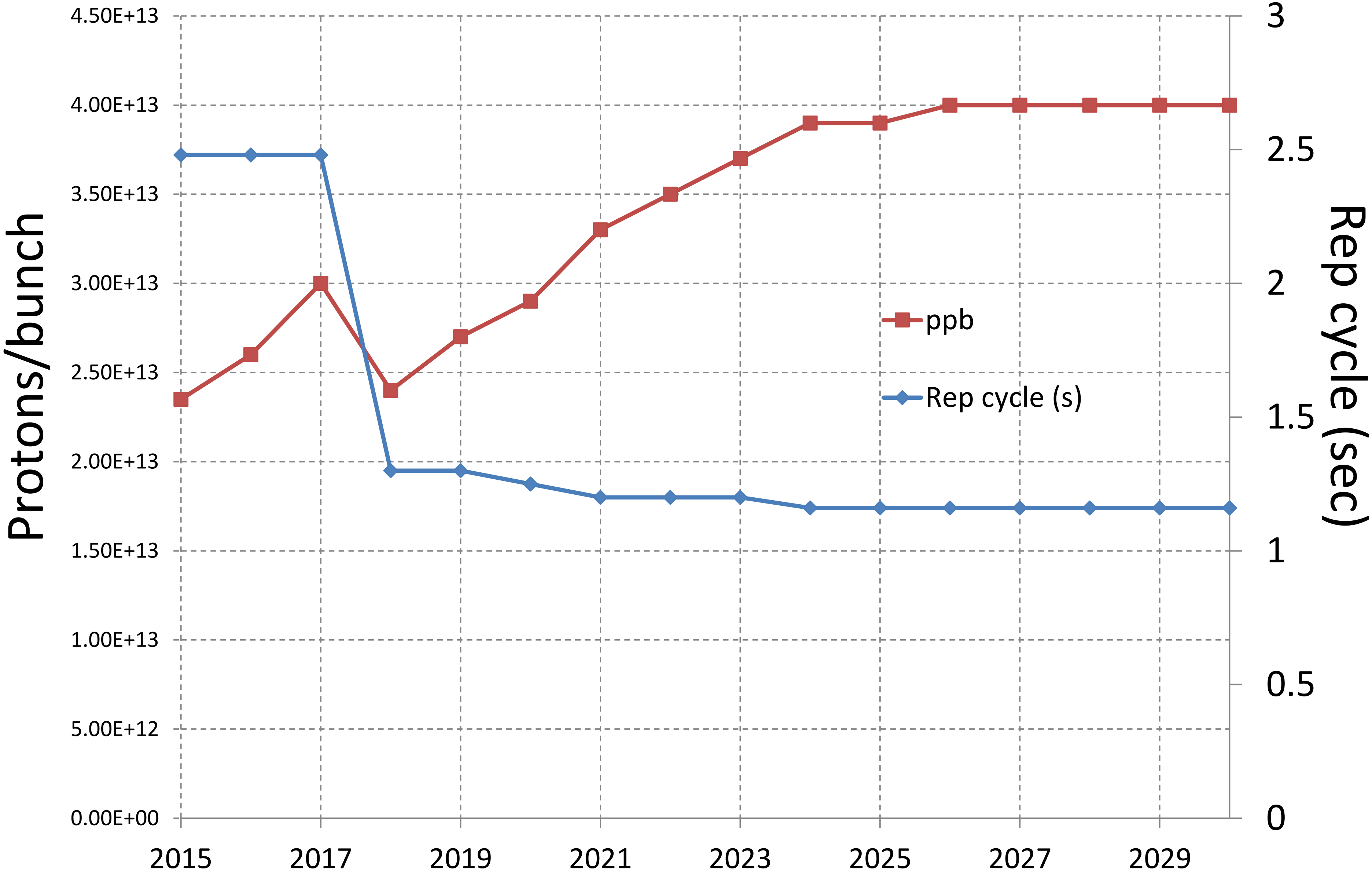
Other Physics at *Hyper-K*

- Atmospheric neutrino flux measurements
- Tau neutrino studies (oscillation-induced, cross section)
- Non-standard Neutrino Interactions in atmospheric neutrinos
- Search for WIMP annihilation at the center of the Earth
- Various nucleon decay modes
  - $p \to \nu \pi^+$, $n \to \nu \pi^0$
  - $p \to l^+ M^0$ (other antilepton + meson modes)
  - $n \to l^- M^+$ (Recent theoretical interest)
  - B+L modes
  - dinucleon decay modes
- $n \leftrightarrow \bar{n}$ oscillations
- Astrophysical neutrino source search
- ...

- The statistical uncertainty at Super-K on many of the analyses above is large so generically we can expect improvements at Hyper-K

T2K2

Assumed ppb & rep cycle



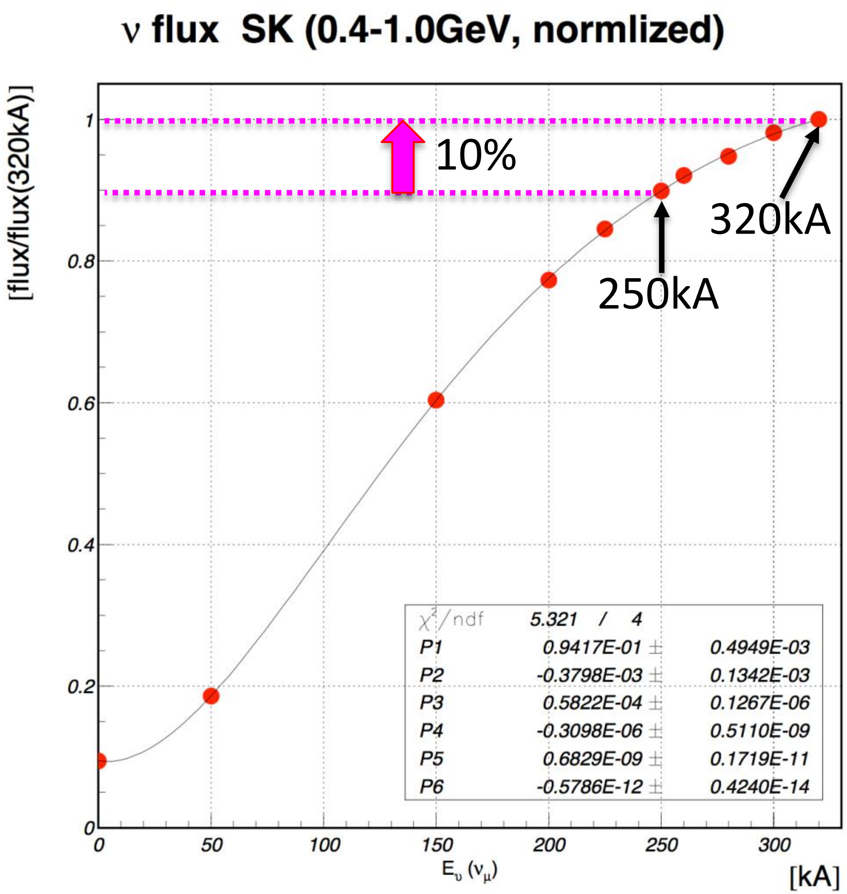
Hardware Improvement (Assumption)

Flux gain by Horn current 250kA → 320kA

- **10% flux gain with 320kA**

Implementation plan

- Three power supplies for three horns
  - Two of three already produced.
  - Two new transformers (one curren being produced).
- Aiming to start 320kA operation from 2017 fall.
  - Timely budget approval is necessar

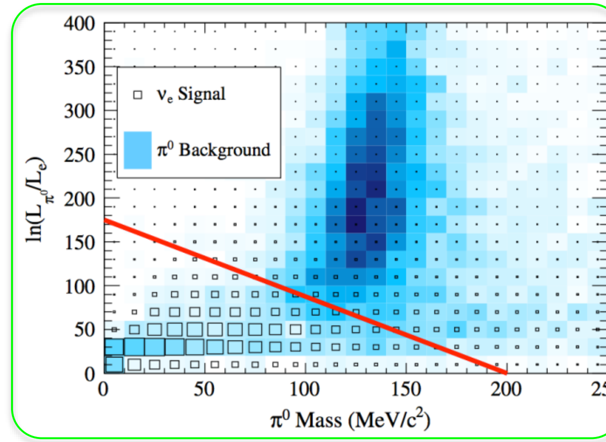


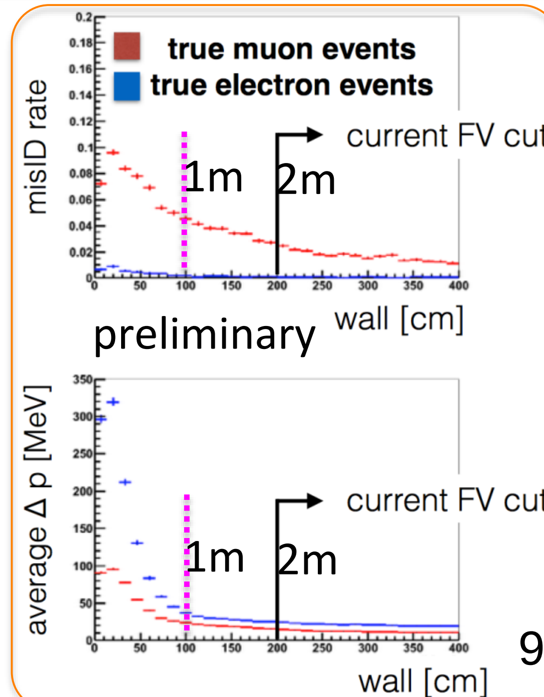
Courtesy of T.Nakadaira

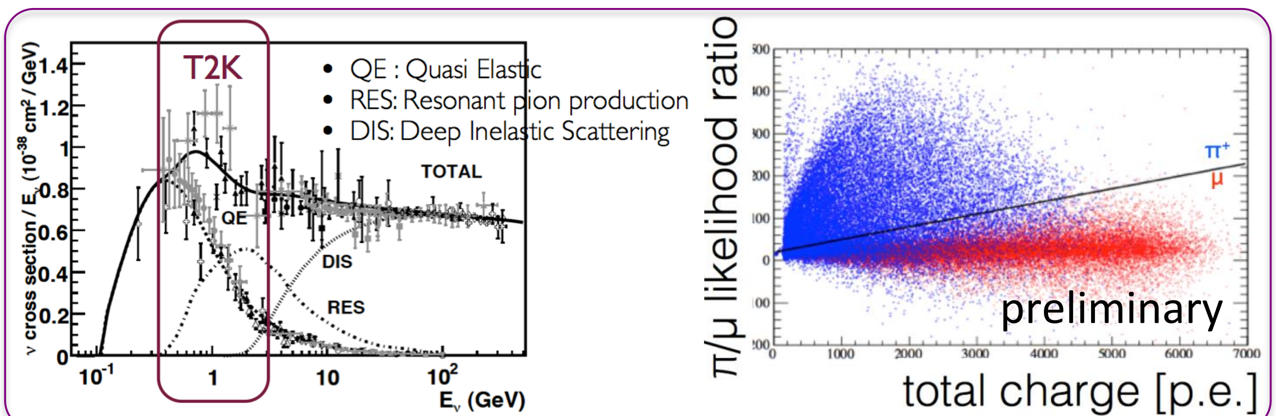
Possible Analysis Improvement

Development of new event reconstruction algorithm for SK

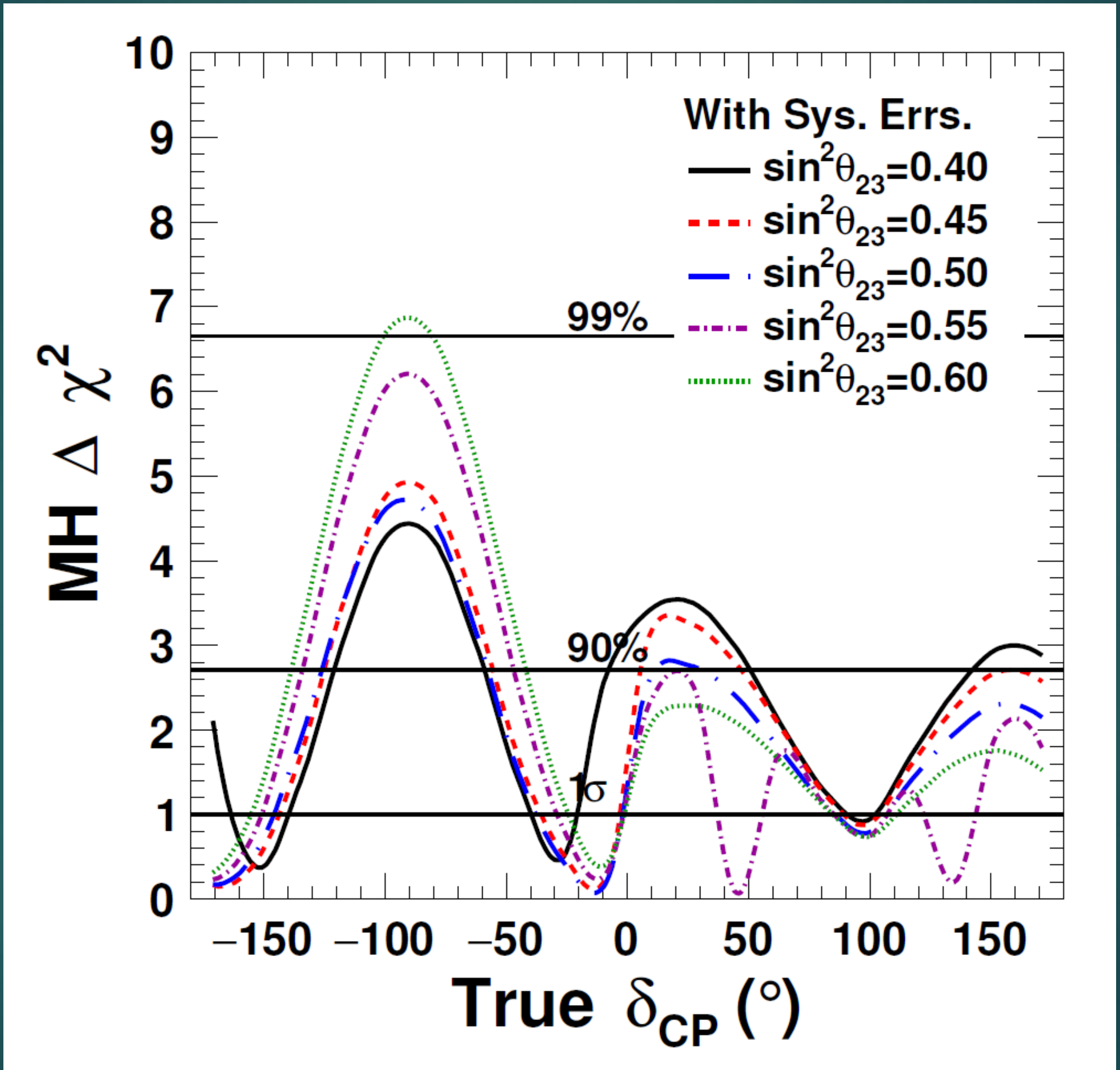
- Better π^0 rejection (done)
- Better vertex resolution:
    - Fid. vol. cut from ID wall
      – 2m → 1m (being studied)
      – ~20% gain
- Better PID → π/μ separation in SK.
    - Exclusive CC1π sample (being studied)
      – ~10% gain by using the sample.







Sensitivity of "T2K2" on MH

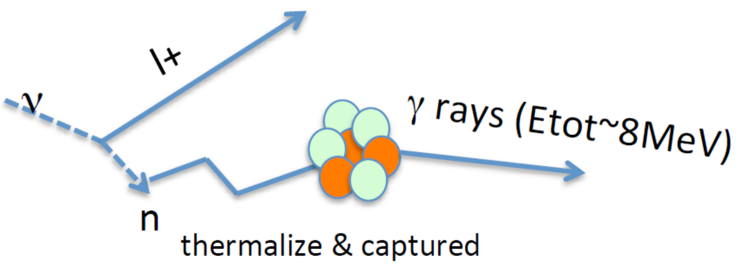


Kameda(ICRR, U.Tokyo)
Aug.11

Super-K-Gd project

=Water Cherenkov detector with Gd dissolved water as neutron absorber

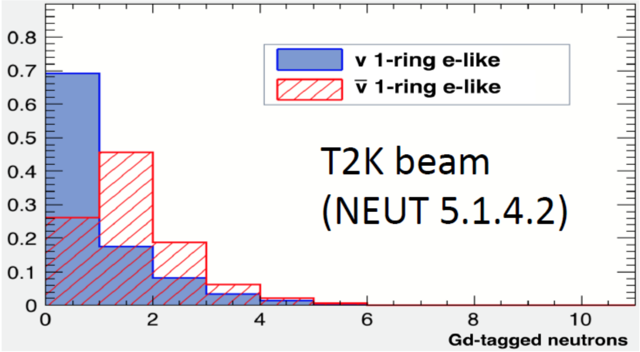
- High efficient neutron tagging using 0.2% $Gd_2(SO_4)_3$ dissolved water.
- Delayed coincidence of γ-ray signal from thermal neutron capture on Gd.



Physics targets:

- Supernova relic neutrino (SRN)
- Reduce proton decay background
- Neutrino/anti-neutrino discrimination (Long-baseline and atm nu's)

and more..



- 5yr evaluation experiment (EGADS) tests water quality, materials, basic techniques,..
- On June 27, 2015, the Super-Kamiokande collaboration approved the Super-K-Gd project.
- Actual schedule including refurbishment of the tank, Gd loading time will be determined soon taking into account the T2K schedule.

Minamino
M.Hartz

Physics requirements vs. detectors (my personal view)

	ν_e cross section	H_2O target	4π accep.	Wrong sign BG	NC, Int. ν_e BG	Muon FS vs. ν	Hadronic FS	# of neutron (Gd)	$CC\pi^0$
Current ND280	OK	OK	OK	Good	OK	OK	OK	Not Good	OK
ND280 (WAGASCI)	OK	Good	Good	Good	OK	OK	OK	Not Good	OK
ND280 (HP-TPC)	Not Good	Not Good	Good	Good	OK	OK	Good	Not Good	OK
ND280 (WbLS)	OK	Good	OK	Good	OK	OK	OK	Not Good	OK
ND280 (Emulsion)	OK	Good	Good	Good	OK	OK	Good	Not Good	OK
νPRISM	Good	Good	Good	OK	Good	Good	Not Good	OK	Good
TITUS	Good	Good	Good	Good	Good	OK	Not Good	Good	Good

(Green) = Good (Yellow) = OK (Red) = Not Good