Status of Long-Baseline Neutrino Oscillation Experiments in Japan

J-PARC

T. Ishida

Neutrino Section, J-PARC Center, KEK

on behalf of the neutrino beam group

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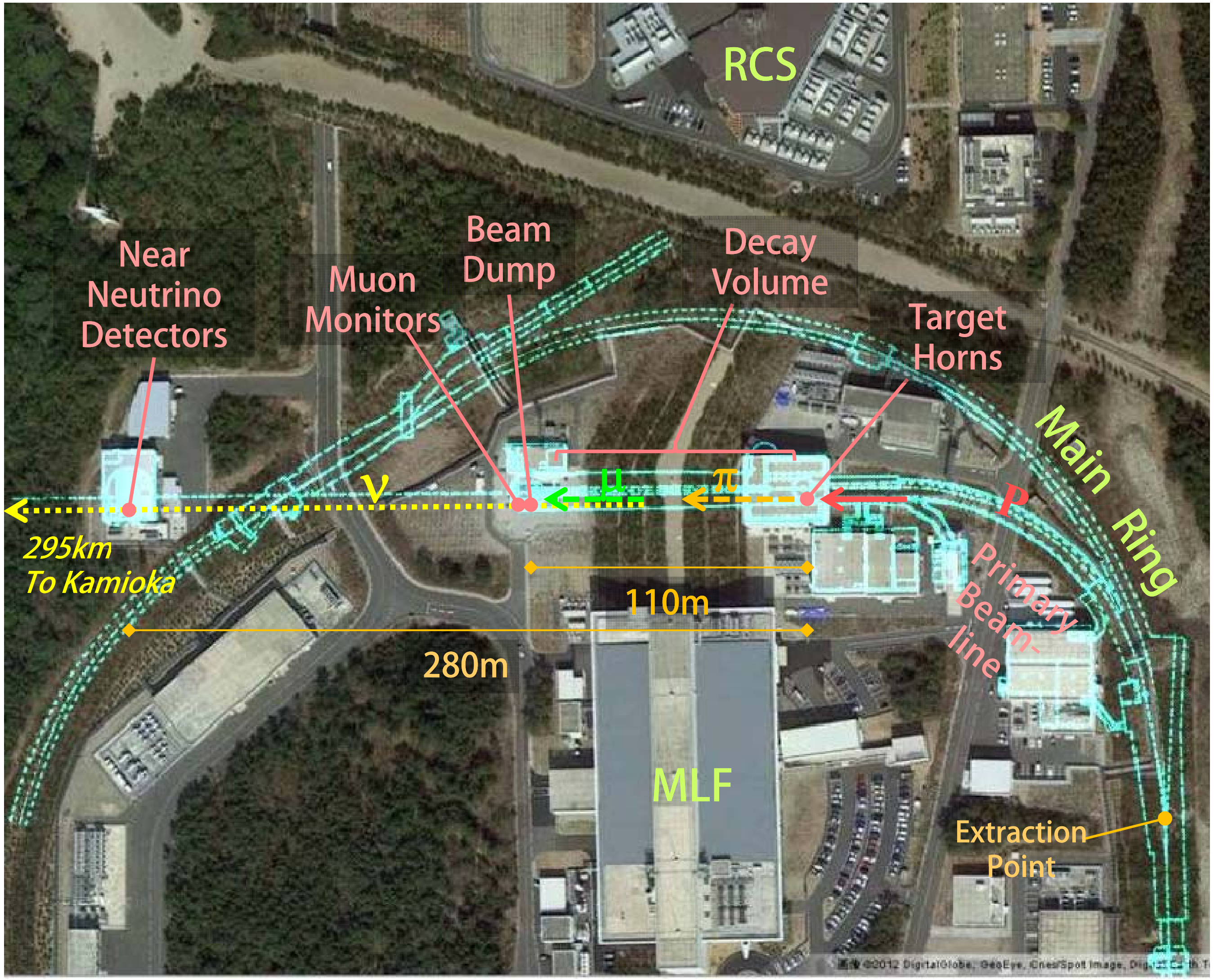
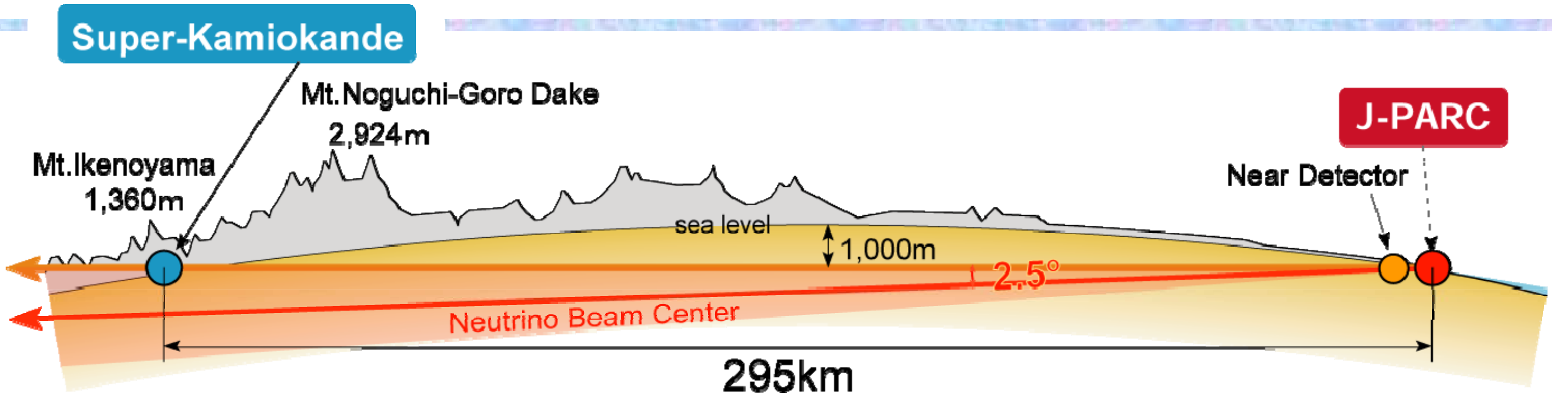
1. Neutrino experimental facility at J-PARC

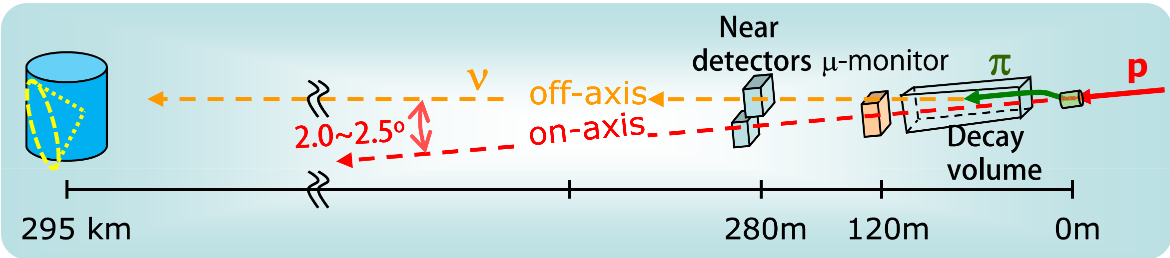
- Conventional (horn-focused) beam-line, designed/constructed for T2K long base-line neutrino oscillation experiment & for its future upgrade to Hyper-Kamiokande

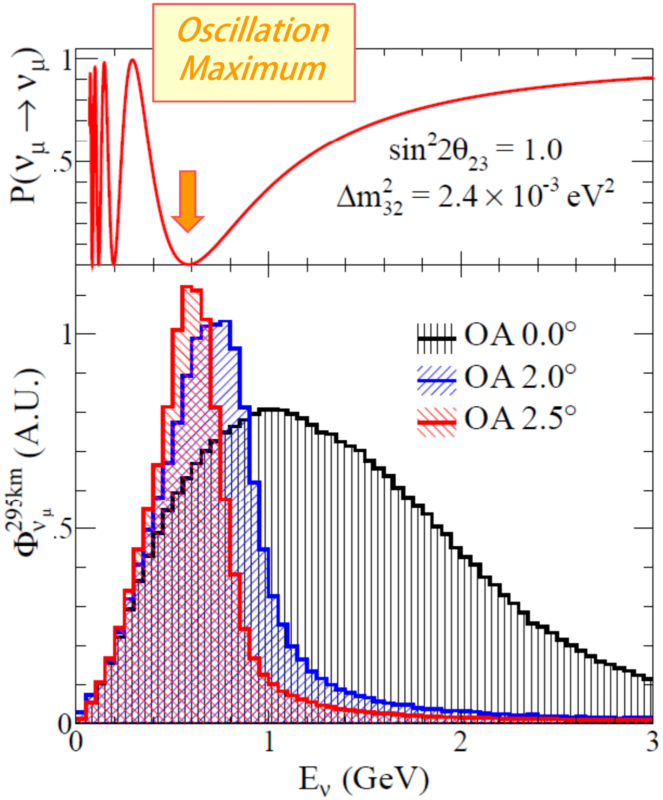


J-PARC, Tokai

Schematic overview: Tunable off-axis beam



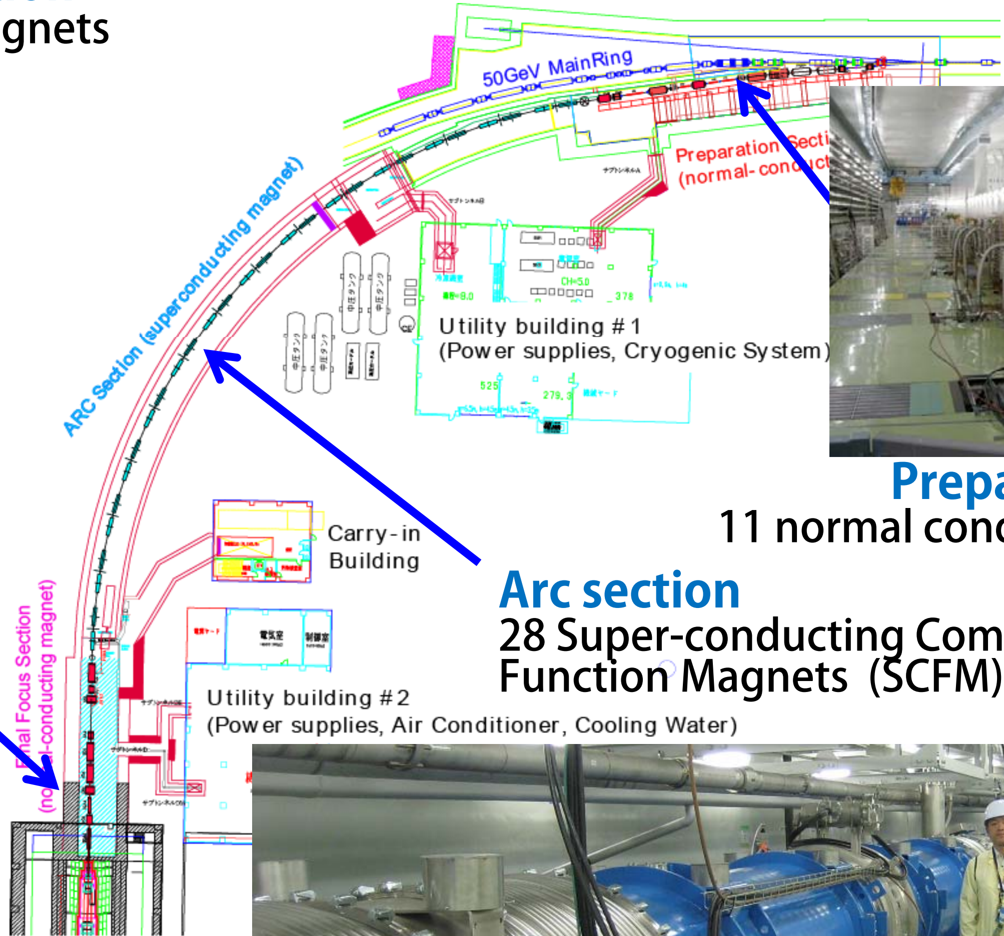




- Conventional "horn-magnet-focused" ν beam
  - 30GeV Protons on a graphite target
  - daughter $\pi^+ \rightarrow \mu^+ + \nu_\mu$
- First application of Off-Axis(OA) beam: 2.0~2.5° wrt. the far detector direction
  - Low-energy narrow-band beam
  - peak tuned to oscillation maximum
  - Small high-energy tail: reduce backgrounds

Primary beam-line

Final focusing (FF) section
10 normal conducting magnets



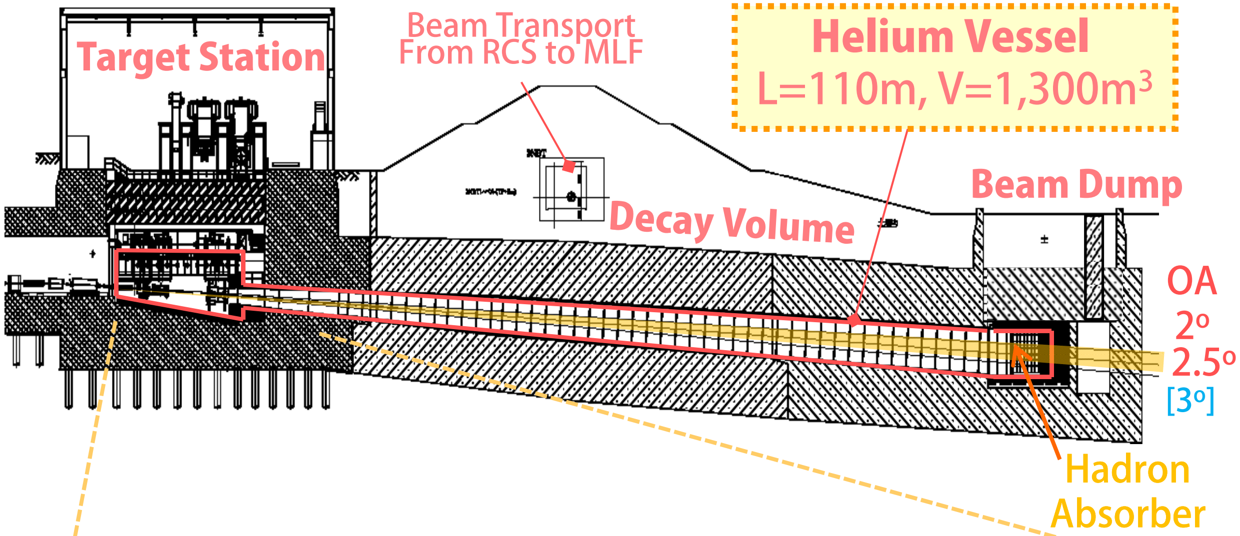
Preparation section
11 normal conducting magnets

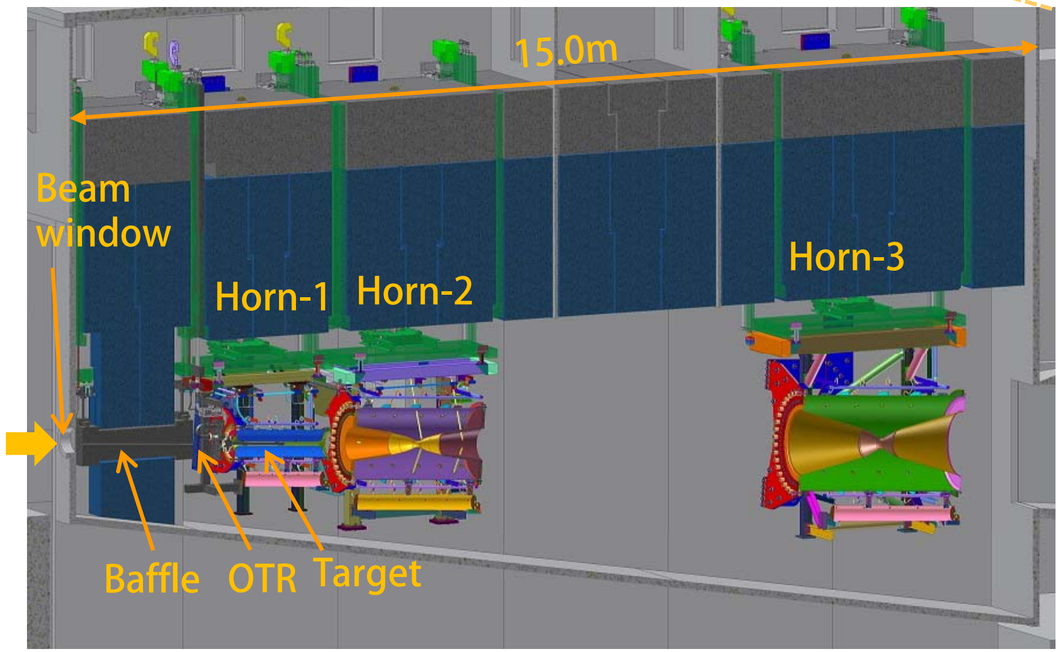
Arc section
28 Super-conducting Combined Function Magnets (SCFM)

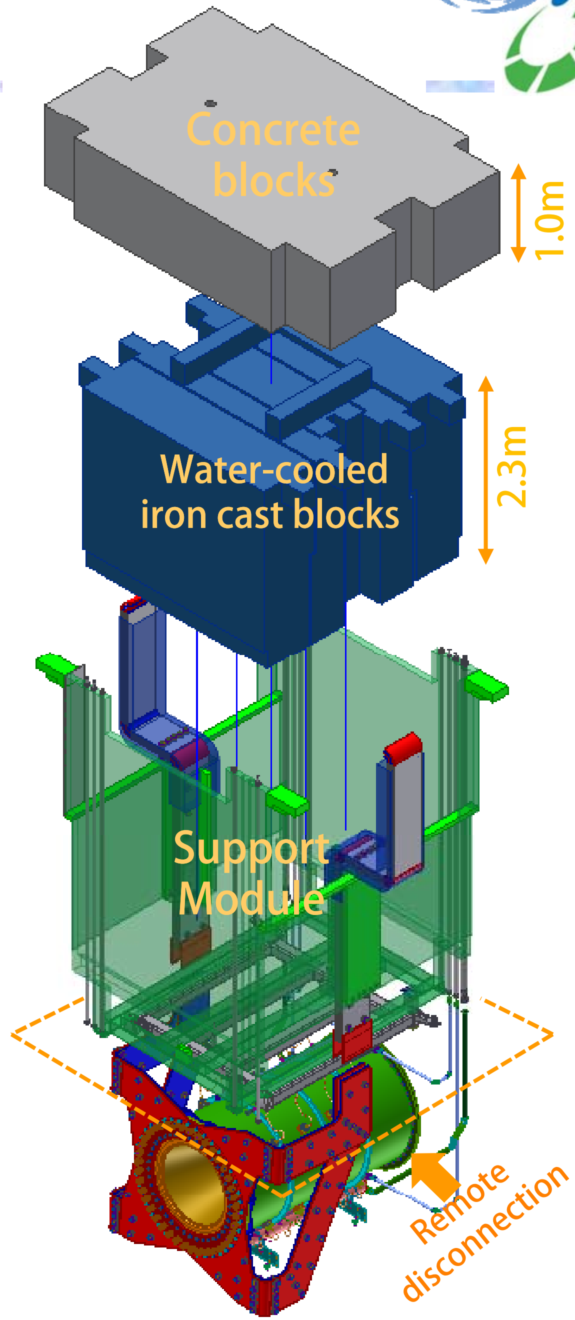
Beam Monitors
- 5 CTs/21 ESMs/19 SSEMs/ 1 OTR / 50 BLMs

⇒ M. Friend/M.Hartz

Secondary beam-line/Target Station

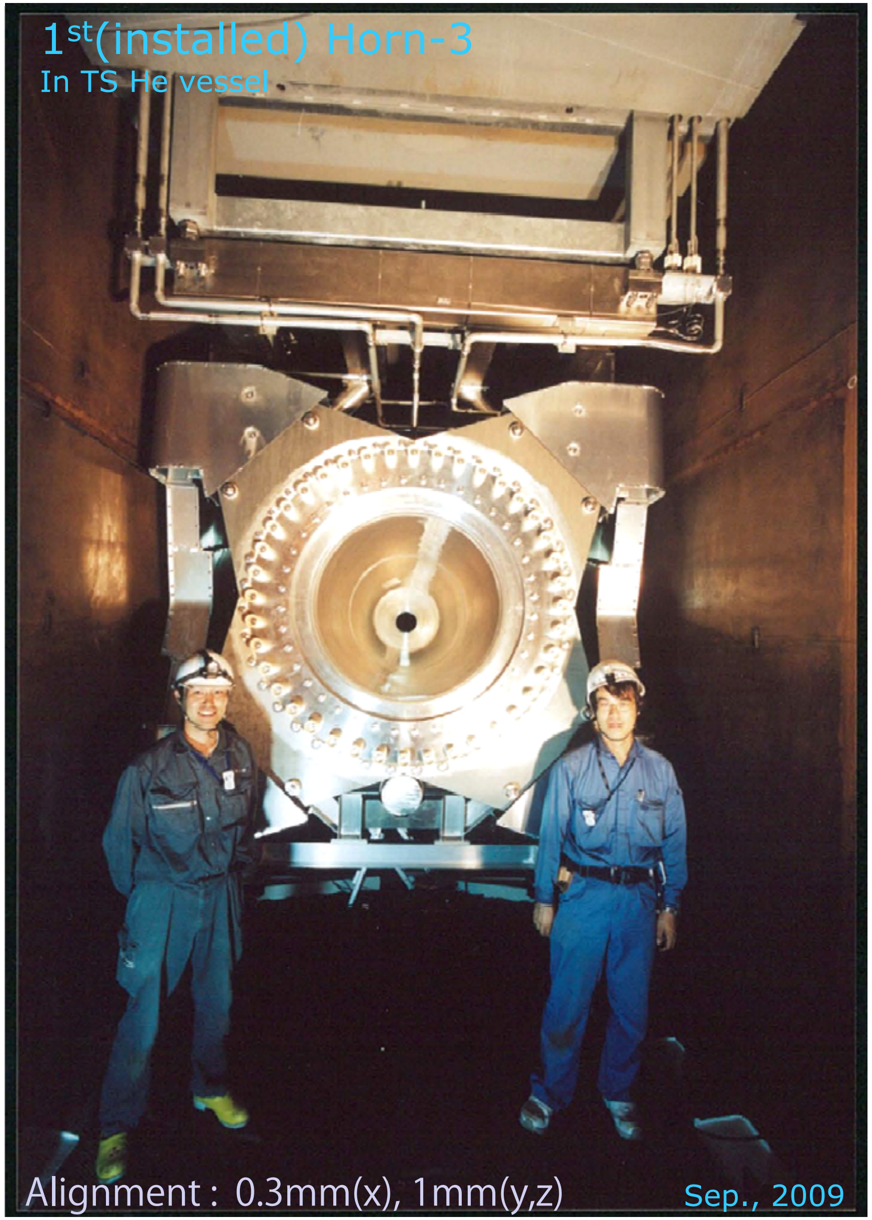


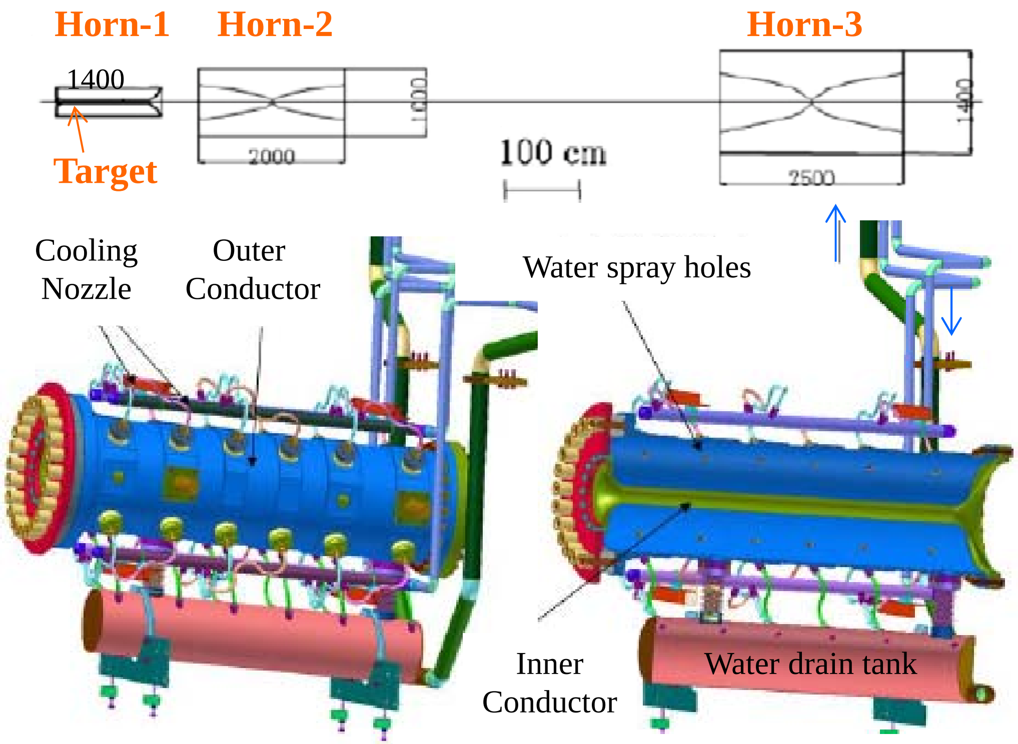




Electromagnetic horns

⇒ T. Sekiguchi / E.Zimmerman

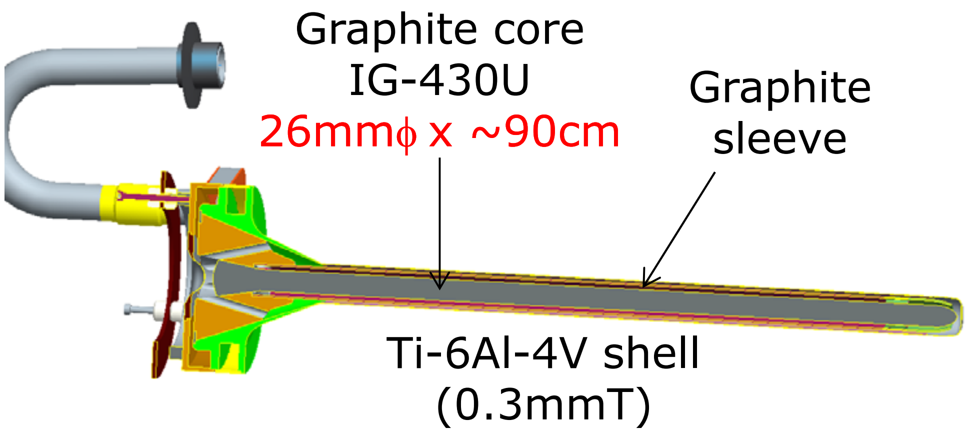


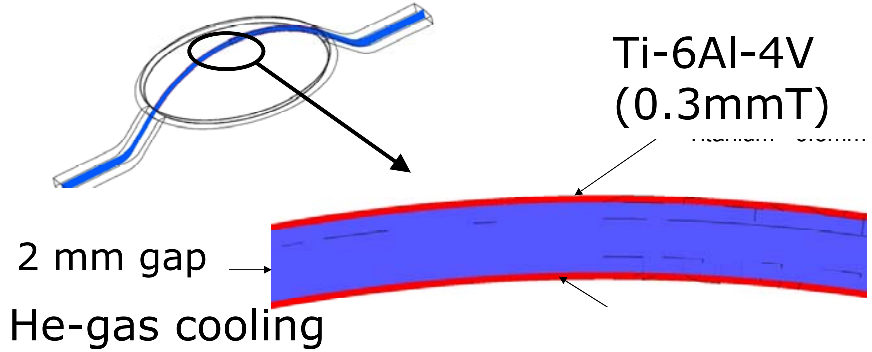


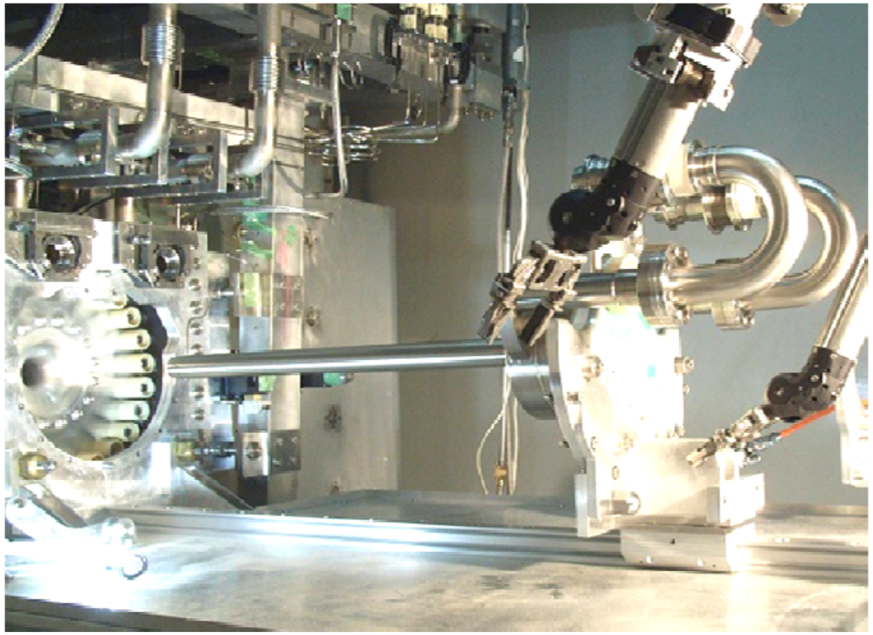
- Aluminum alloy A6061-T6
  - Inner conductor: t3mm, outer: t10mm.
- 320kA pulsed current (250kA in use so far)
  - Max field: ~2.1T, pulse width: 2~3ms
- Spraying water to inner conductor
  - 15kJ (beam) + 10kJ (Joule)=25kJ
  - Keep <80℃ : cooling capacity ~2MW

Target / beam window

⇒ C.J.Densham / T.Nakadaira







- Designed for old parameters of MR 750kW beam: cycle: 2.1s, PPP: 3.3×10^{14}
- Present expected parameters: Doubled rep-rate, MR cycle: 1.3 s, PPP: 2.0×10^{14}

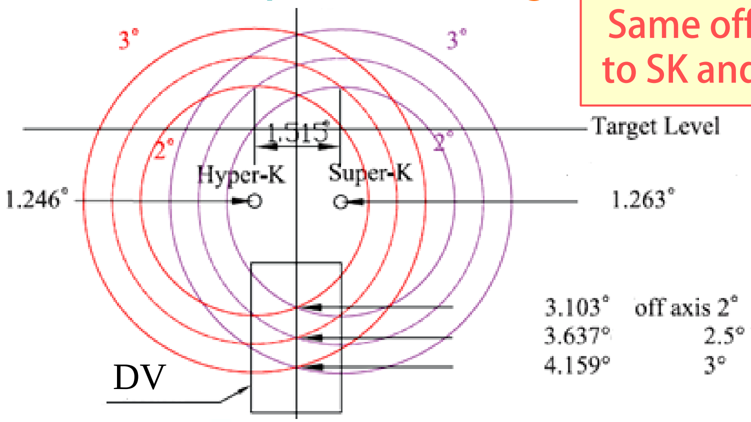
60% reduction

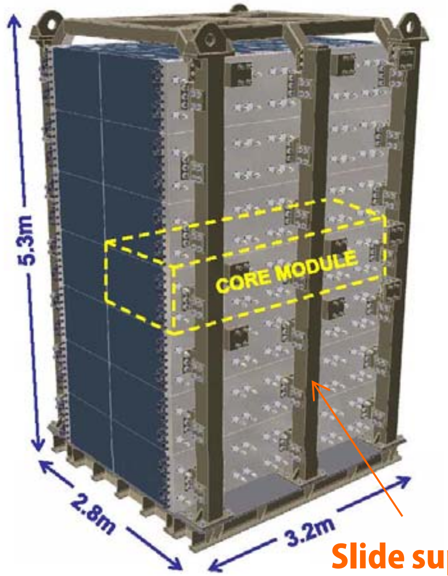
Decay volume / hadron absorber

- 94m-long tunnel with rectangular cross section ($1.4m_w \times 1.7m_h \rightarrow 3.0m_w \times 5.1m_h$), filled with He (1atm)
- Covered off-axis region : 2.5±0.5° (2.0~3.0°)
- No access possible: designed for 3~4MW beam

Steel plates(16mmT) cooled by water circuits

Same off-axis angle to SK and to Hyper-K





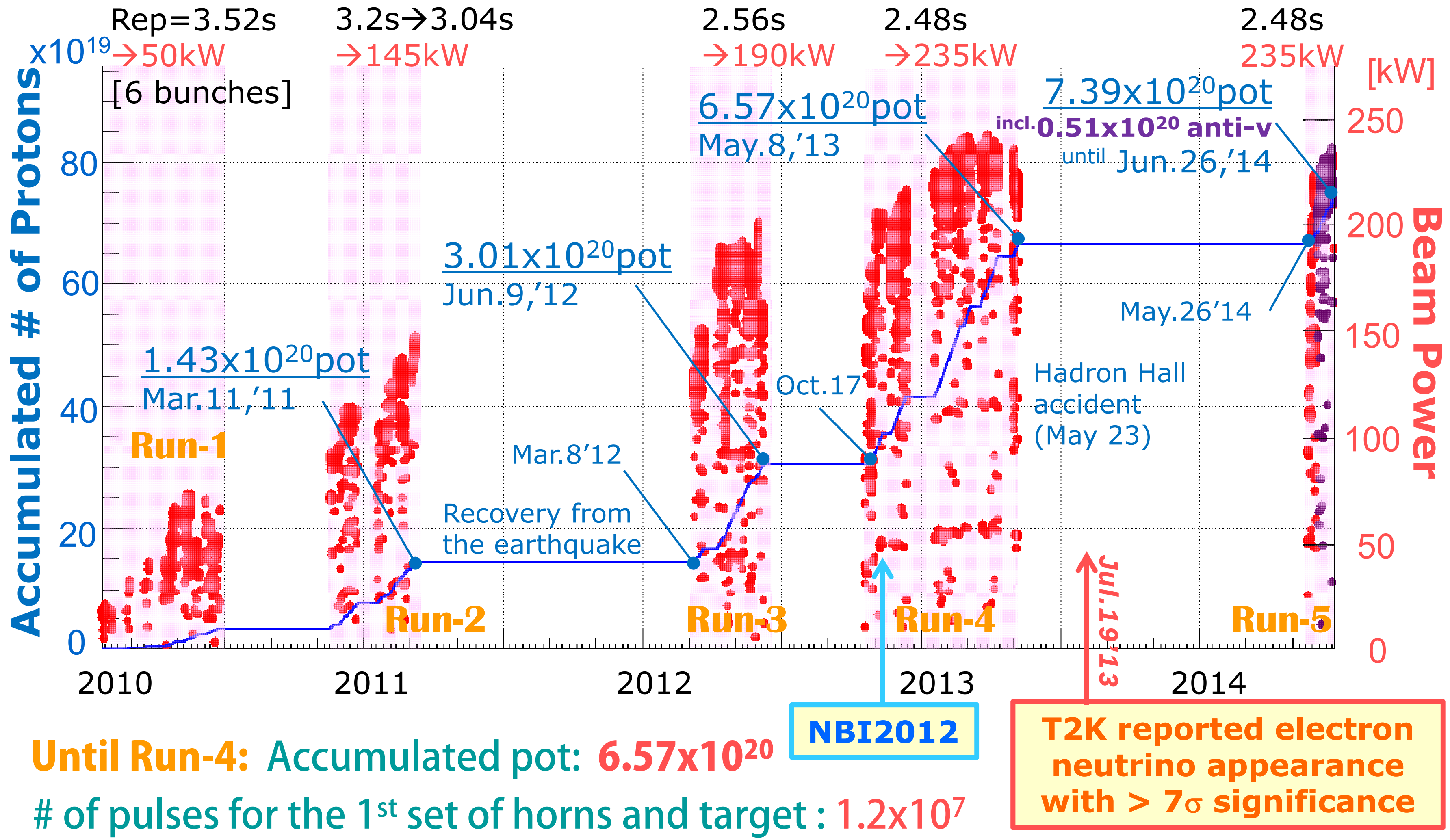
7 extruded large graphite blocks

Aluminum cast water cooling plate

Slide support frame

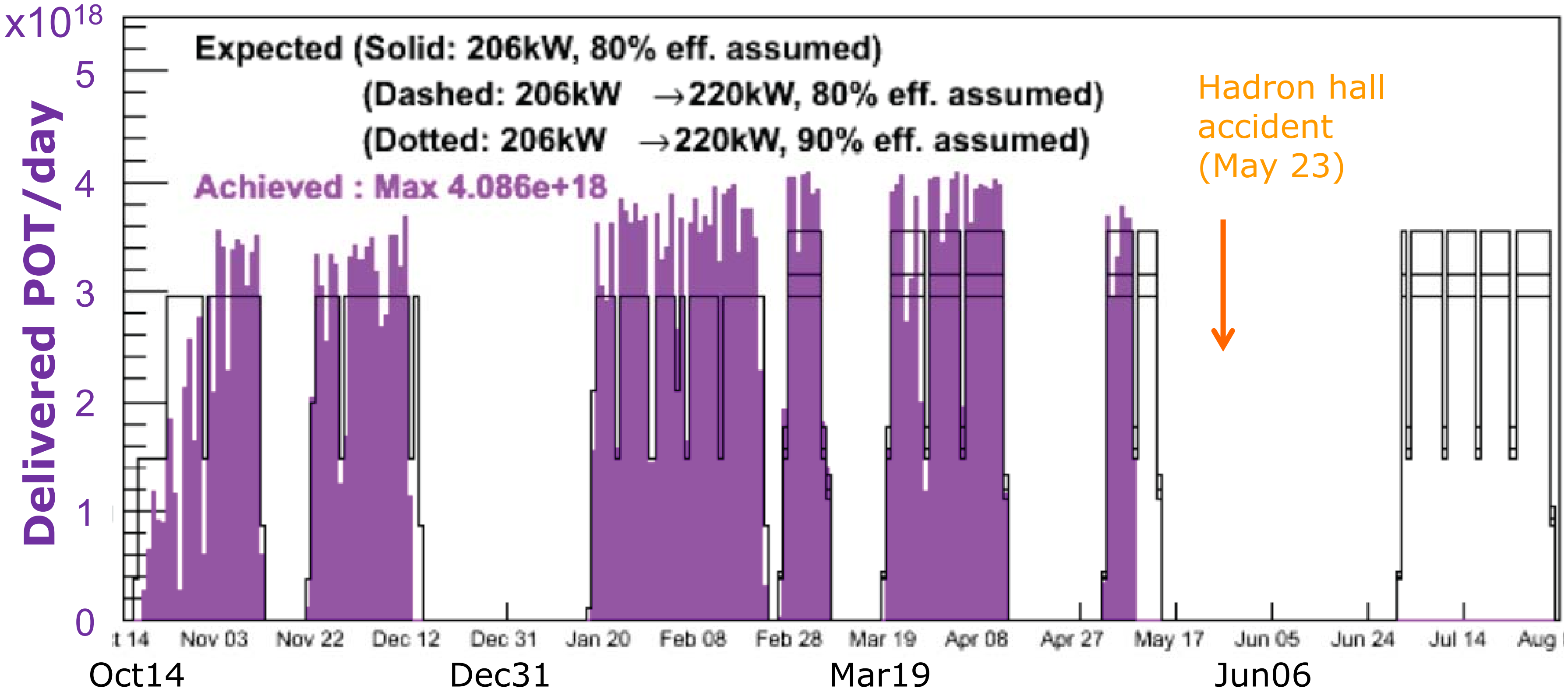
⇒ NBI2010

2. Status of the facility since NBI2012



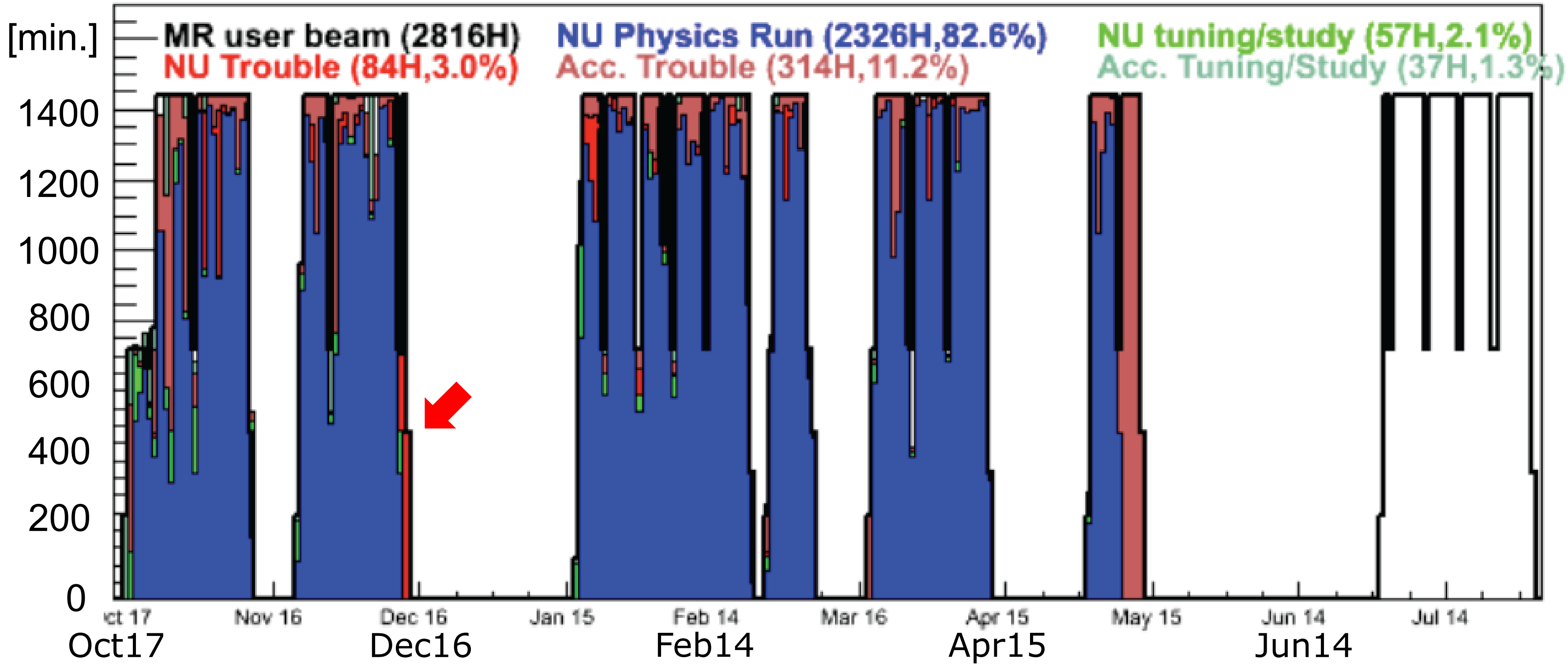
- **Until Run-4:** Accumulated pot: **6.57×10^{20}**
  # of pulses for the 1st set of horns and target : 1.2×10^{7}
- Long shutdown after R4 (Hadron hall accident) is devoted to **replace all 3 horns**
- **Until Run-5:** Accumulated *pot*: **7.39×10^{20}**, including 0.51×10^{20} of anti-ν mode operation.

MR Fx beam delivery status [Run-4]



- Original schedule for R#4: Oct. 2012 ~ end of July 2013
  - Requested: $>8\times10^{20}$ POT ⇒ Allocated FX user time: 3624hours (151days)
  - Expected POT = 7.54×10^{20} [assume 206kW x 80% running time efficiency]
- Stable operation at **230kW** running time efficciency: 83%
  - $>1.2\times10^{14}$ppp : the world record of extracted protons per pulse for synchrotrons
  - As of May 16, delivered POT: $\sim6.7\times10^{20}$ > expected : $\sim6.5\times10^{20}$

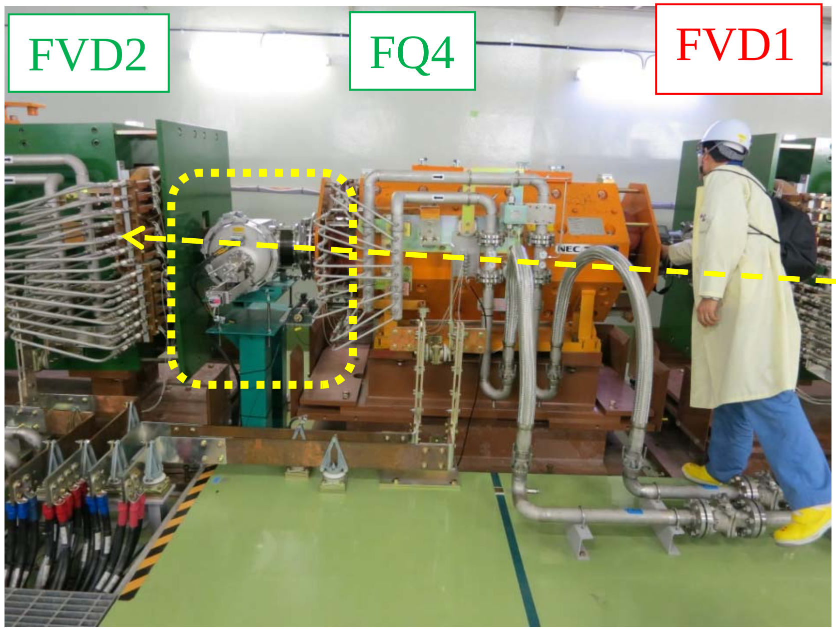
Run time usage [Run-4]

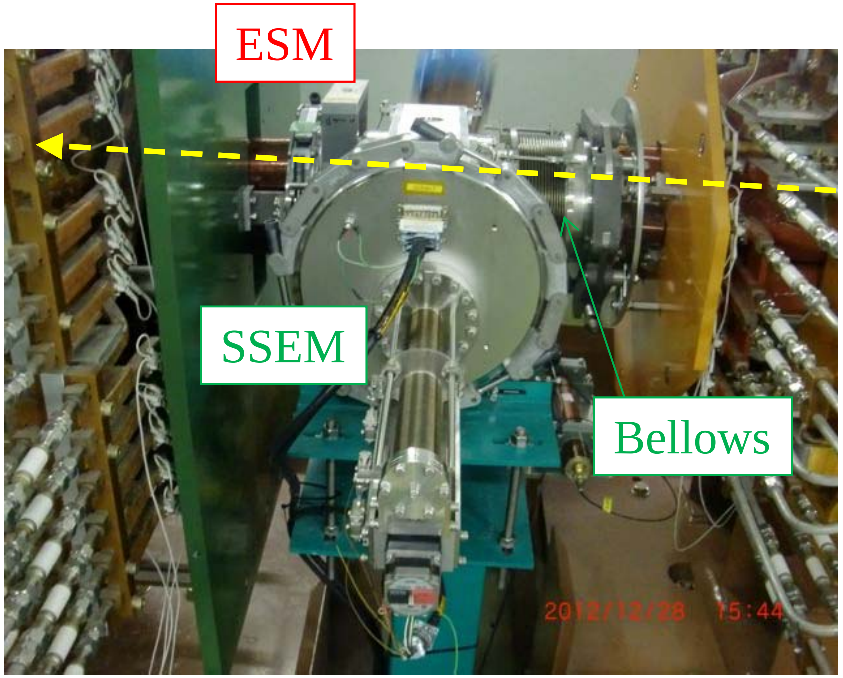


- From Oct.'12 to May'13, overall running time efficiency was ~82.6%
  - Physics run: 2,326 hours over 2,816 hours of MR user beam
- Troubles at the neutrino facility was 3% (84 hours)
  - Prefilters of degassing system of He vessel cooling water were clogged (Nov,2013, ~8 h x 2)
  - **Vacuum leak at primary beam-line due to beam hit** (Dec.12,'13 ~35 h)
  - Network trouble (~2.5hours)

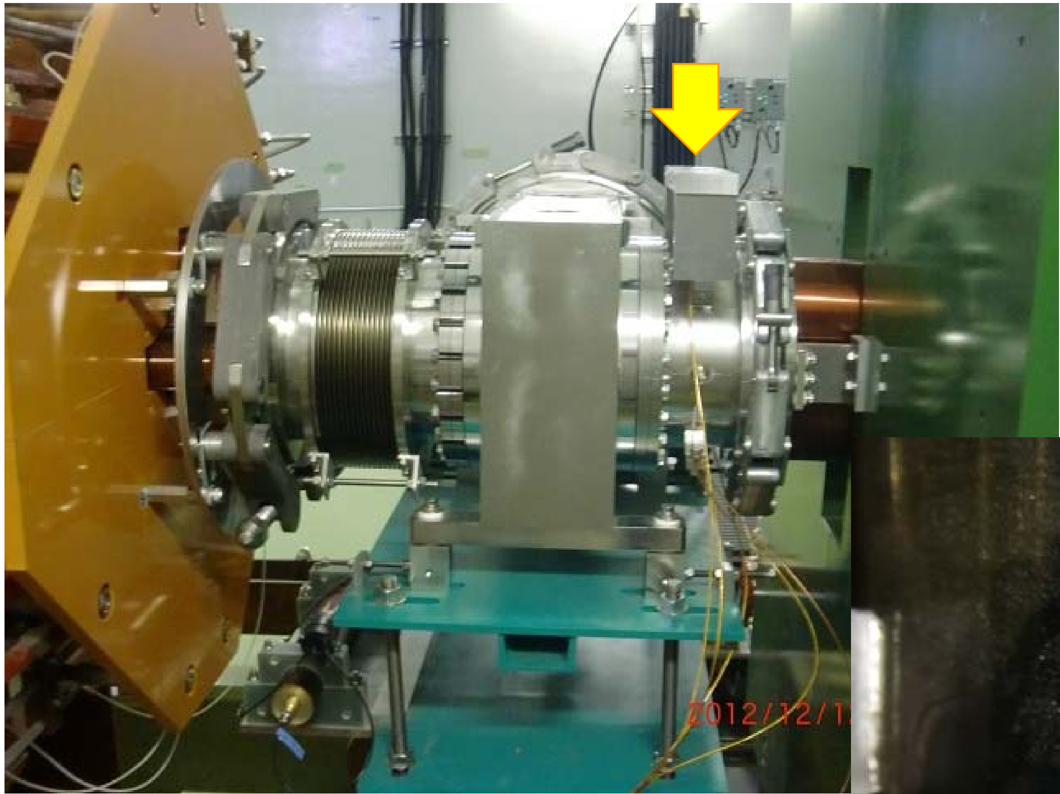
Accidental beam hit & vacuum leak [Dec.12, 2012]

- Final Focusing Section: 4xQ / 1x(H+Steering) / 2x(V+Steering)
- Trouble happened during beam tuning to increase power (210→217kW)
  - Unexpected turning-off of 1 bending magnet (FVD1, 25mrad bend) without alarm
  - Beam hit the beam duct and beam monitors (SSEM/ESM).
  - The vacuum leak at a feed-through of ESM.





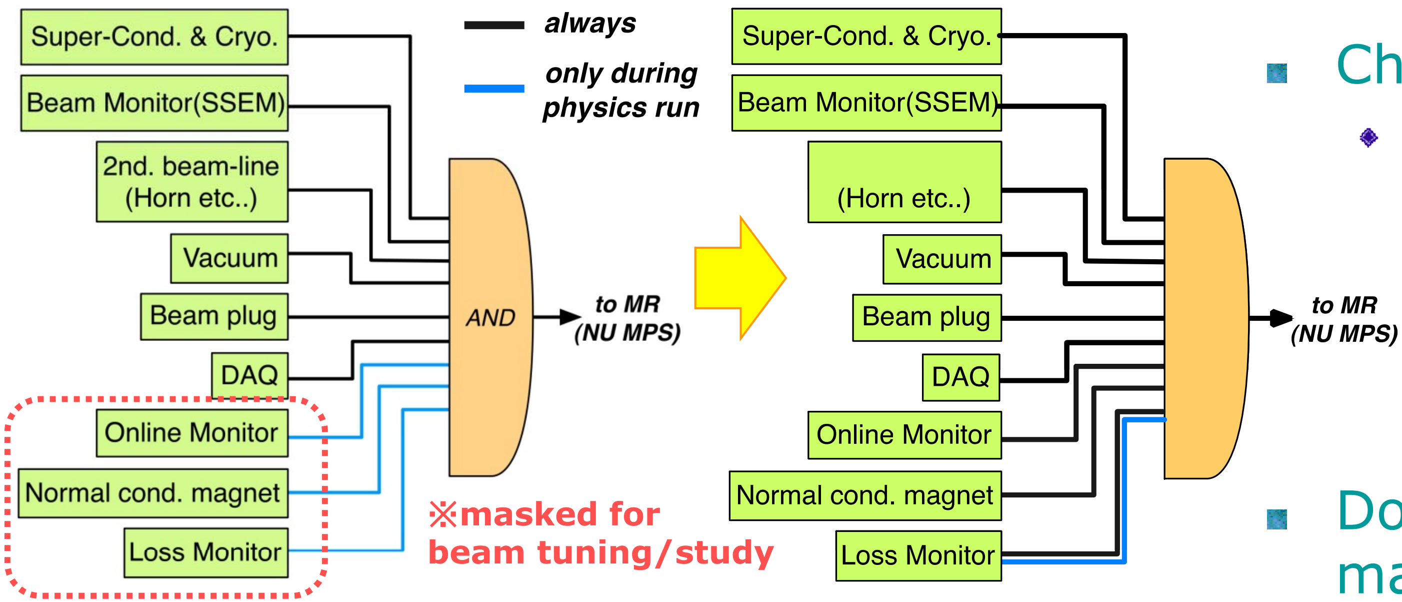
The feed-through causing vacuum leak



Fixing work was completed during new-year holidays of 2013: Replace the broken ESM by spare

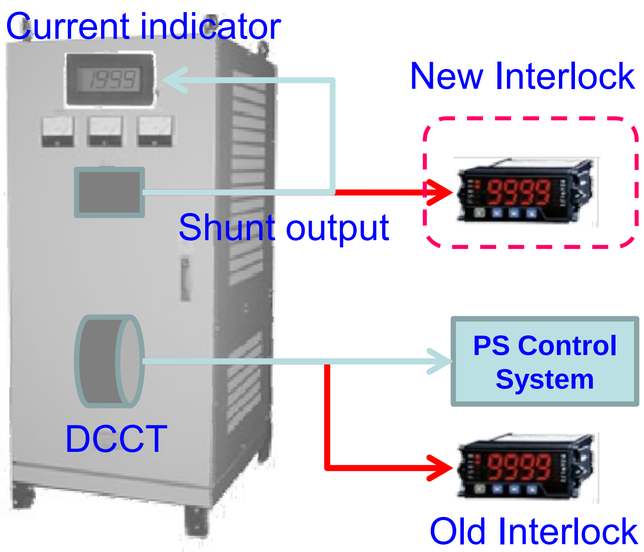
- The problematic feed-through was on top of ESM.
- No damage can be identified with eyes.

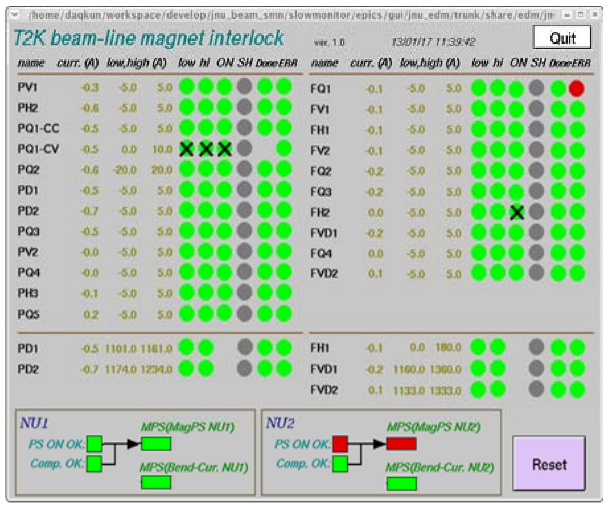
MPS interlock improvements



- Change MPS logic
  - to use always all interlock, except for beam loss monitor

For PD1,PD2, FVD1, FVD2, & FH1

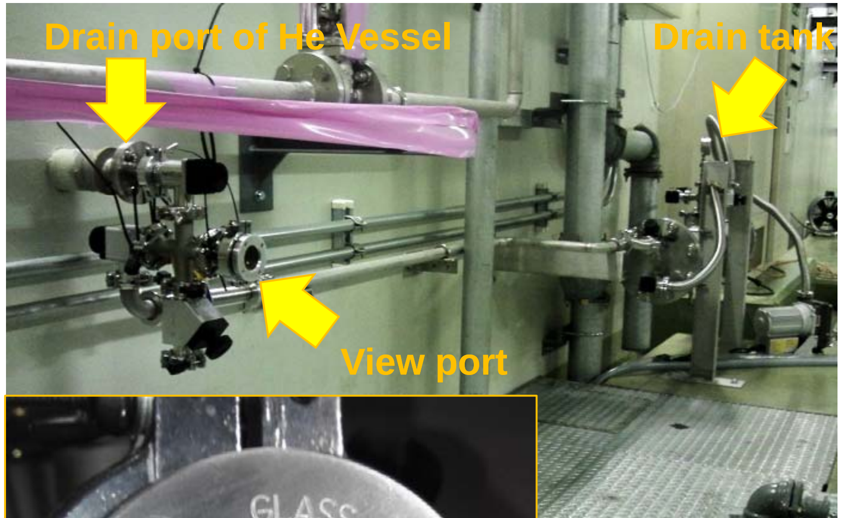


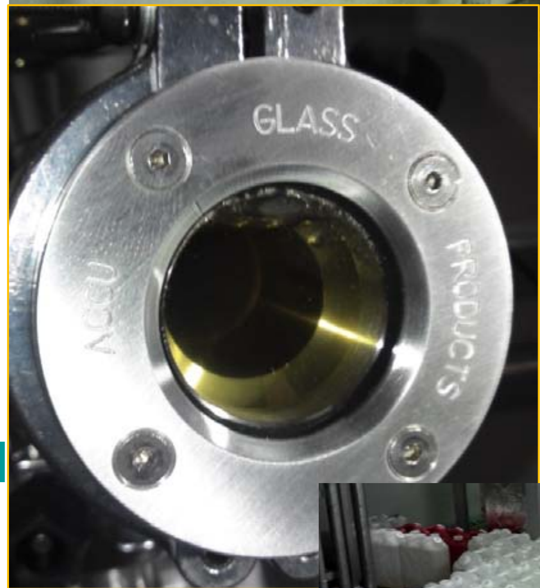


- Doubling of NC magnet power supply interlock
  - In addition to the existing interlock of current fluctuation, implement an interlock for the absolute current of bending magnets

Horn water leak and drainage from He vessel

- Since October 2012, water leak occurred at Horn CW system.
  - ~10L/day (~5L/day w/o beam)
  - due to temperature or vibration(?)
- On Jan.2013 the drain port of the vessel at TS B2F was opened.
  - Water comes out.
  - Transparent, with tiny yellow color.
  - possibly no corrosion at the vessel.
  - In total only 55L. pH: 8~9
  - ^{3}H: ~4kBq/cc, ^{7}Be, ^{22}Na
- Dew condensation continuously comes out to a drain tank, installed at the outlet of He compressor.
  - ~120L / 2 weeks, ~10L/day
  - Comparable to the leak rate.
- **We decided to continue R#4** with periodically draining water.





Temporarily kept at B1F floor in many 20L plastic containers

Hydrogen Production in Horns

- After beam power reaches to >200kW, hydrogen production in horn cover gas became biggest problem.
  - Cover gas is circulating through H_2-O_2 recombine system.
  - For the 1st set of horns, only one port available for charging He gas.
  - Forced flushing was only possible with water port, when beam is off.
- On Feb.~Mar.2013 gas chromatograph was installed to TS 1F.
  - H_2 after 1 week of 220kW beam: 1.6% ⇔explosion limit >4%)
  - After a few times of forced flushing, it reduces to ~0.4%.
- We decided to flush horn cover gas in every week basis, on accelerator maintenance day, during R#4
  - This limits maximum acceptable beam power to ~300kW

gas chromatograph at TS-1F

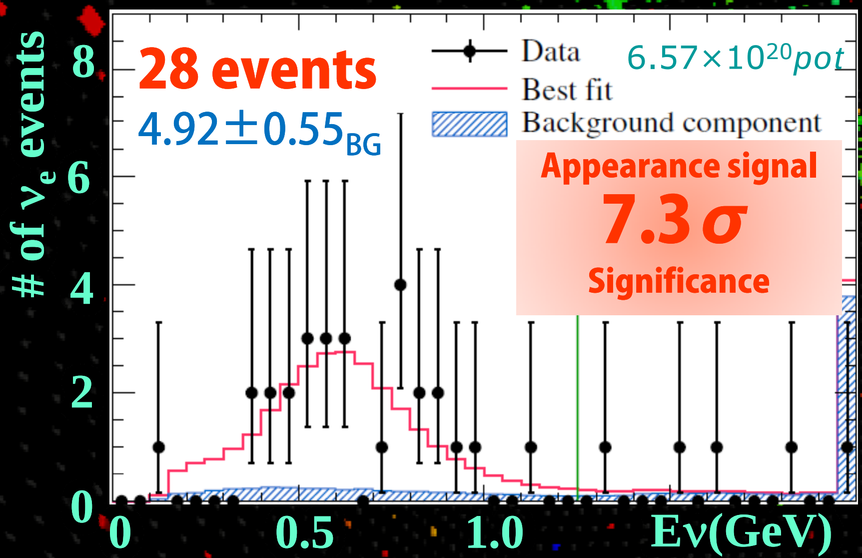
- Coolant Helium gas for target, beam window, and He vessel
- Cover gas of horn cooling water

T2K ν_e appearance observation July 19, 2013

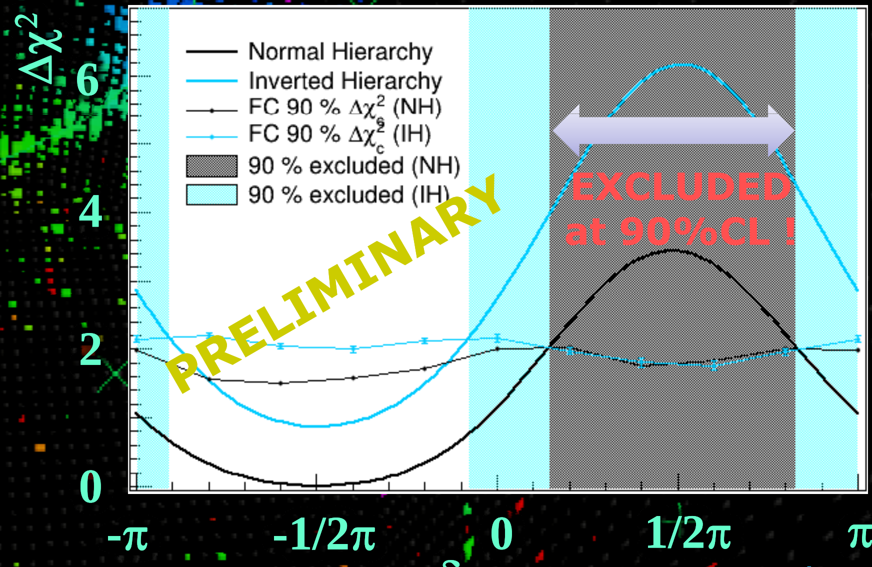
- Definitive observation on ν_μ turning to ν_e (Run-1~4 data : 6.6×10^{20}pot)
  - *Neutrino experiments come closer to see CPV in lepton sector !*
  - With 10 times more data (7.8×10^{21} *p.o.t.*), T2K has the opportunity to establish *evidence* (~3σ) of CPV.
- A prompt realization of the design beam power of 750 kW is highly desired to the J-PARC Main Ring and the neutrino experimental facility

⇒T.Koseki/T.Nakadaira

- A power upgrade to Mega-Watt class beam will directly enhance reach of the future project: LBL from J-PARC to Hyper-Kamiokande



⇒ Phys. Rev. Lett. 112, 061802 (2014)

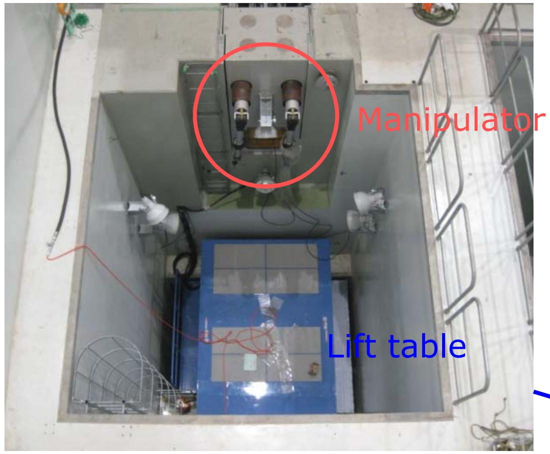


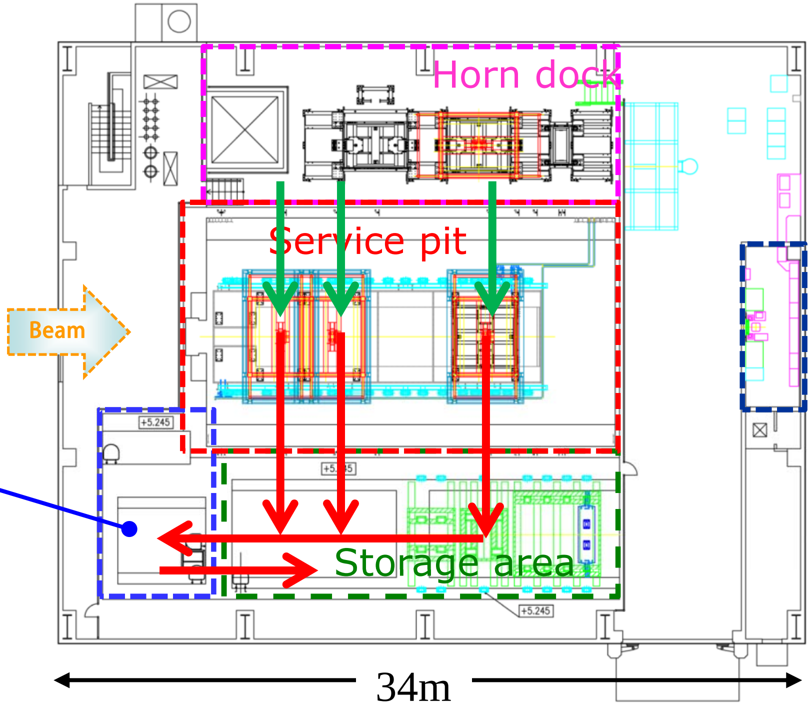
δ_{CP} ⇒ arXiv:1405.3871 [hep-ex]

Replacement of horns (2013 shutdown)

- Originally we scheduled to replace Horn-2/-3 in 2013 summer shutdown.
- Hadron hall accident ⇒ we encountered unexpectedly long shutdown
- Many reasons to replace all horns:
  - Water leak somewhere of horns
  - H_2 production from horn conductor-cooling water (limit beam up to 300kW)
  - Stripline cooling capacity (up to 400kW)
- We decided to replace all horns to improved spares for higher power operation

Maintenance area





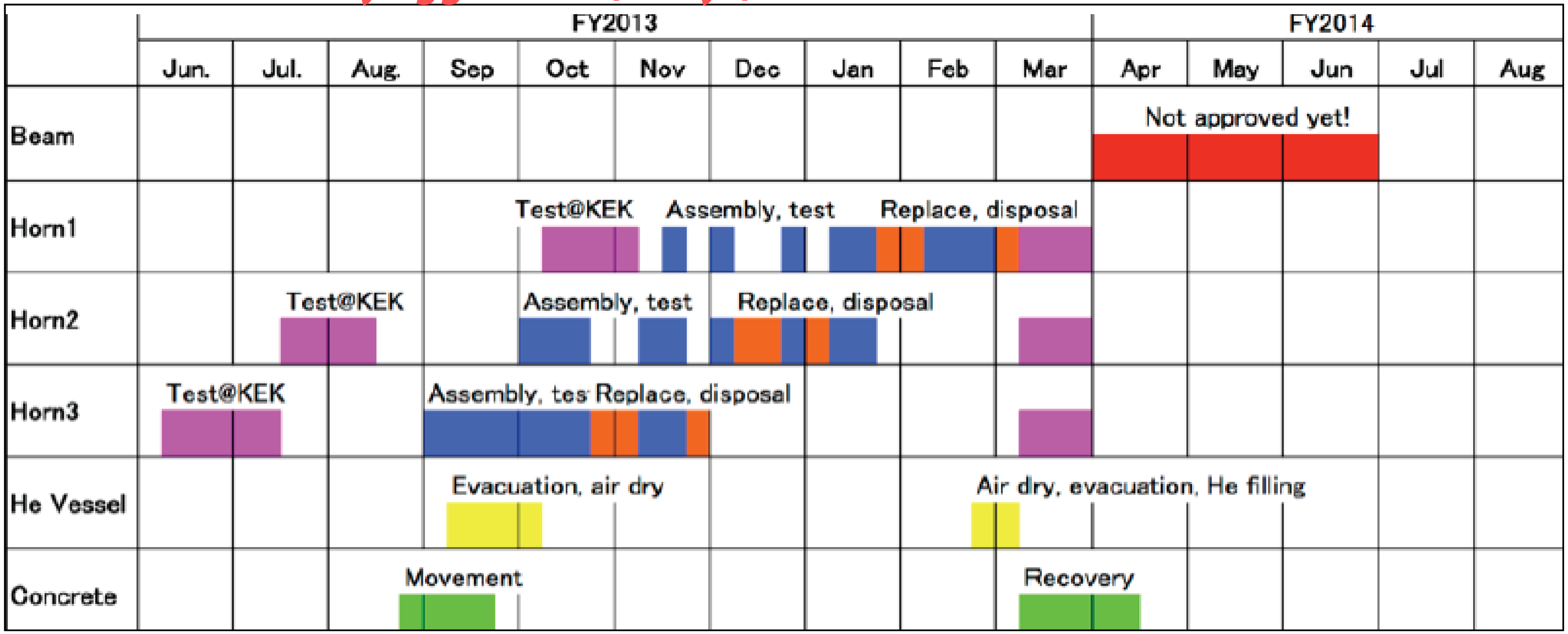
Control room

Every process managed remotely at control room

Replacement of Horns (cont.)

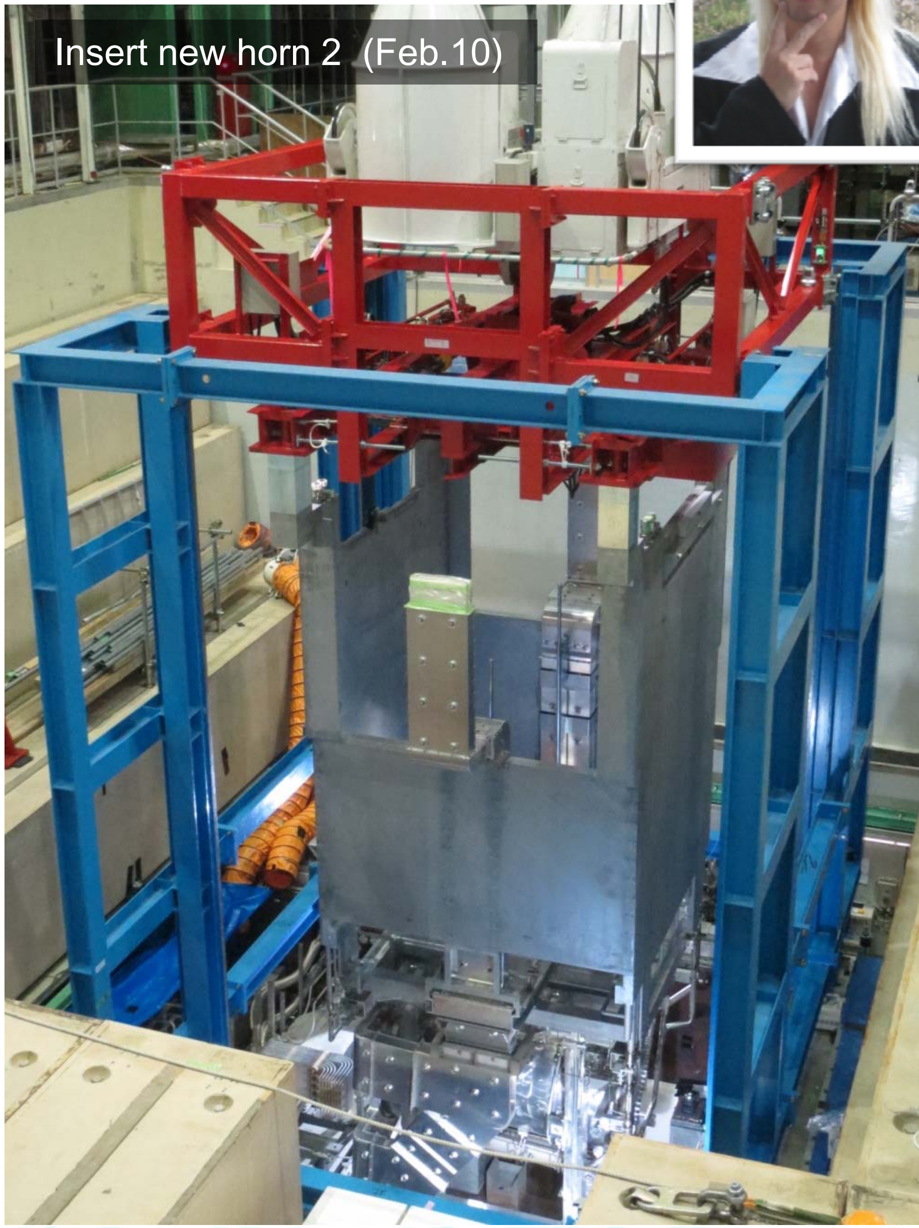
- Tremendous amount of works started from Jun 2013:
  - Test at KEK⇒transport to Tokai⇒assemble to support module⇒test
  - He vessel evacuation/dry air flushing ⇒open vessel
  - Cooling water dilution/drainage ⇒ disassemble pipes/bus-bars
  - Remove old horn⇒ inetall new horn ⇒ dispose old horn
  - Reassemble pipes/bus-bars⇒test⇒close vessel⇒evacuation/fill He

Very aggressive (crazy?) schedule as of October 2013



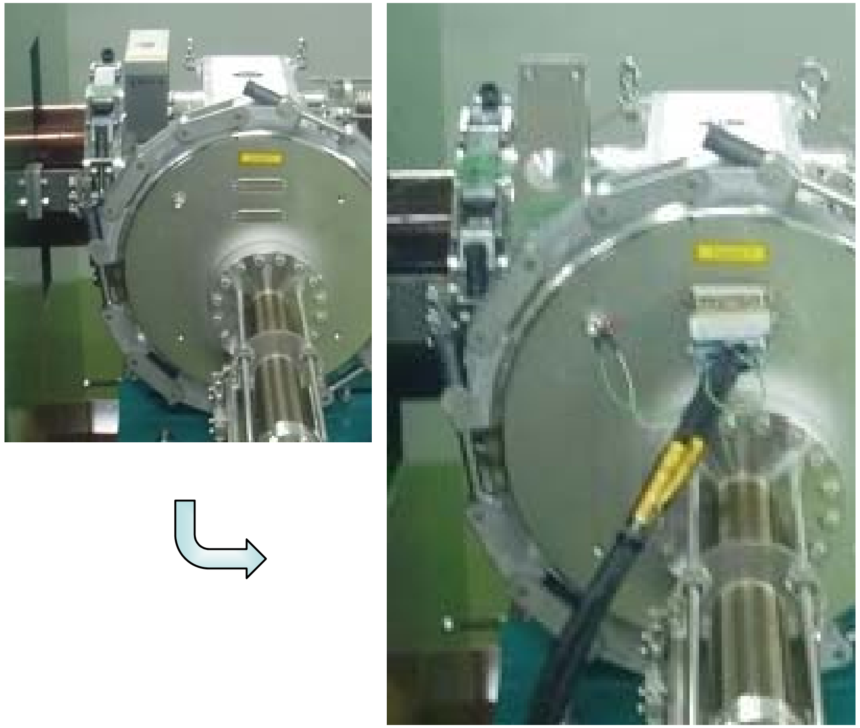
Remote maintenance

⇒



- Scheme worked in perfect manner
  - It only took a few hours to take out each old horn to maintenance area
- Started from Sep. ⇒completed on April
  - Only one month of delay
- Residual dose of Horn-1: ~150mSv/h
  - 6.7×10^{20}pot after 1year cooling
- Radiation level at border of control area
  - ~2.5 μSv, (4 μSv/h max) [Horn-2]

Works at primary line



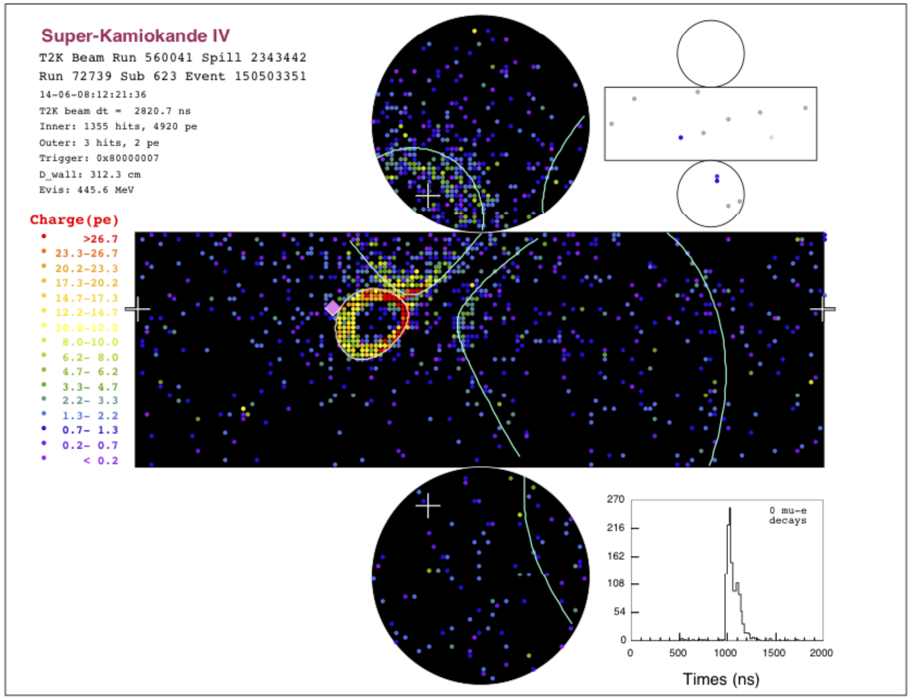
- The bombarded final bend (FVD2) was rolled out from beamline [Oct. 2013] ⇒no damage was found.
- For bends (PD1, PV2, FVD1, FVD2), stainless steel ducts were replaced with titanium alloy ones (Oct.~Nov. 2013)
- 4 ESMs downstream of the bends were rotated by 45 deg (Nov.~Dec. 2013)

T2K Run-5

- Beam commissioning started from May16,2014
- Very careful beam studies
  - Beam-based-alignment of secondary line w/ horn off (Beam scan)
  - MUMON measurement guaranteed relative alignment of new set of horns wrt the baffle collimator is < 2mm

⇒T.Hiraki

- Physics run with anti-neutrino mode operation was started on June 4, 2014
- On June 8, 1st beam-induced candidate event was observed at Super-Kamiokande
- **0.51x10^{20} of anti-ν mode operation by June 26**



3. Physics reach of T2K/J-PARC to Hyper-Kamiokande

J-PARC PAC May.2014 (C.K.Jung)

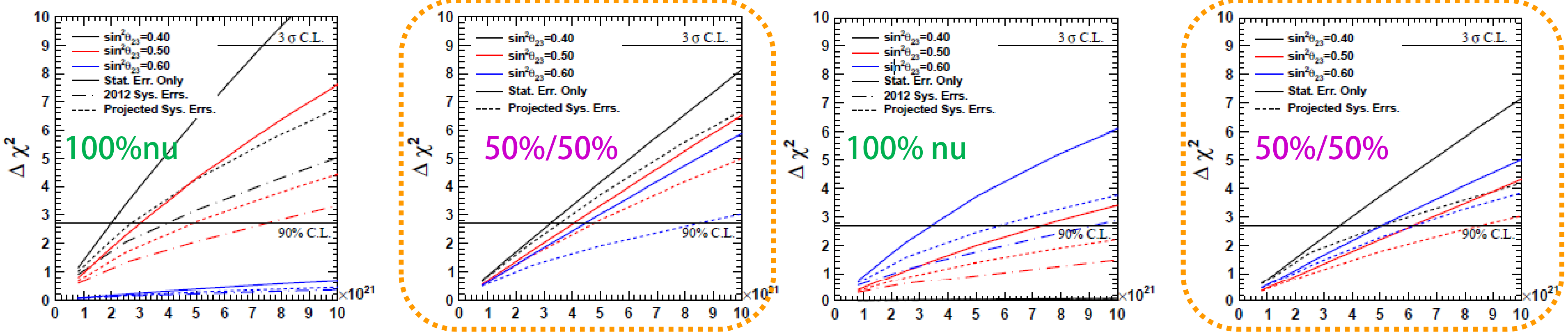
Optimum Run Strategy to Sustain the Best Sensitivity on δ_{CP} throughout T2K Runs

Reconfirmation of 50%:50% Strategy

- Previously, based on the future sensitivity task force study in 2013 we concluded that 50%:50% nu-mode to antinu-mode run ratio is a reasonable optimal choice to reach our long-term physics goals
- A new study reconfirmed that 50%:50% ratio is optimal to sustain the best sensitivity on δ_{CP} throughout T2K runs

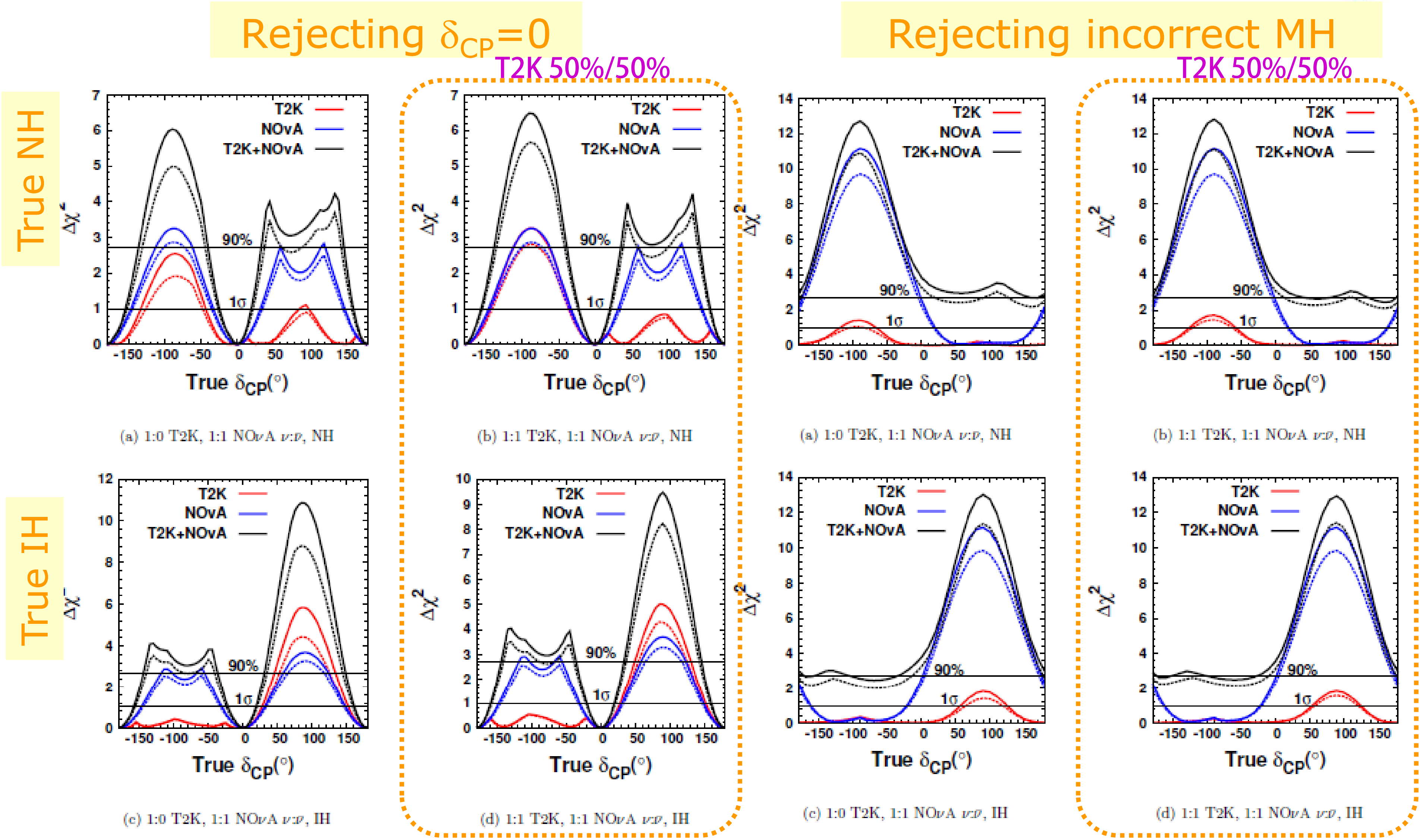
Expected $\Delta\chi^2$ for δ_{CP}=0 hypothesis as func. of POT

(90°　,IH)　　　　(-90°　,NH)



⇒a paper for T2K(+NOvA) future sensitivity studies to be appeared on arXiv very soon

Sensitivities in combination with NOVA

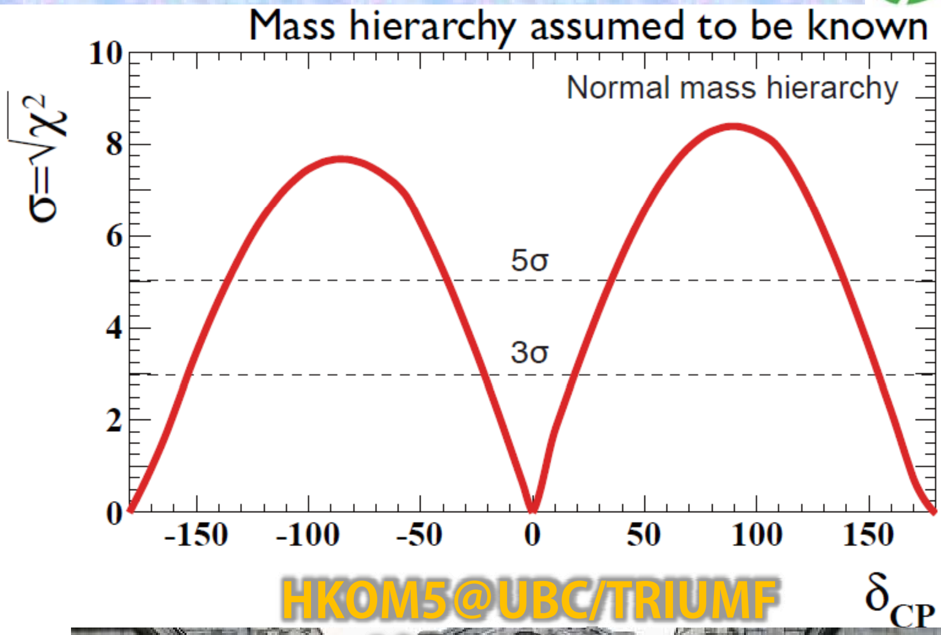


- Based on NOVA's TDR: 1.8×10^{21} POT for ν and 1.8×10^{21} POT for anti- ν modes.
- Dashed (solid) curves: normalization systematics (not) considered

LBL experiment from J-PARC to Hyper-Kamiokande

Hyper-Kamiokande Project

- *P58: A Long Baseline Neutrino Oscillation Experiment Using J-PARC Neutrino Beam and Hyper-Kamiokande* was presented at 18th J-PARC PAC (May 2014) with many updates on sensitivities to δ_{CP} based on the recent progress
  - With integrated beam power of **7.5MW × 10⁷s** (1.56x10²² POT), CP violation will be established (>3σ) for 76% of δ_{CP} space.
    ⇒LoI can be found at J-PARC PAC page.



- You can find further information on 5th Hyper-Kamiokande Open Meeting at Vancouver (July 2014)
  ⇒http://indico.ipmu.jp/indico/conferenceDisplay.py?confId=34

4. Summary

- Operational status of the neutrino experimental facility:
  - ~230kW continuous operation for the T2K experiment has been realized since Oct. 2012 to May 2013 (Run-4)
  - With this much of beam power, we encountered many serious troubles:
    - Vacuum leak at primary beam-line due to accidental beam hit
    - Horn water leak
    - Hydrogen production in horn cover gas ·········
  - Thanks to the struggles we observed ν_e appearance with7.3σ significance.
    - **We highly appreciate strong supports from NBI community !**
  - Many works during shutdown 2013 ~ 2014
    - Replacing all horns / improve MPS / replace beam ducts···
  - Anti-neutrino mode running was started from Run-5 (end of May~June 2014).
    - Accumulated *pot*: $7.39\text{x}10^{20}$, with $0.51\text{x}10^{20}$ of anti- ν
- We are expecting much more outputs
  - T2K+NOVA has good opportunity to observe CPV / MH with 2~3σ significance
  - For the next period Oct. 2014 – Jun. 2015 (Run 6),T2K requests 4.4×10^{20} POT [4.0×10^{20} anti nu-mode]
  - Hyper-K project requests $\underline{7.5\text{MW} \times 10^7\text{s}}$ for the neutrino facility to establish CPV