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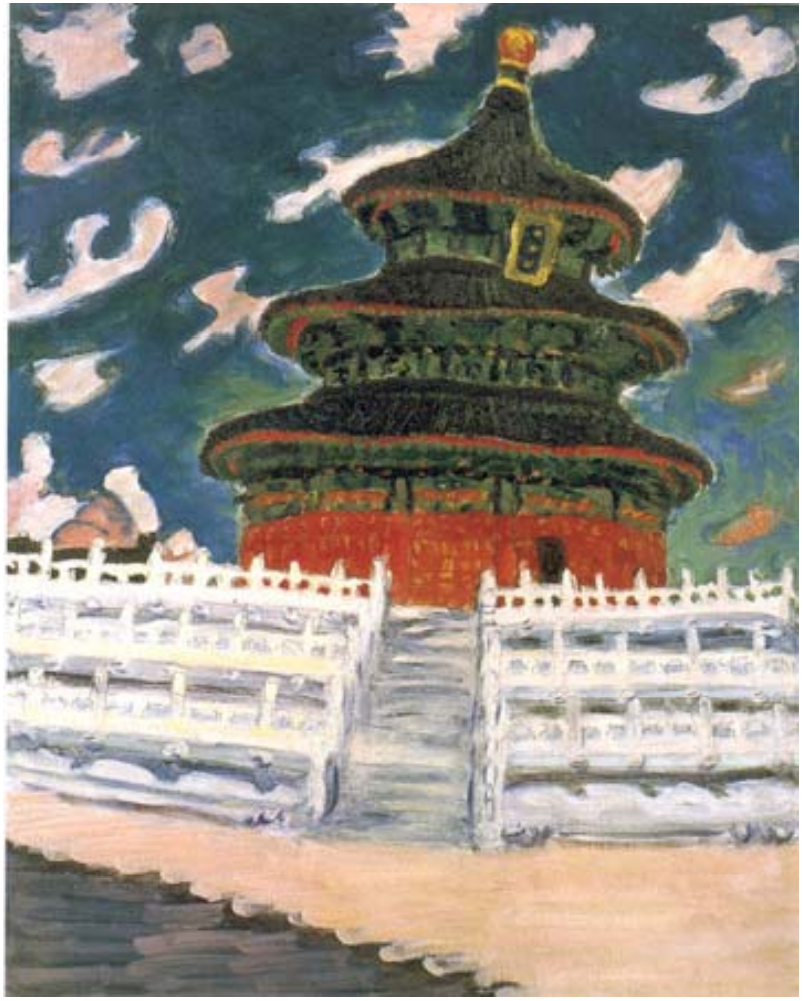

梅原龍三郎 作 雲中天壇
Temple of heaven in dancing clouds
By Ryuzaburo Umehara (1888-1986)

T2HK: Tokai-to-Hyper-Kamiokande

J-PARC upgrade plan for future and beyond T2K

T.Ishida for Hyper-K Working G. &
for Neutrino Experimental Facility G.
J-PARC Center / KEK

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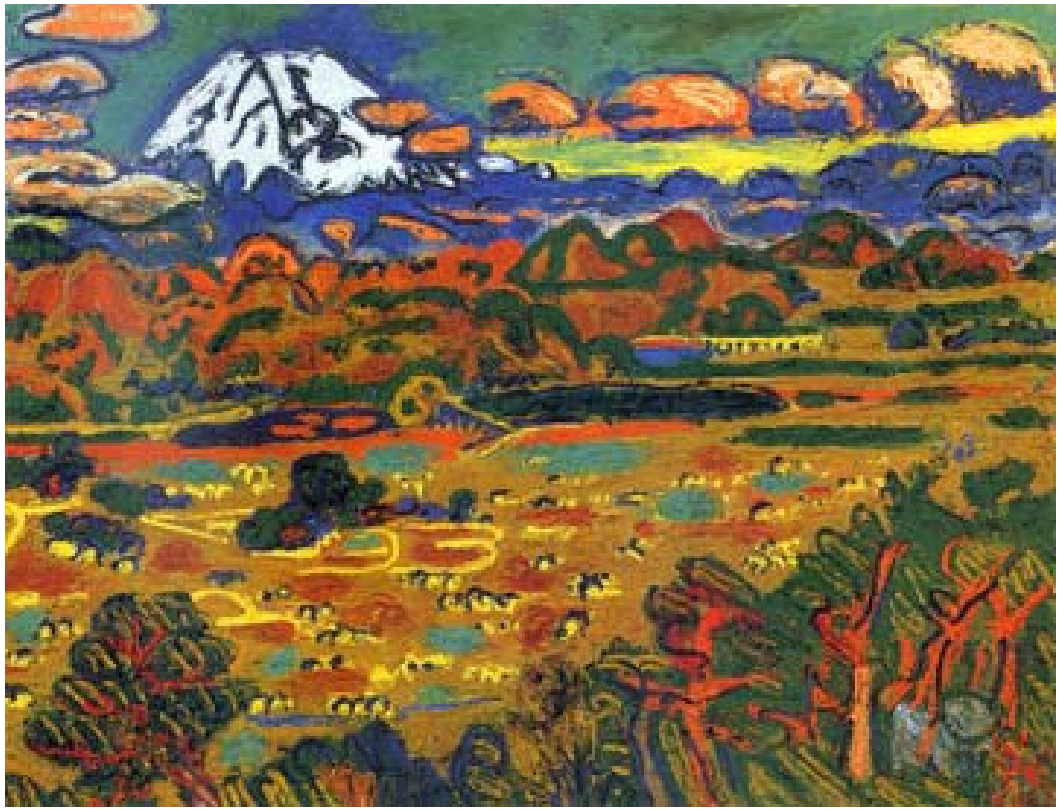

1. Project overview

T2K ν_e appearance (Jul.2013)

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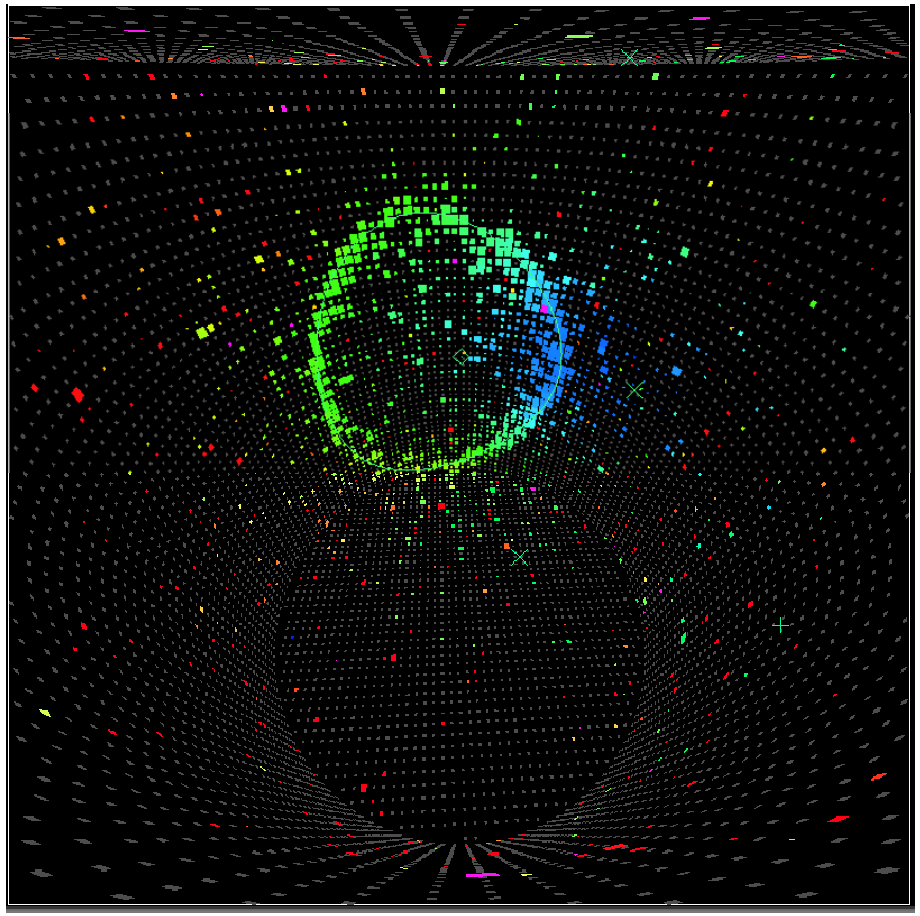
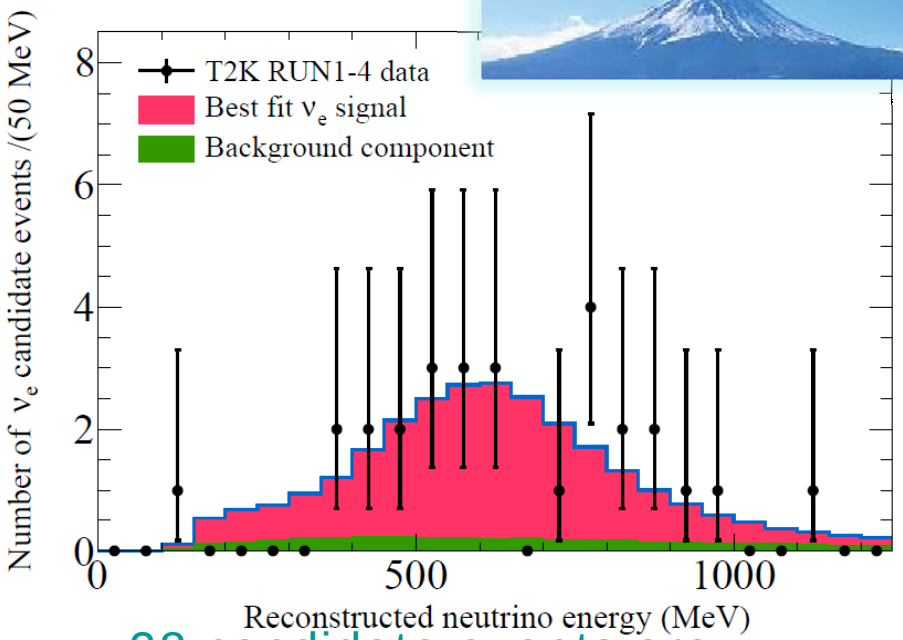
The 1st ν_e candidate event after EQ (Mar.2012)





- 28 candidate events are observed with 6.39×10^{20}pot
- $N_{exp}=4.64\pm0.52(\sin^2 2\theta_{13}=0)$
  20.44 ± 1.80 (=0.1)
- Significance=7.5σ

Open door to CPV searches by super-beam experiments

⇒ M.Friend (WG1) / A.Kaboth (J12)
M.Wilking (EPS-HEP2013)
TI (KEK seminar)
http://jnusrv01.kek.jp/public/t2k/sites/default/files/130719-KEK-seminar.pdf

T2HK: Future LBL plan using J-PARC

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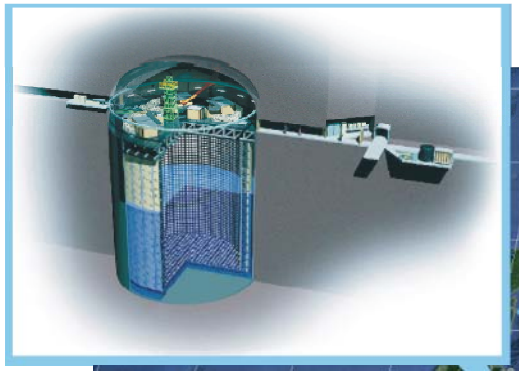

Super-Kamiokande
(ICRR, Univ. Tokyo)

Neutrino Facility
at J-PARC
(KEK-JAEA, Tokai)

Hyper-Kamiokande

⇒LoI: The Hyper-Kamiokande Experiment
http://arxiv.org/abs/1109.3262

T2HK: Tokai to Hyper-Kamiokande

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- Natural extension of the technique being proven by the success of T2K
  - Off-axis narrow band beam, E_ν ~0.6GeV, 750kW~1MW
  - Hyper-Kamiokande: HUGE water Cherenkov detector
- Mainly focus on measurement of CP asymmetry
  - 295km baseline (=less matter effect)
- Complementary to >1,000km baseline experiments (LBNE/LAGUNA-LBNO)
  - Sensitivity (CP/MH), technology (WaterC./Liq.Ar)
- Rich programs with both near and far detectors
  - Proton decay / atm.ν / solar・SNν / ν interaction…

Candidate site

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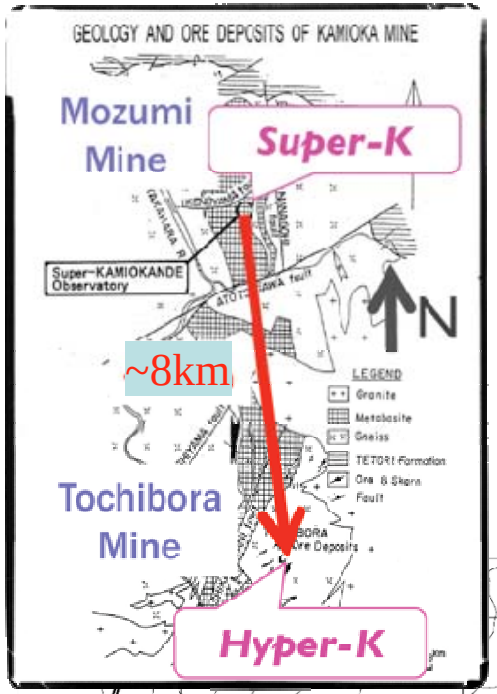
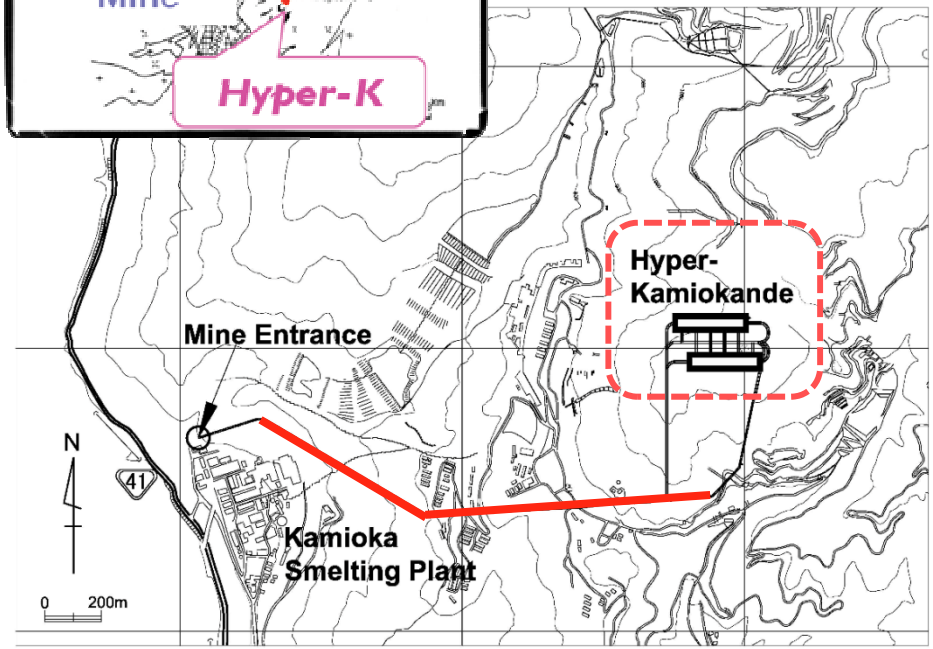
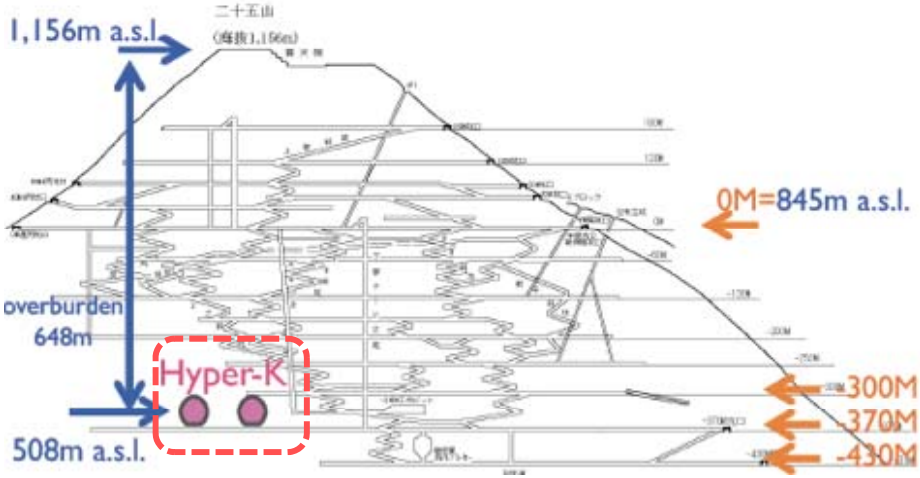


- 8km south of Super-K
- Same off-axis and baseline as T2K
- Horizontal access from entrance
- 648m of rock (1750m.w.e.) overburden
- 13,000m^3/day natural water (1Mt/80days)





The Hyper-Kamiokande detector

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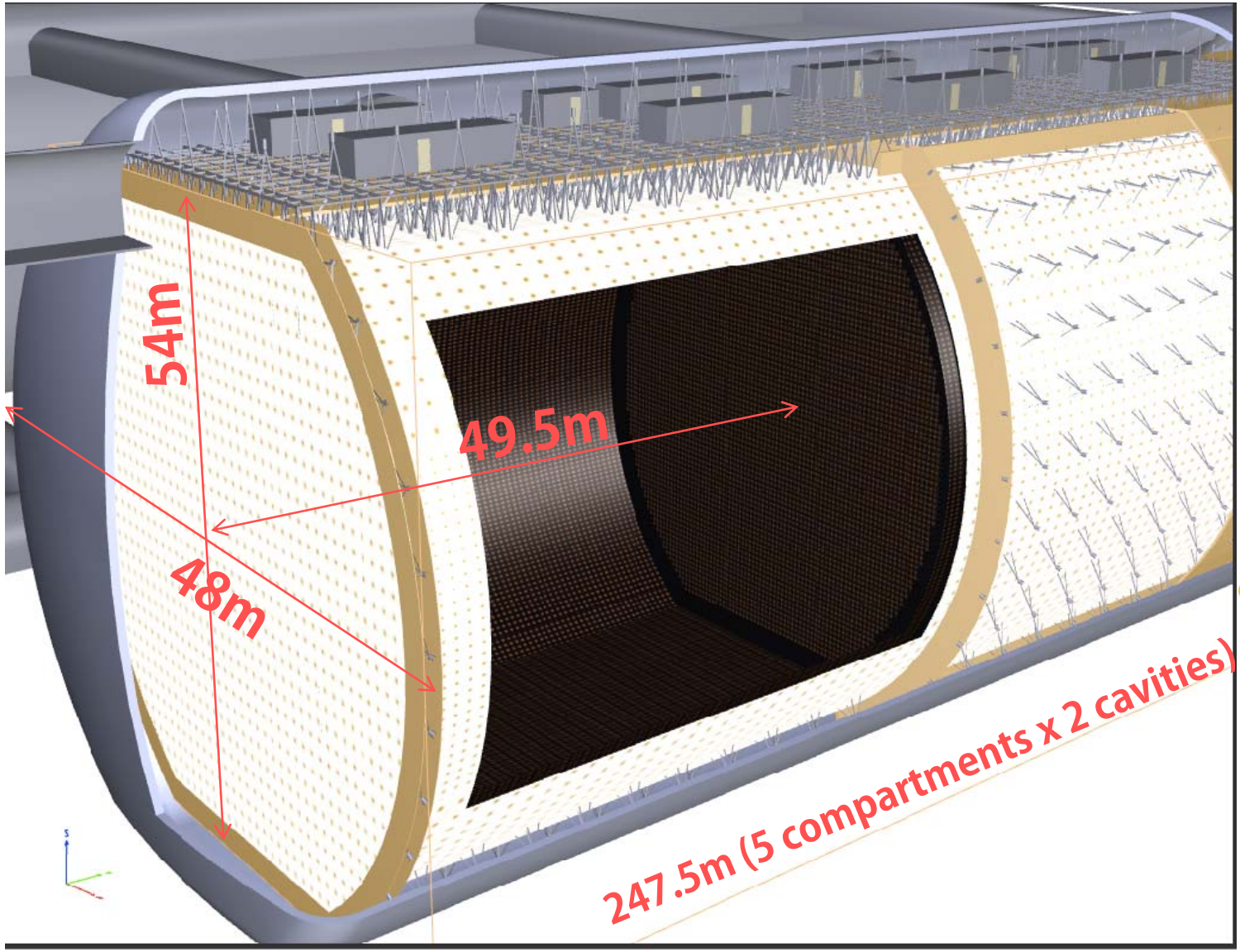

Total Volume
=0.99 Megaton
Inner Volume
=0.74 Mton
Fiducial Volume
=0.56 Mton
(0.056×10)
x25 of Super-K

Outer Volume
=0.2 Megaton

Photo-sensors
99,000 20"ΦPMTs
for Inner Det.
(20% photo-
coverage)

25,000 8"ΦPMTs
for Outer Det.

On-going R&Ds

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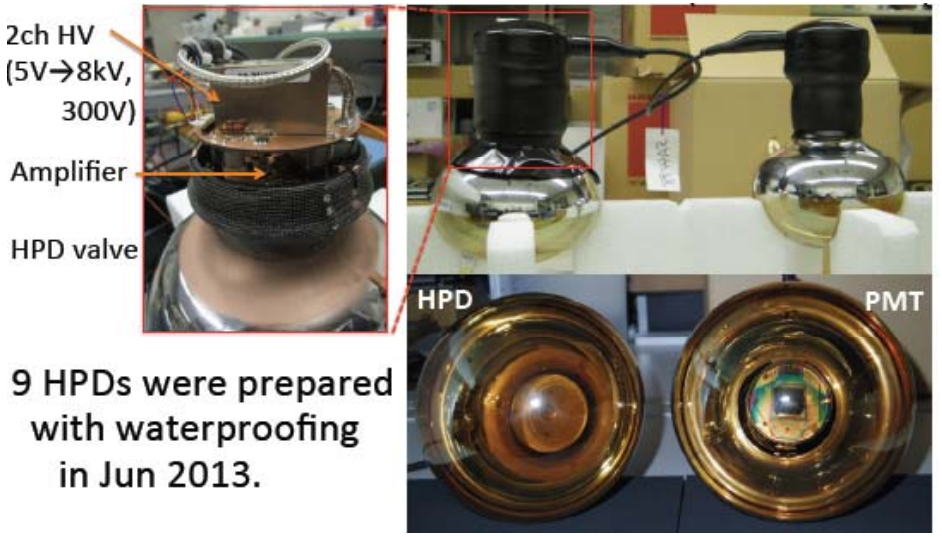
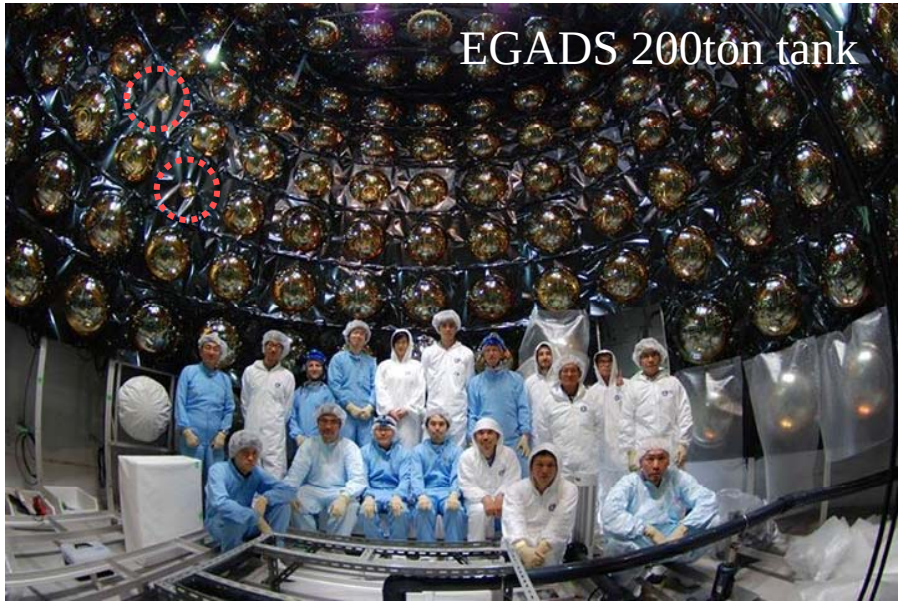
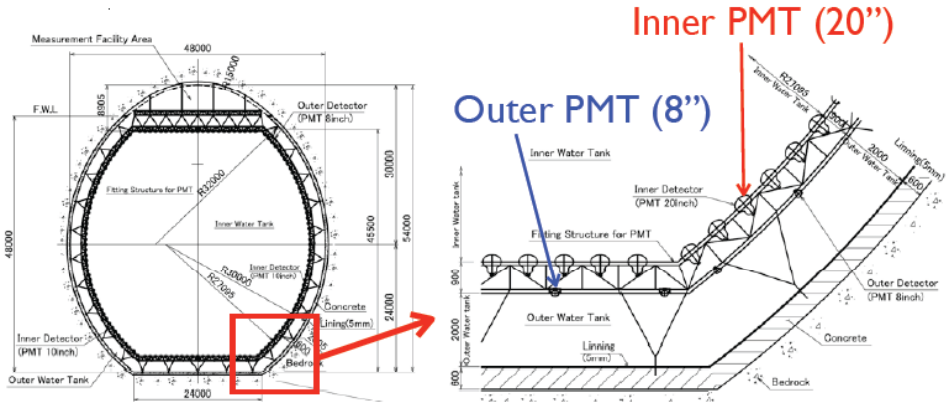
- Geological survey, cavern stability
- Detector shape, segmentation wall, tank liner, PMT support
- Water purification, quality control
- New sensor: High-QE PMT / Hybrid Photo Detector (HPD)
- DAQ electronics (water tight?)
- Calib. source deployment system
- Software, physics potential studies
- Near detector design
- **R&D budget approved in July**
  - 1kt Hyper-K prototype etc.



9 HPDs were prepared with waterproofing in Jun 2013.





Target schedule

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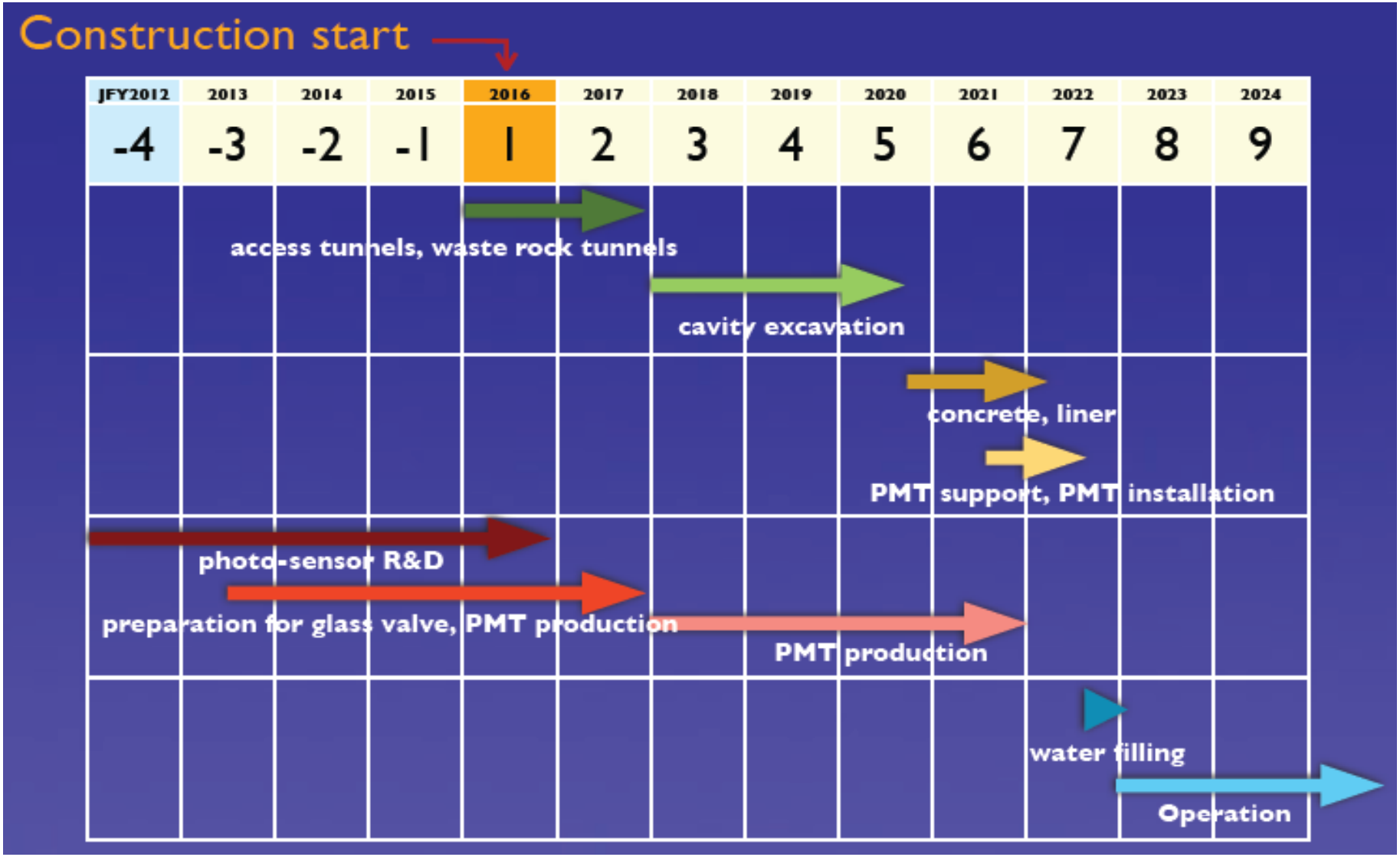

⇒ T.Nakaya / M.Yokoyama, Snowmass on the Mississippi, Aug.1, 2013

$\nu_\mu \rightarrow \nu_e$ probability

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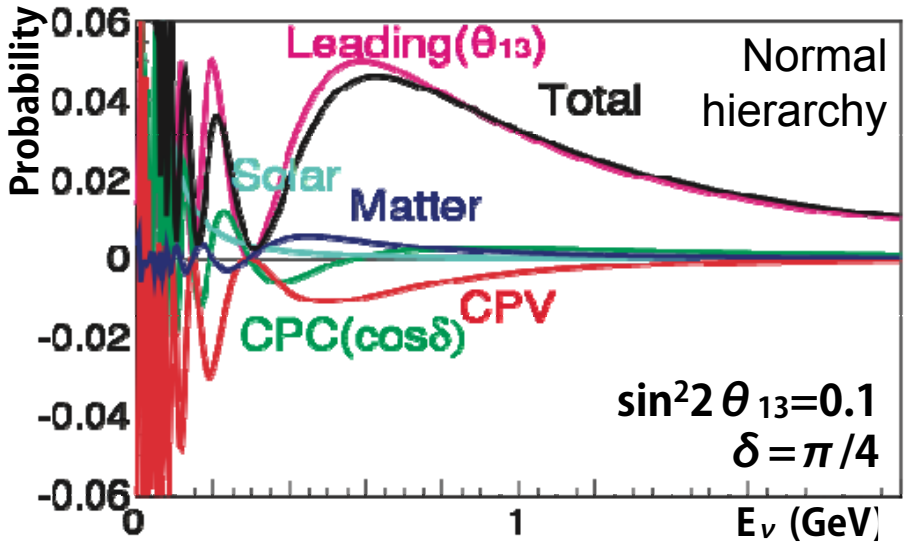
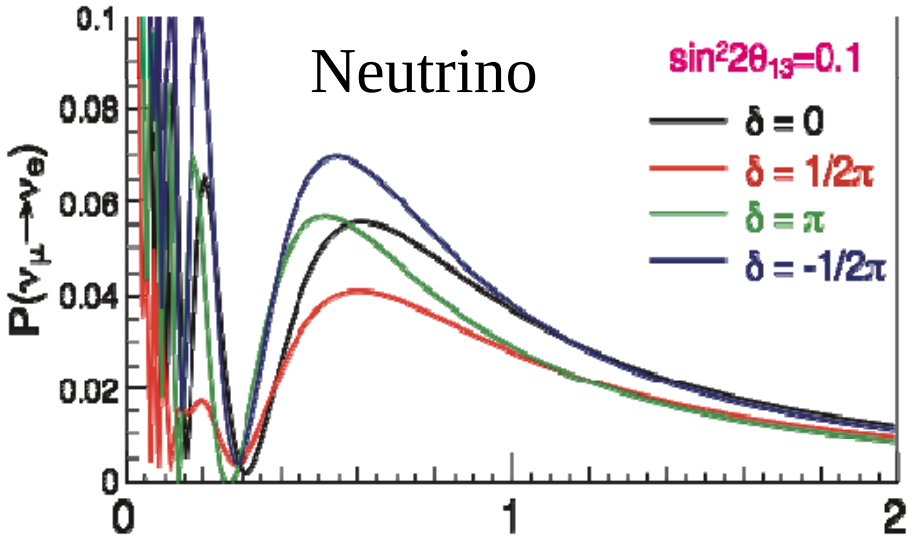
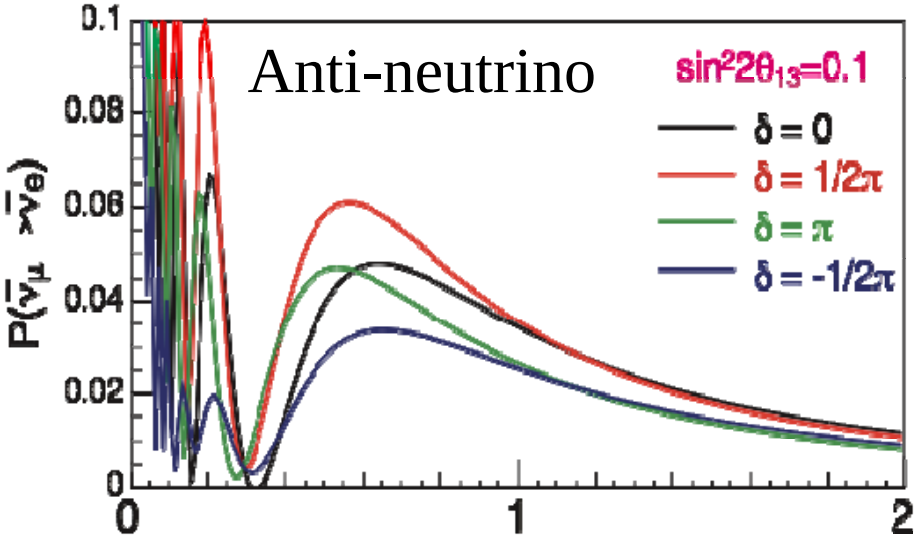


$$CPV \propto \sin\theta_{12} \times \sin\theta_{13} \times \sin\theta_{23} \times \sin\delta$$

- At maximum violation, ~±25% difference expected from $\delta = 0$





Expected ν_e CC candidates (LOI)

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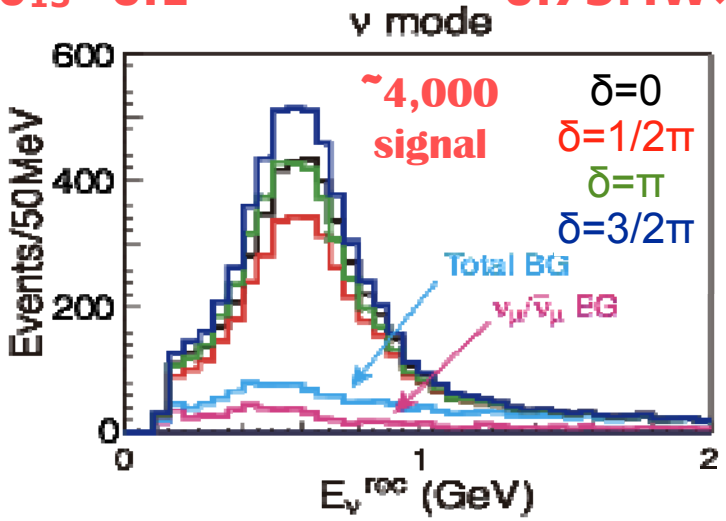
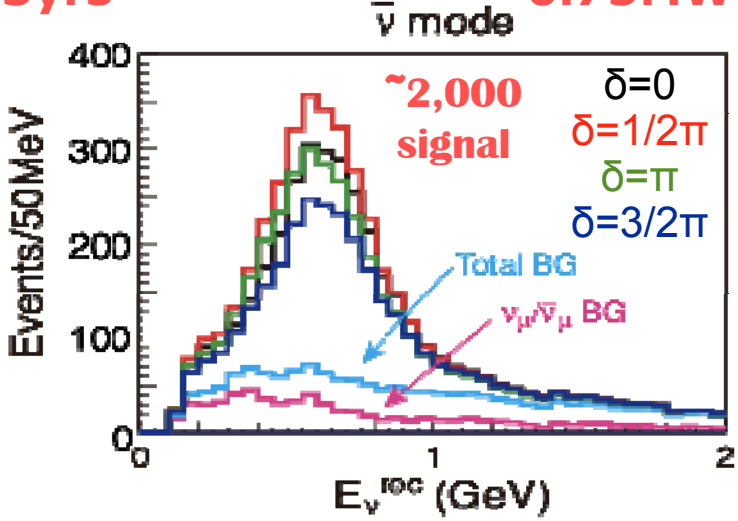
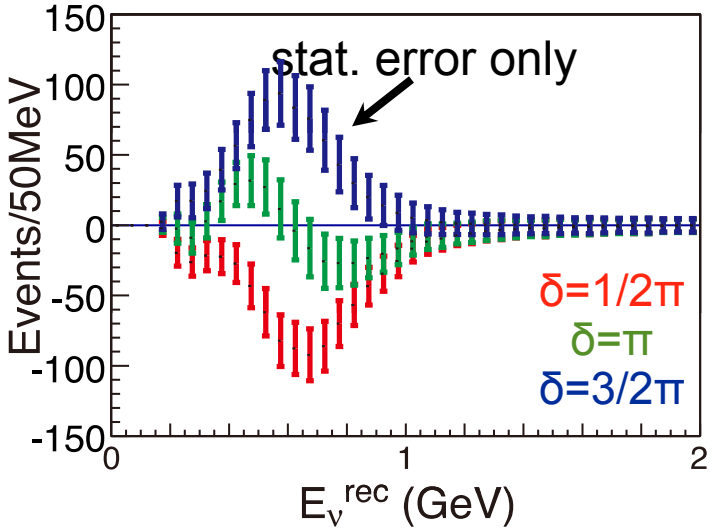
$\sin^2 2\theta_{13}=0.1$ 0.75MW×3yrs 0.75MW×7yrs

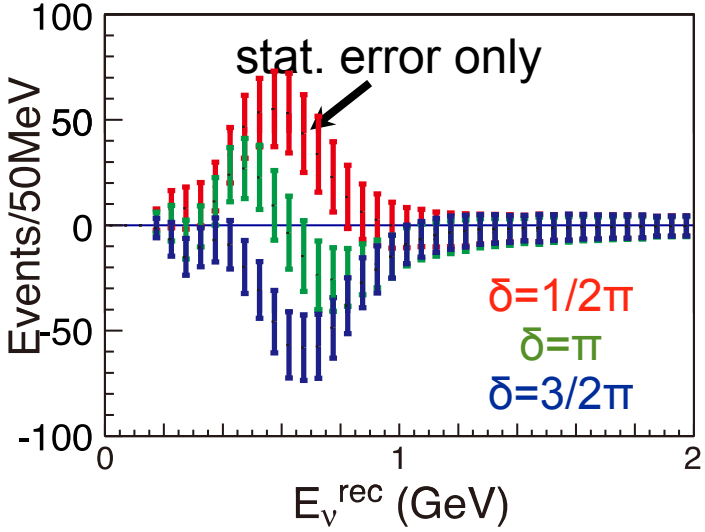
ν_e candidates





diff. from δ=0 case





- Further BG suppression expected with reconstruction improvement

CPV discovery sensitivity

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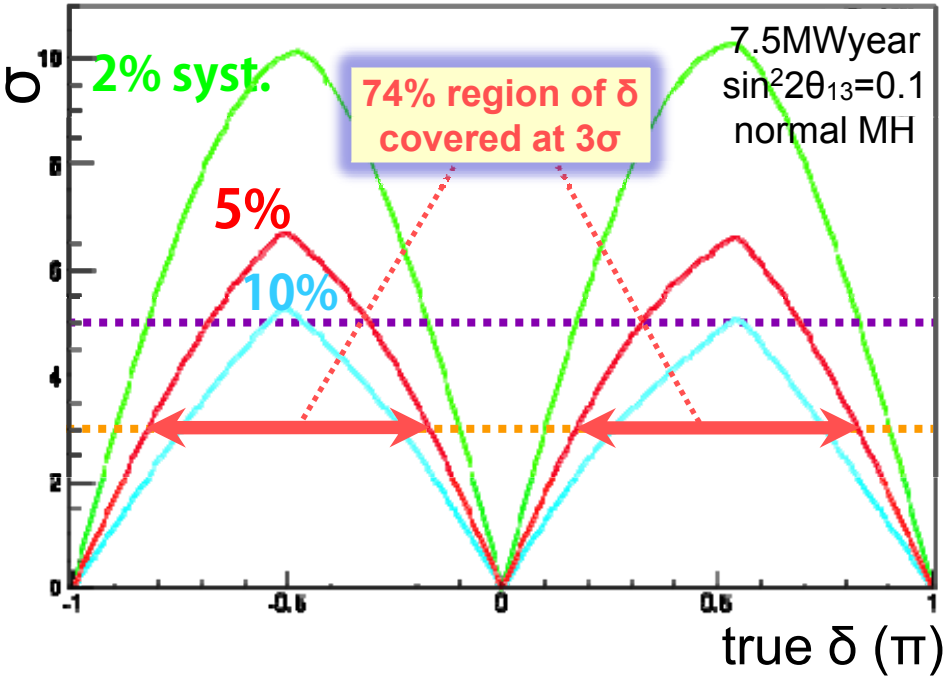
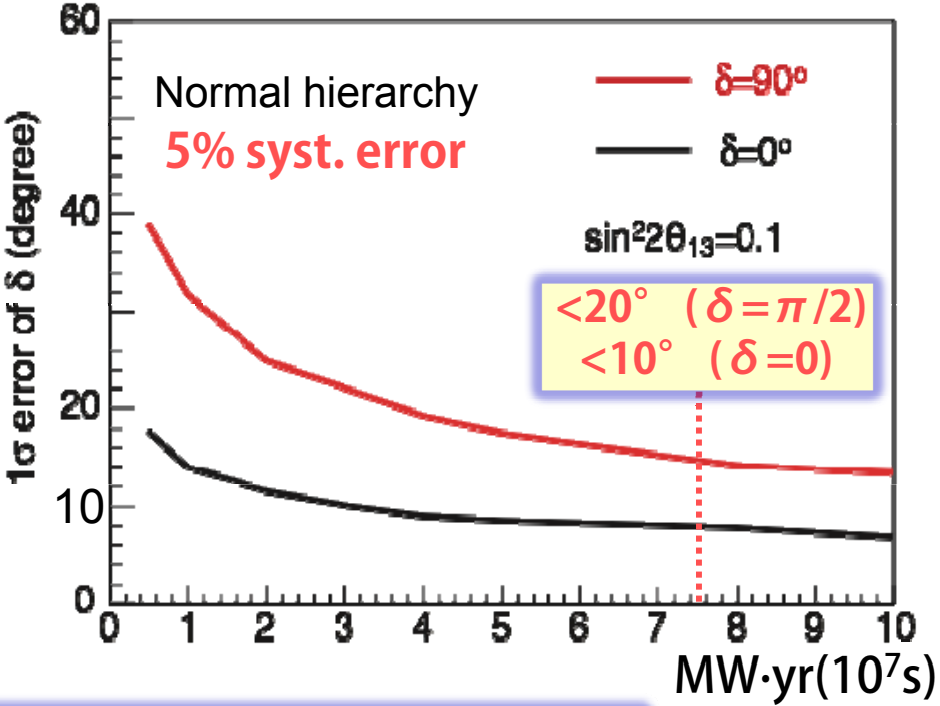
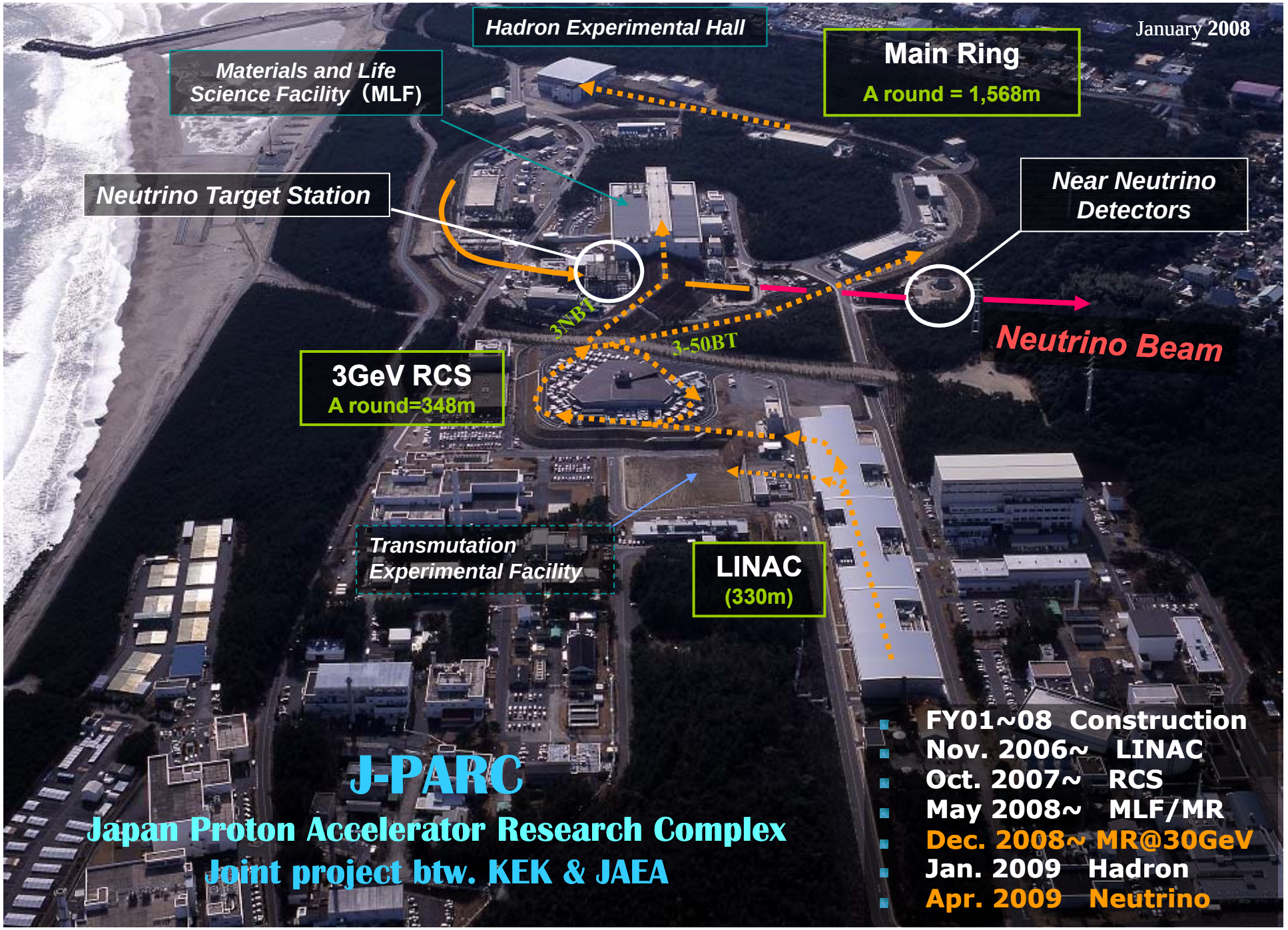




High sensitivity to CPV w/ <~5% sys. Error

- To go to CPV discovery, intensity upgrade of J-PARC is the key together with the efforts to reduce systematic errors
- Required run-time in LOI: 7.5MW x years
  - 750kW (J-PARC MR design power): 10 years = 3yr x ν + 7yr x ν bar

2. Operation status of J-PARC MR / neutrino experimental facility


January 2008
Hadron Experimental Hall
Main Ring
A round = 1,568m
Materials and Life Science Facility (MLF)
Neutrino Target Station
Near Neutrino Detectors
3NBT
3-50BT
Neutrino Beam
3GeV RCS
A round=348m
Transmutation Experimental Facility
LINAC
(330m)
J-PARC
Japan Proton Accelerator Research Complex
Joint project btw. KEK & JAEA
FY01~08 Construction
Nov. 2006~ LINAC
Oct. 2007~ RCS
May 2008~ MLF/MR
Dec. 2008~ MR@30GeV
Jan. 2009 Hadron
Apr. 2009 Neutrino

The neutrino experimental facility

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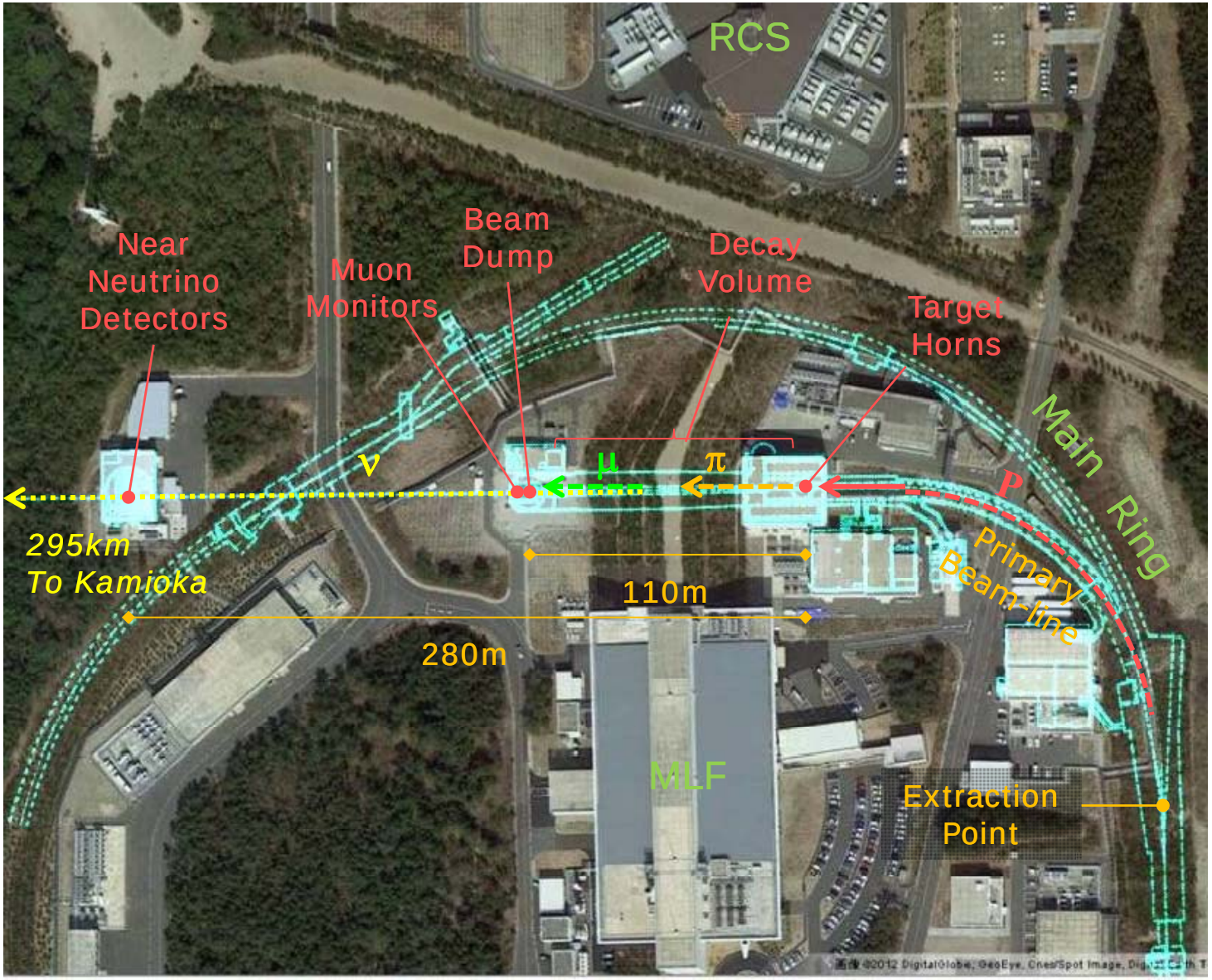
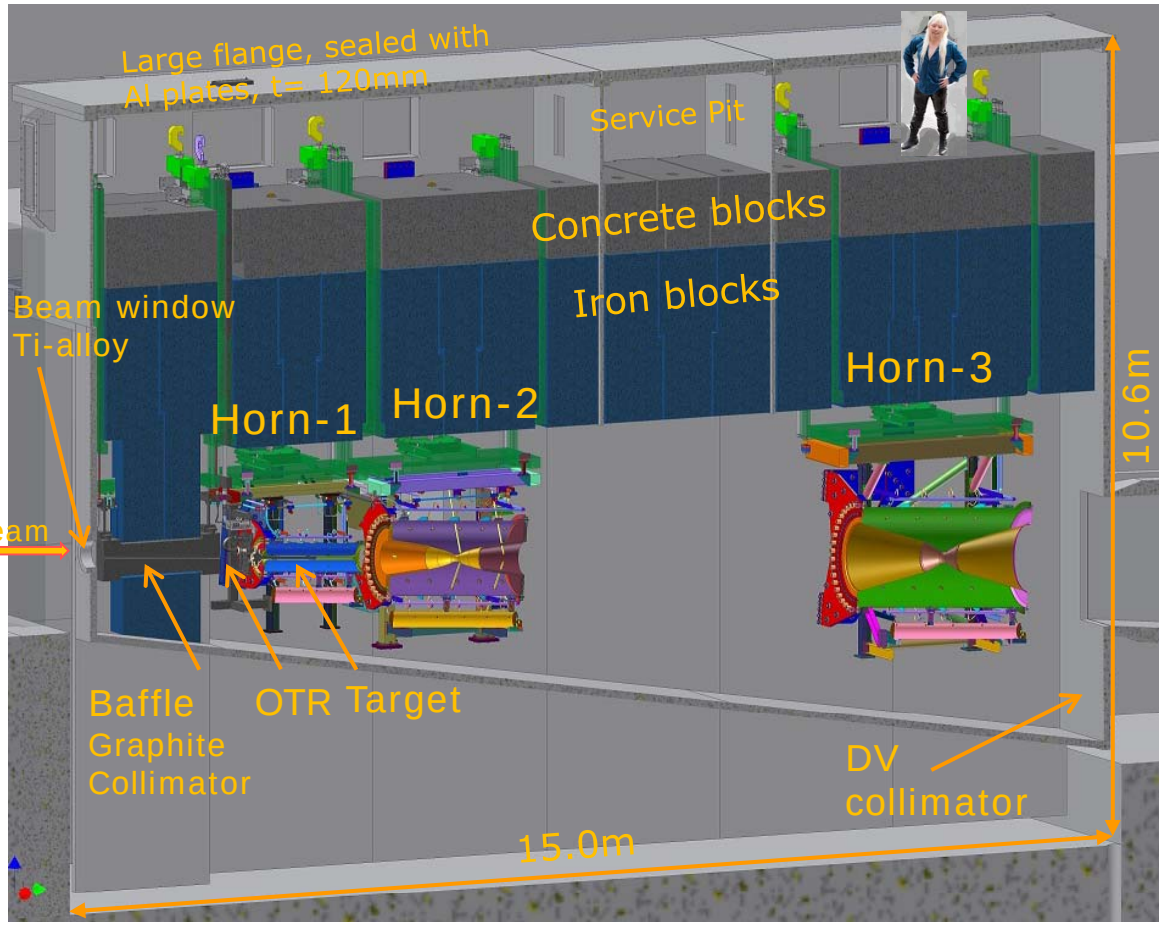


Target Station (TS)



- 3 horns / a baffle are supported from the wall of vessel by support modules.
- Apparatus on the beam-line are highly irradiated after beam. Remote maintenance is key issue.

An experience in 2011 summer⇒ TI (WG3-NuFact2012)

Electromagnetic Horns

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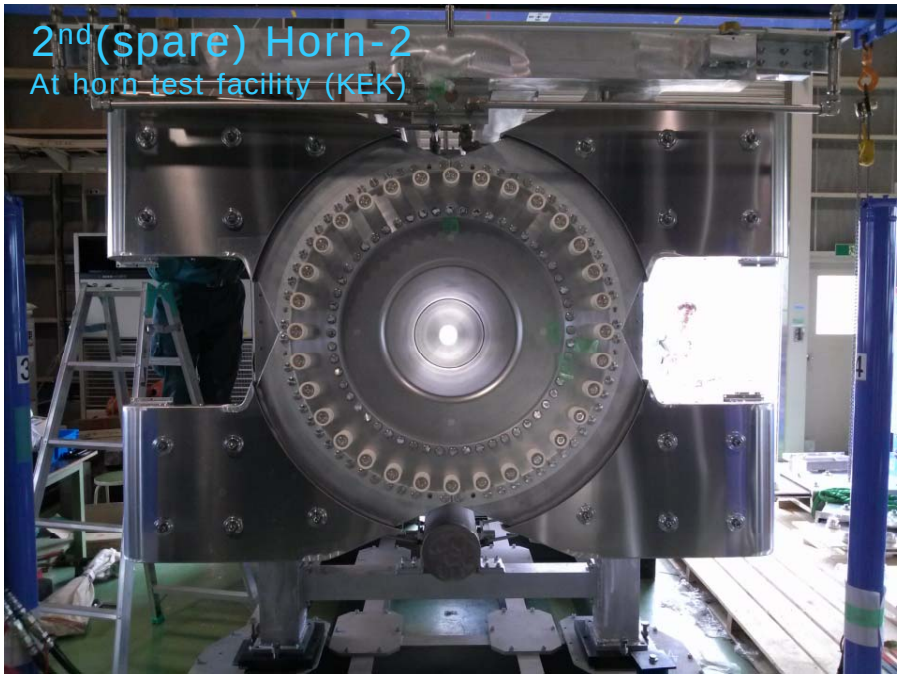

- Aluminum alloy A6061-T6
  - Inner conductor: t3mm, outer: t10mm.
- 320kA pulsed current (rated), 250kA in use
  - Max field: ~2.1T, pulse width: 2~3ms
  - Operation cycle: 2.48 s → 1.28 s
- Spraying water to inner conductor
  - 15kJ (beam) + 10kJ (Joule)=25kJ

⇒ T.Sekiguchi (WG3)

Target (He-cooled graphite)

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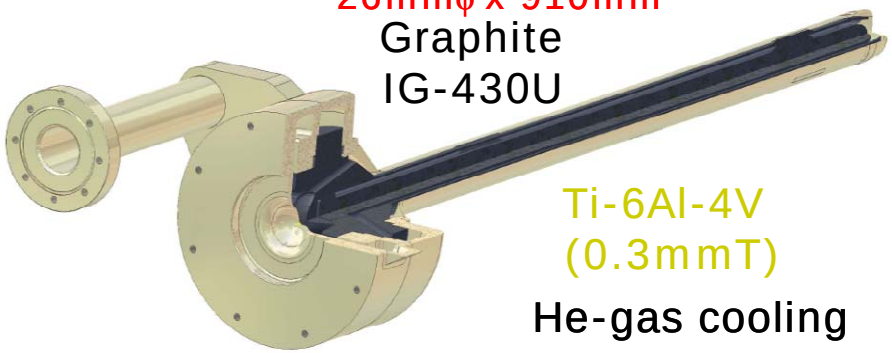
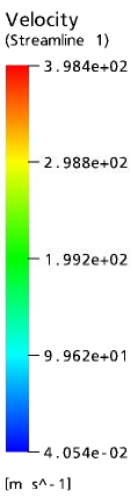
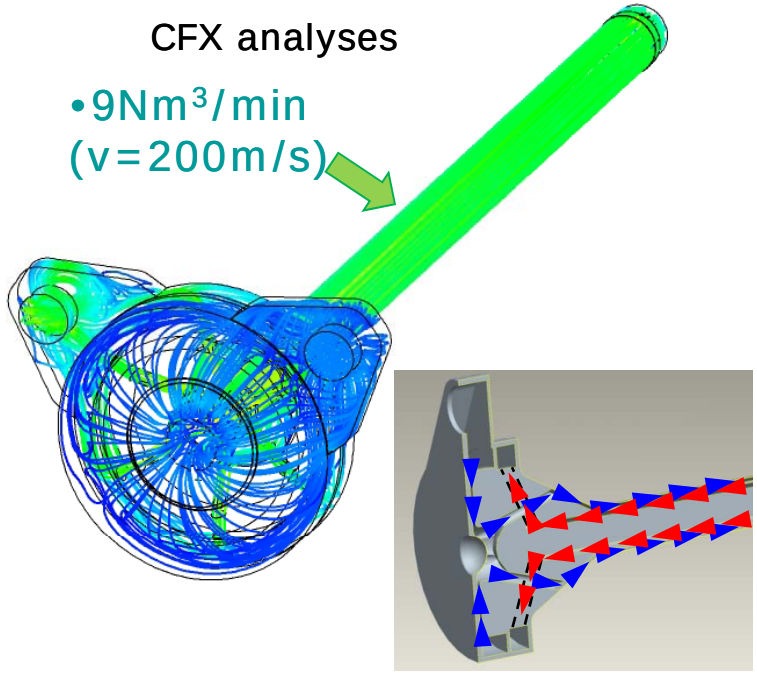
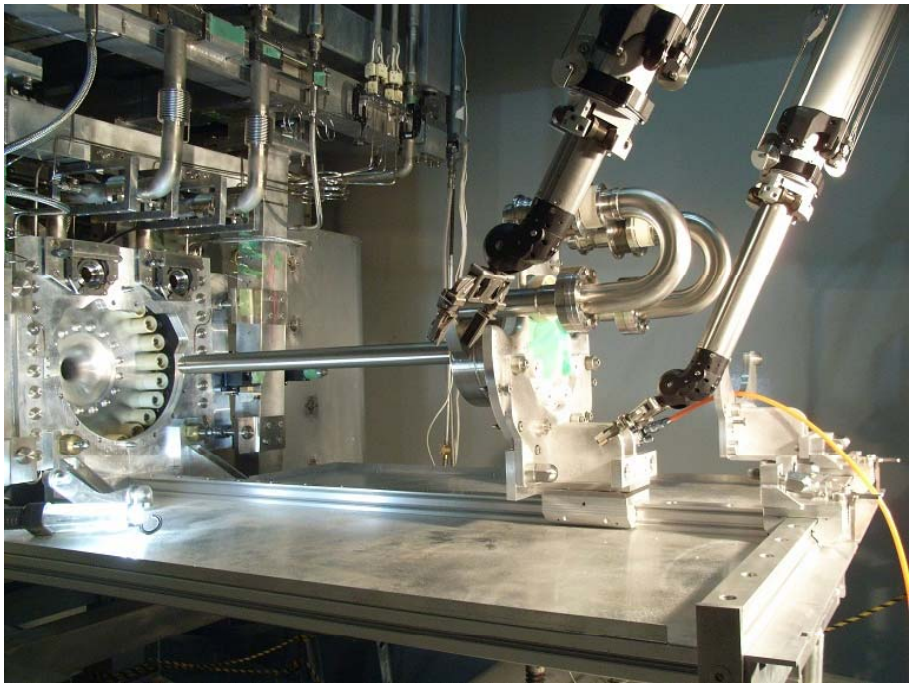
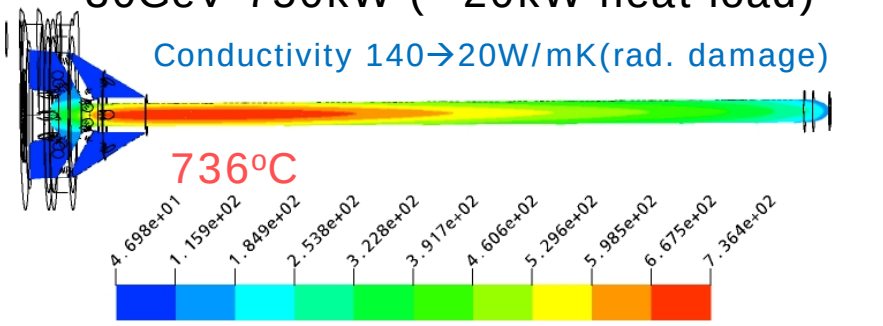








30GeV-750kW (~20kW heat load)



ΔT~200K ~7MPa (Tensile strength 37MPa)

⇒ C.J.Densham (P#3)

- **Remote maintenance**

Delivered POT to neutrino facility

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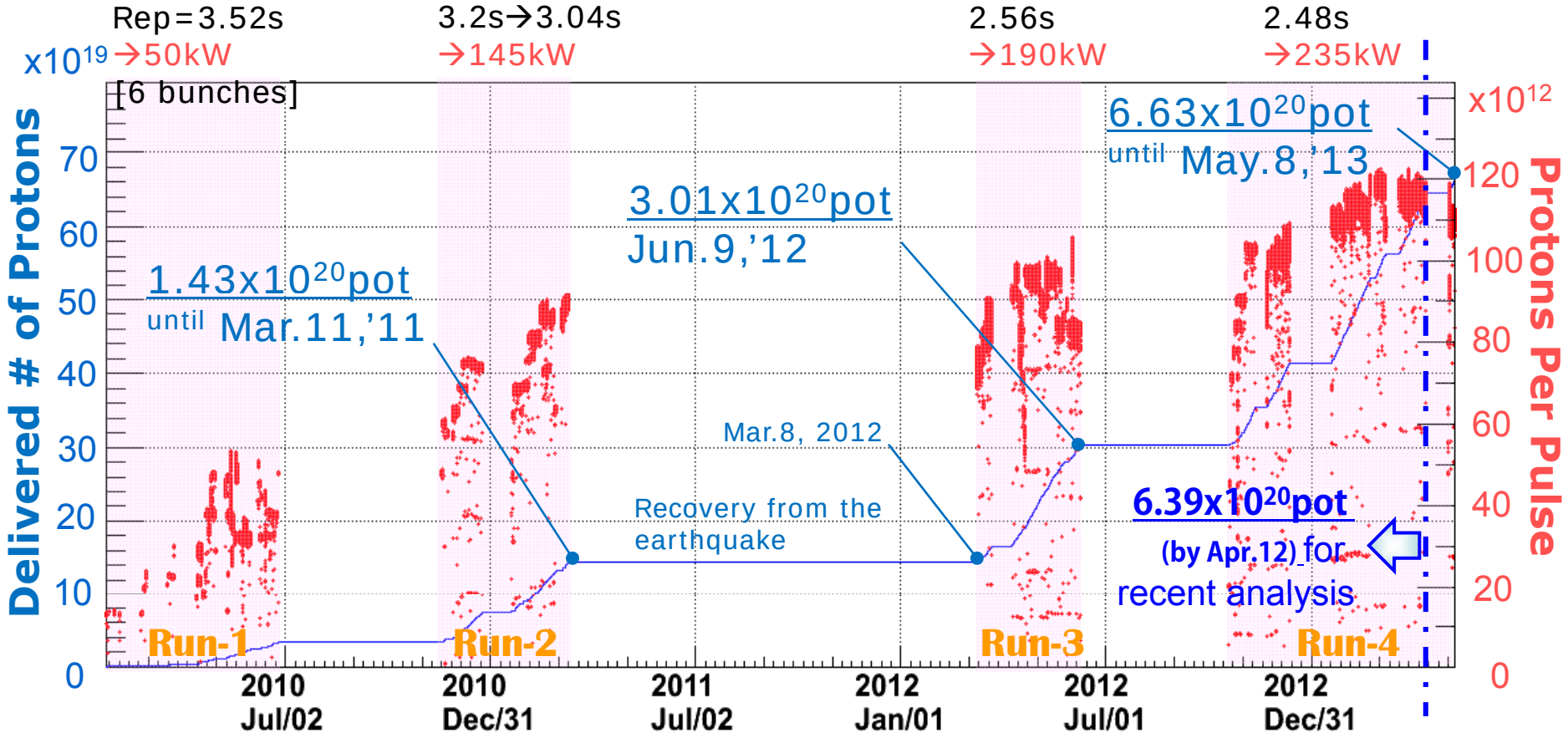
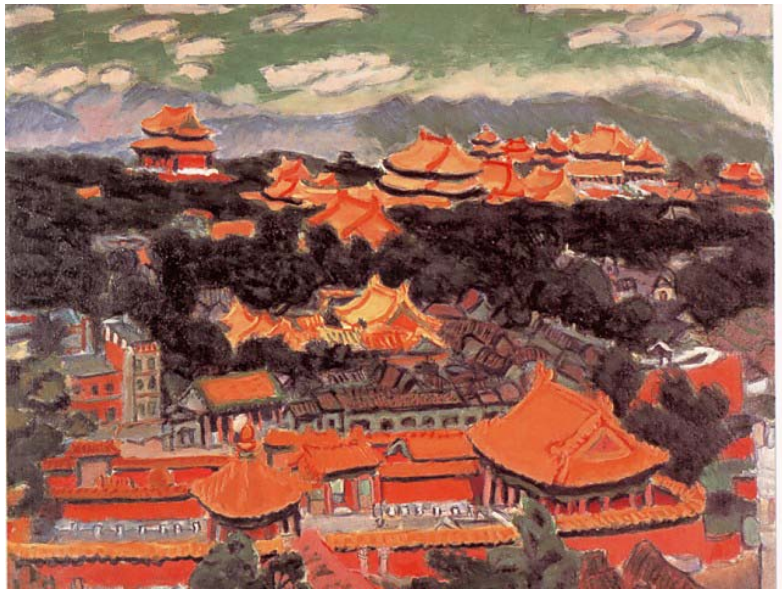


- Stable operation at ~220kW (235kW for trial)
  - >1.2x10^{14}ppp (1.5x10^{13}x8b) is the world record of extracted protons per pulse for synchrotrons.
- Accumulated *pot* : 6.63x10^{20} by May.8 (6.39x10^{20}pot by Apr.12).
- Accumulated # pulses : 1.2x10^{7}, no replacements for horns/target



3. Upgrade plan for J-PARC accelerators /neutrino experimental facility

Accelerator upgrades by T.Koseki (J-PARC Acc.)
at 1st Hyper-K open meeting (Aug.2012)
http://indico.ipmu.jp/indico/contributionDisplay.py?contribId=13&sessionId=3&confId=7

Neutrino experimental facility upgrades:
TI (WG3-NuFact2012)
TI (2nd Hyper-K open meeting, Jan.2013)
http://indico.ipmu.jp/indico/contributionDisplay.py?contribId=29&confId=10
M.Tada (3rd Hyper-K open meeting, Jun.2013)
http://indico.ipmu.jp/indico/contributionDisplay.py?contribId=42&confId=23

LINAC Upgrade

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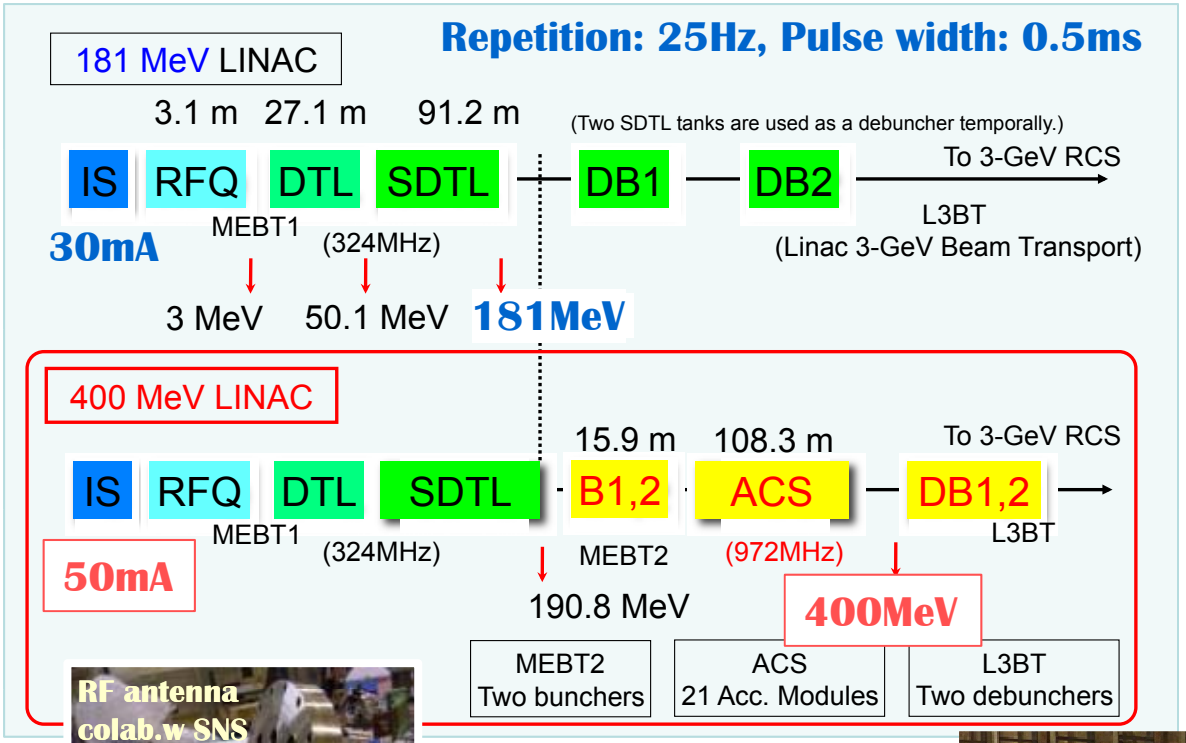
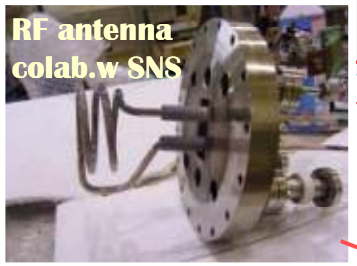
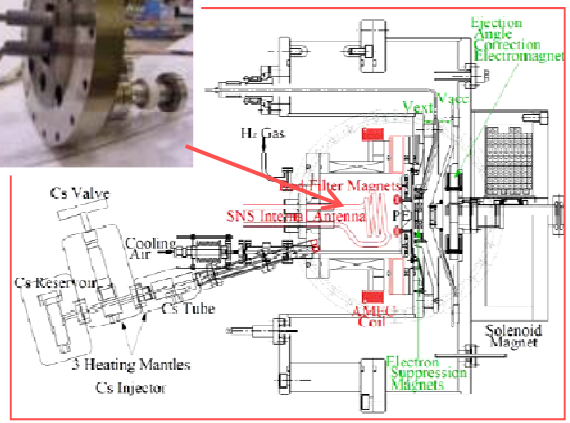
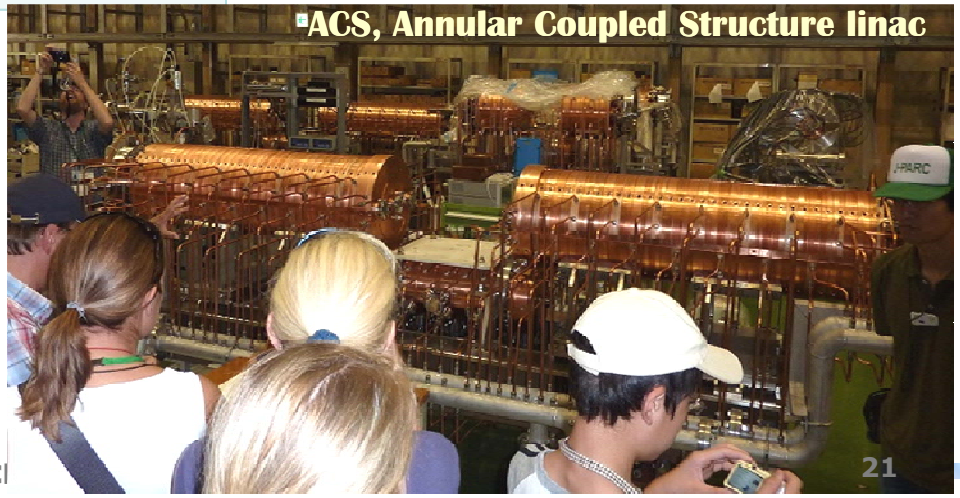


- New accelerating structure, ACS, will be installed to increase the extracted beam energy from 181MeV to 400MeV
- Front-end part (IS+RFQ) will be replaced to increase peak current from 30mA to 50mA







To achieve 750kw rated power

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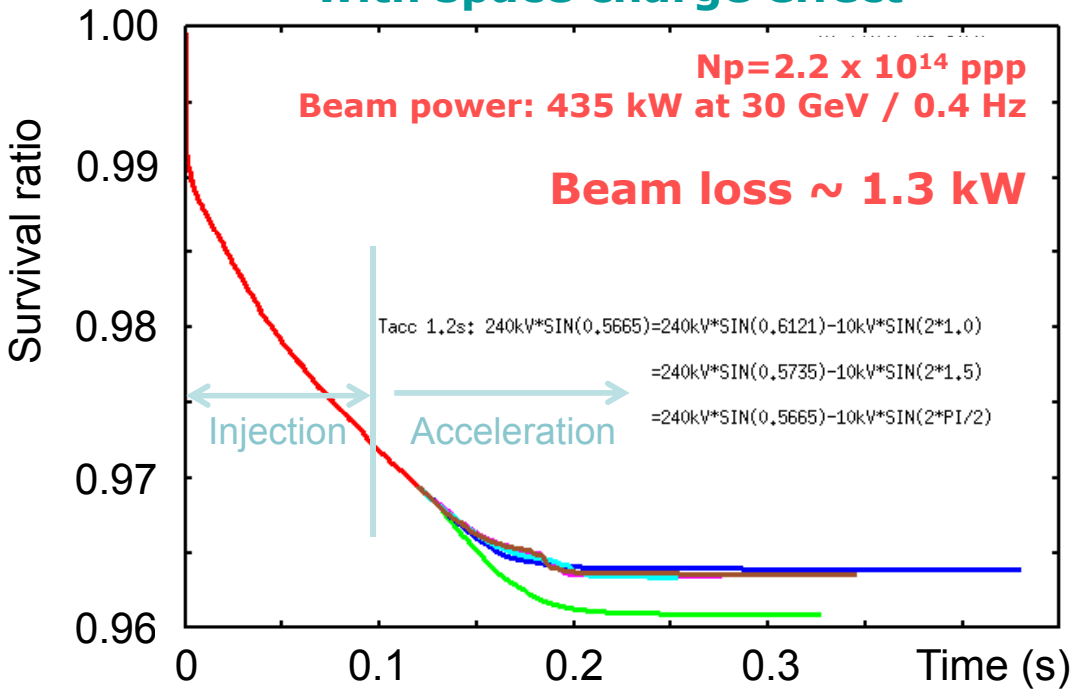
Tracking simulation of MR FX with space charge effect



(50GeV, 3.5s cycle, 3.3x10^{14} ppp)

→ 30GeV, 2.1s cycle, 3.3x10^{14} ppp

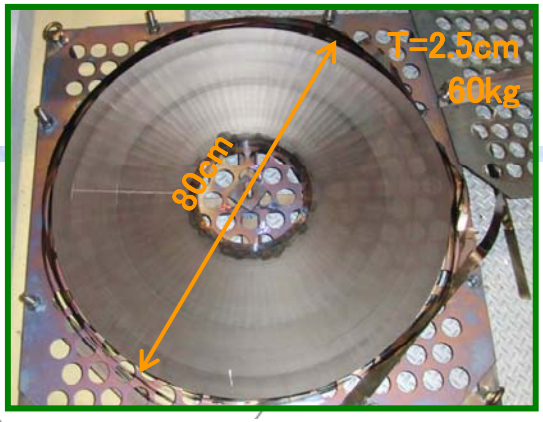
→ **30GeV, 1.3s cycle, 2.0x10^{14} ppp**

- Number of particles in one pulse is limited by the beam loss due to the space charge effect
  - **~450kW** is estimated upper limit with current apparatus
- To achieve rated power :
  1. Higher beam energy than 30 GeV (Original plan)
  2. **Higher repetition rate than 0.4 Hz**
- For >30GeV, saturation effect deteriorates the field quality of the main magnets
- Total magnet power consumption

$$P_{50GeV} = 2P_{40GeV} = 4P_{30GeV}$$

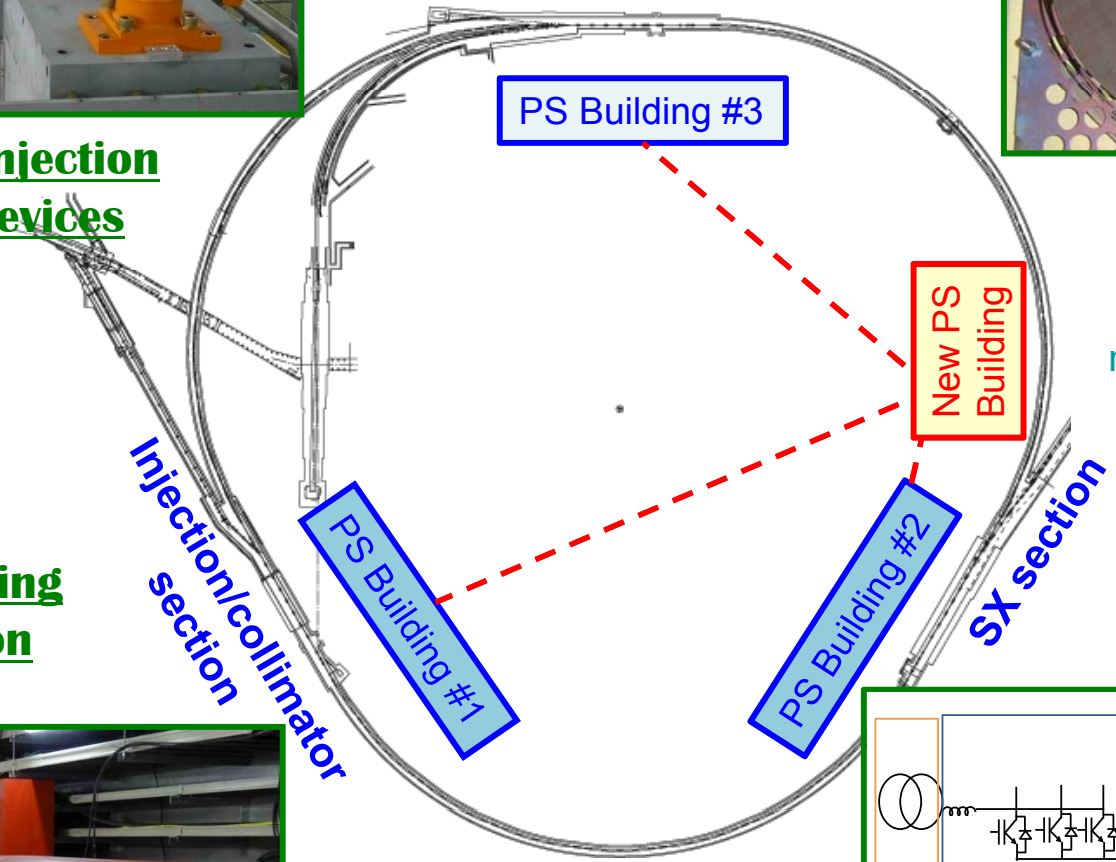
MR 1Hz Operation

(3) Upgrade of injection and extraction devices



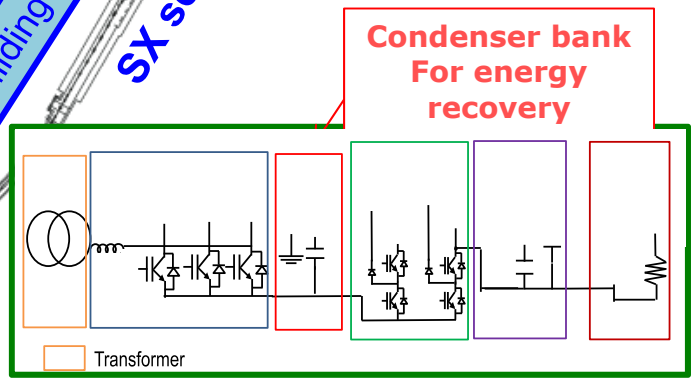
(2) Replacement of the rf cavities

New magnetic core material, which has x2 times higher impedance than present one, is developed.



(4) Upgrade of ring collimator section

2kW→3.5kW



(1) Replacement of

All the main magnet power supplies will be replaced with newly developed high rep./low ripple PS. A new PS building to be constructed.

The midium-term plan of MR-FX

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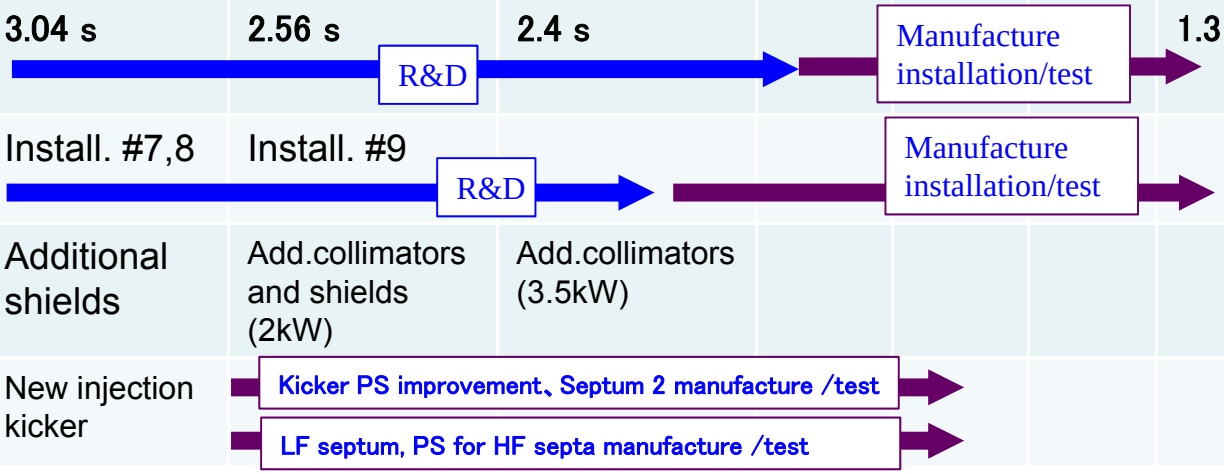
KEK

JFY	2011	2012	2013	2014	2015	2016	2017
			LINAC	IS/RFQ			
FX power [kW]	150	200	300	400			750
Cycle time of main magnet PS New magnet PS for high rep.	3.04 s	2.56 s	2.4 s				1.3 s
Present RF system New high gradient rf system	Install. #7,8	Install. #9					
Ring collimators	Additional shields	Add.collimators and shields (2kW)	Add.collimators (3.5kW)				
Injection system FX system	New injection kicker						



- Rep. rate will be increased (0.4Hz ⇒1Hz) by replacing magnet PS's and RF cavities
  - A new budget is needed for replacing MR main magnet power supplies.
- Note this is a possible schedule before the Hadron-hall accident (May 2013).
  - We are making the best efforts to investigate the cause / prevention of recurrence
  - Schedule of beam restart / LINAC upgrade are both not yet determined.

⇒ For more info, http://j-parc.jp/HDAccident/HDAccident-e.html

Doubled rep.rate: Impact to target

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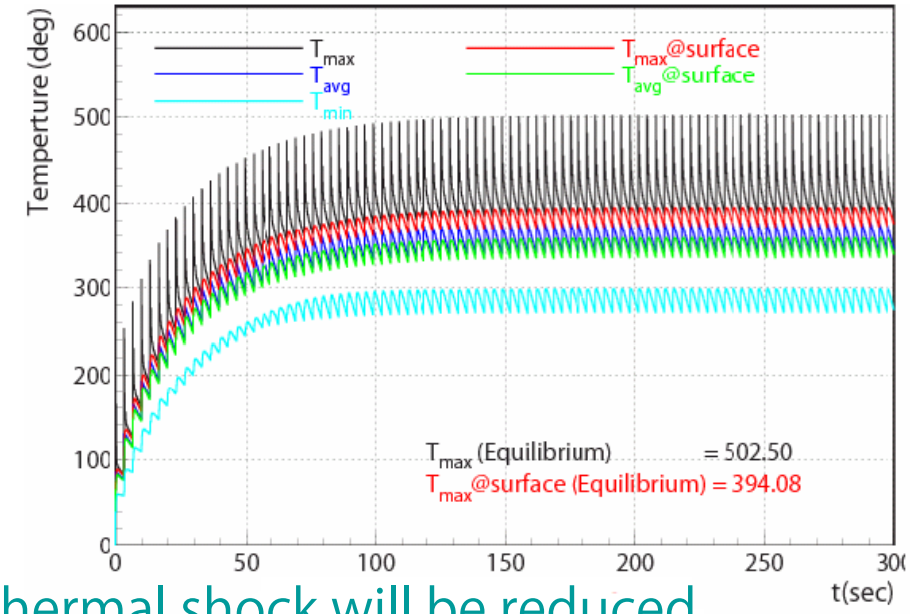
Temperature of target as func. of time



- Instantaneous heat deposit / thermal shock will be reduced
  - With 750kW beam (30GeV,3.3x10^{14}ppp): $\Delta T = 200K/spill$, σ_{eq}=7.2MPa
  - Safety factor = Strength(37MPa) / Stress x fatigue(0.9) = ~3.5 ($\propto$ 1/ppp)
- Keep temperature of graphite around 400~800℃
  - Slow down degradation of thermal conductivity by rad. damage (0.25DPA/yr)
- Oxidization due to contamination in He gas reduces graphite strength
  - Assuming O_2=100ppm and temperature =700°C, safety factor >2 for **5 yrs**.

⇒ **T.Nakadaira, talk at Neutrino Beam Instrumentation WS (NBI2010)**
http://kds.kek.jp/materialDisplay.py?contribId=7&sessionId=4&materialId=slides&confId=5611

Doubled rep.rate: Impact to Horn

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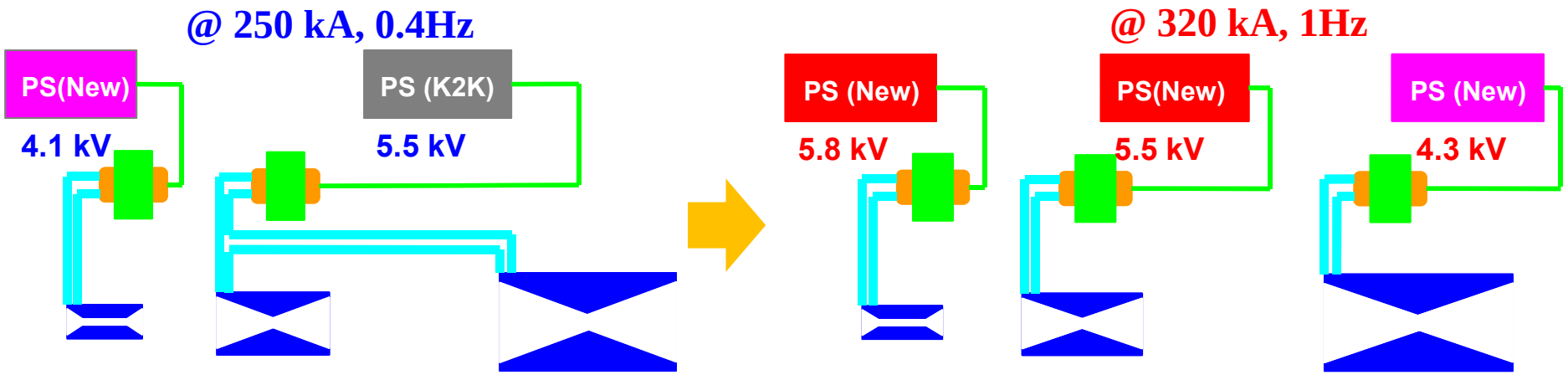

- Individual power supply for each horn
  - Reduce charging voltage, which greatly reduces risk of failure.
  - It will make possible to operate horns with rated 320kA.
- Various upgrades
  - Forced cover gas flow for Hydrogen-Oxygen recombination system
  - Low impedance strip lines
  - Improvement for connection of strip line cooling ducts

⇒ T.Sekiguchi (WG3)

4. Summary

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- J-PARC MR/neutrino exp. facility realized 220kW operation
  - 30GeV, 2.5s cycle, 1.2x10^{14}ppp: world record of extracted *ppp* for synchrotron.
  - The first set of 3 horns/target has been used w/o serious troubles for all periods.
- Upgrade plan of J-PARC accelerators towards rated 750kW oper.
  - Increase #p/bunch : 1.2 x10^{14} →2.0x10^{14} *ppp*
    - MR collimator capability: 450W → 2KW → 3.5kW
    - LINAC energy upgrade : 181MeV → 400MeV
    - LINAC frontend (IS/RFQ) upgrade: 30mA → 50mA
  - Double MR rep-rate: 2.5s →1.3s cycle
    - Replace all magnet power supplies / higher gradient RF core etc.
  - 5yr plan for MR upgrade to realize 750kW beam (*before hadron hall accident*)
    - We are making the best efforts to investigate the cause / prevention of recurrence.
    - Schedule of beam restart / LINAC upgrade are both not yet determined.
- Upgrade of neutrino beam-line to accept 750kW beam
  - Doubled rep.rate is plausible to reduce thermal shock on target
  - Individual 3 power supply for each horn make 320kA-1Hz oper. possible.
  - Current all 3 horns (target) to be replaced to ones with upgrades
    - Hydrogen-oxygen recombination in coolant water / efficient strip line cooling

International Hyper-K meetings

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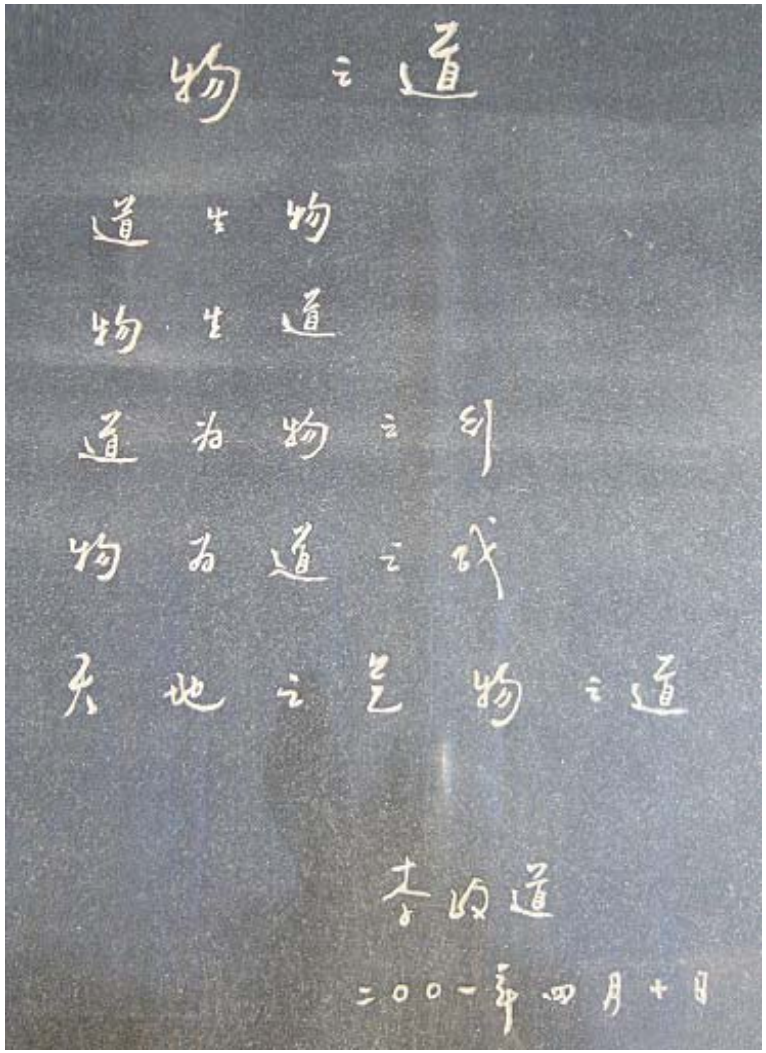
- Opened to the international community
- Three open meetings so far, very active working groups
  - http://indico.ipmu.jp/indico/conferenceDisplay.py?confId=23
- Next meeting: Jan 27-28, 2014 @ Kavli IPMU, Japan



Tao
~ the ultimate principle of the universe