Prospects for Neutrino physics in Japan

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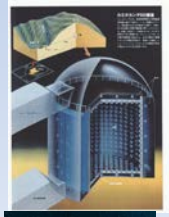
IPNS/KEK, J-PARC

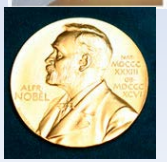
Neutrino experiments in Japan

’80s ’90s ’00s

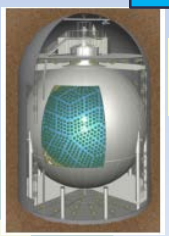
Kamiokande (1983~1996)



3000ton Water



KamLAND (2002~)



1000ton pure oil Liq Scint.

→ 0n2b w/ Xe ballon

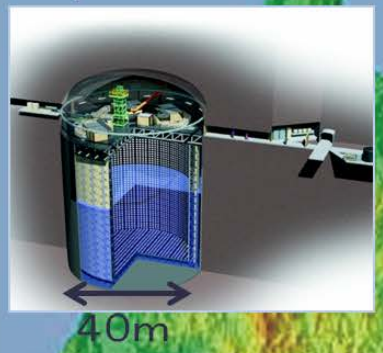
Super-Kamiokande (1996~)

50,000ton Water

World first accelerator-based long baseline experiment

K2K

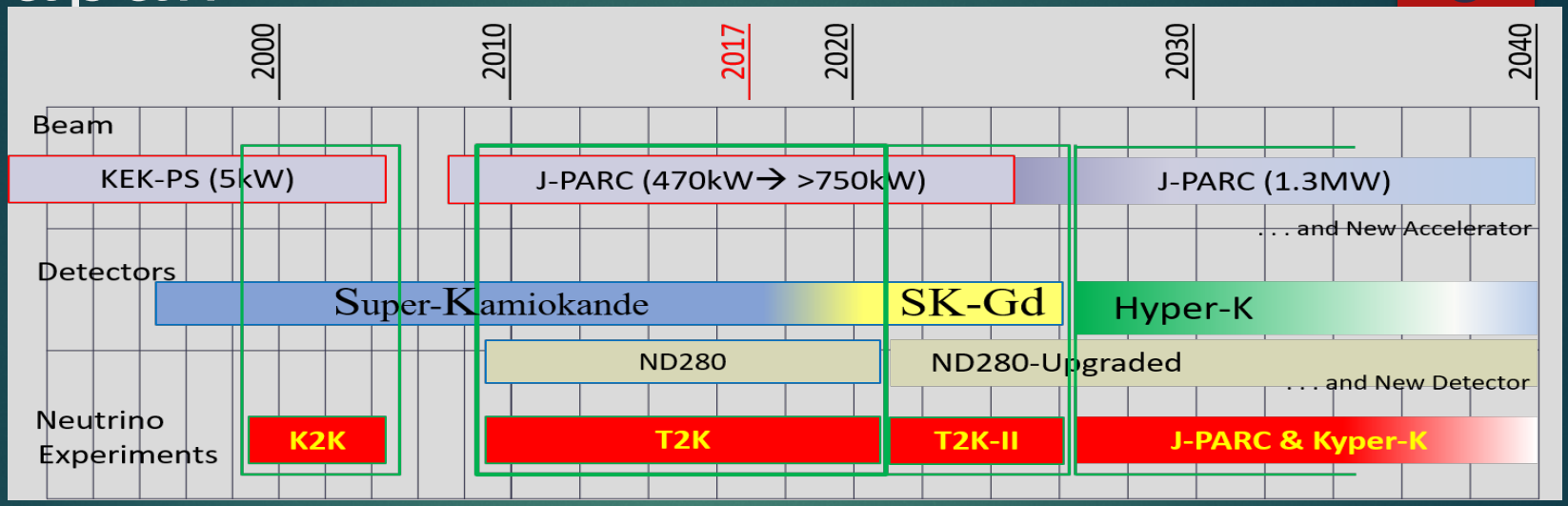
(1999~2004)



T2K(2009~)

2nd gen. LBL experiment w/ ~MW beam (~100xK2K)

Accelerator-based neutrino program in Japan

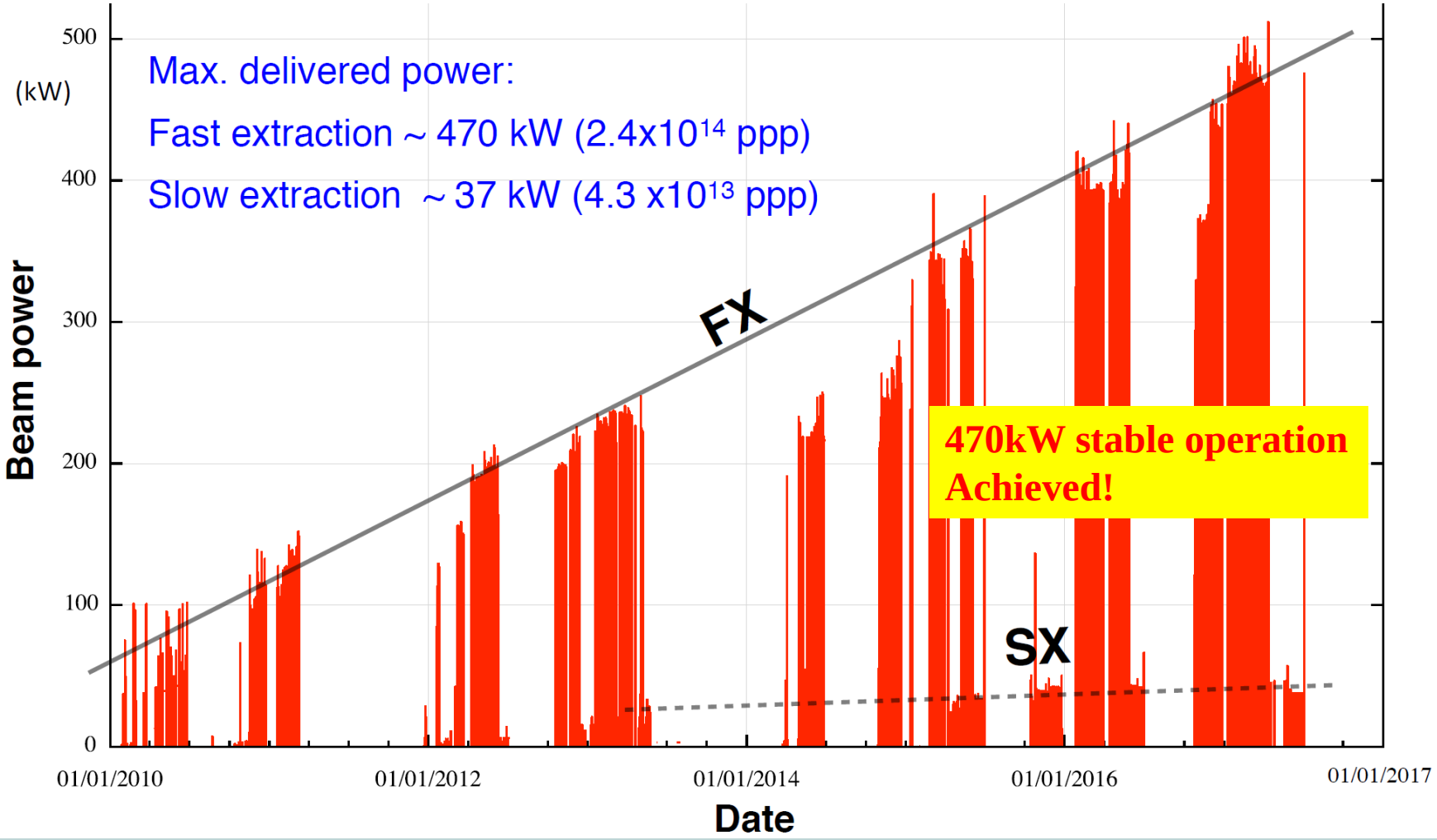


Hyper-Kamiokande (260kt)

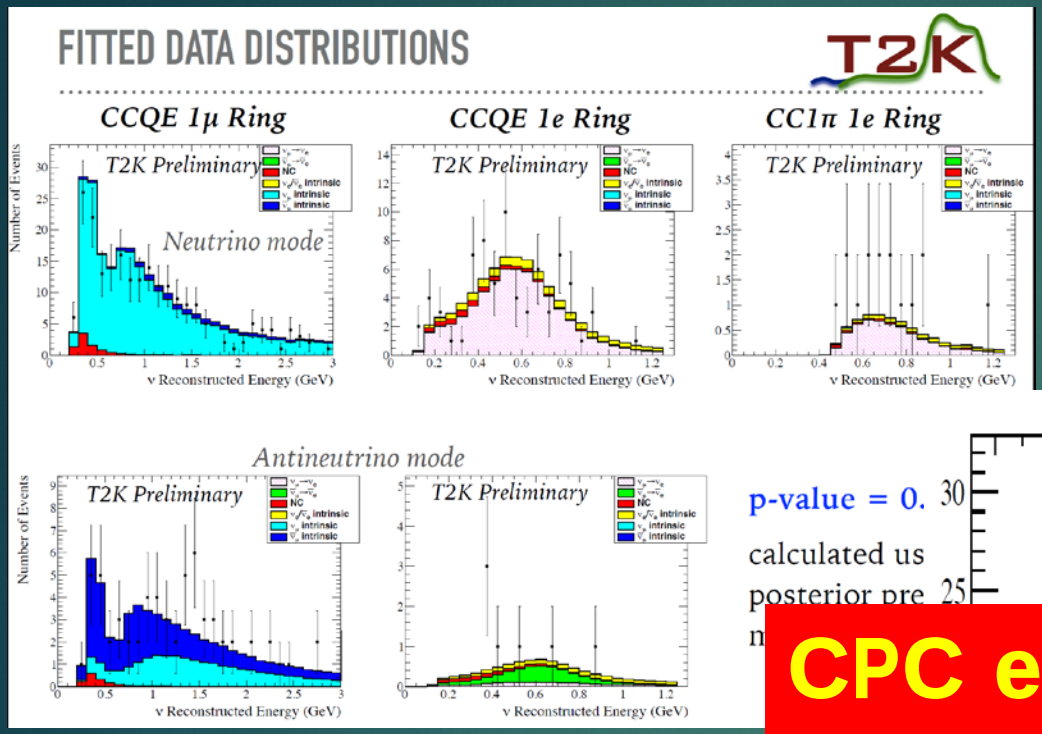
Bird's eye photo in January of 2008

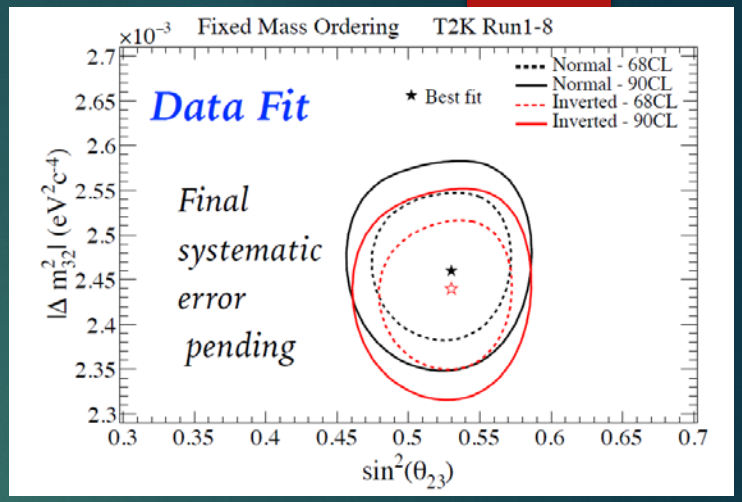
MR: Beam power history

- In the operation from Jan to April 2017, the beam power was mostly about 470 **kW with 2.4×10^{14} protons per pulse**.
- The beam power of SX mode was limited to **~37 kW** in June 2017 because of ESS trouble.

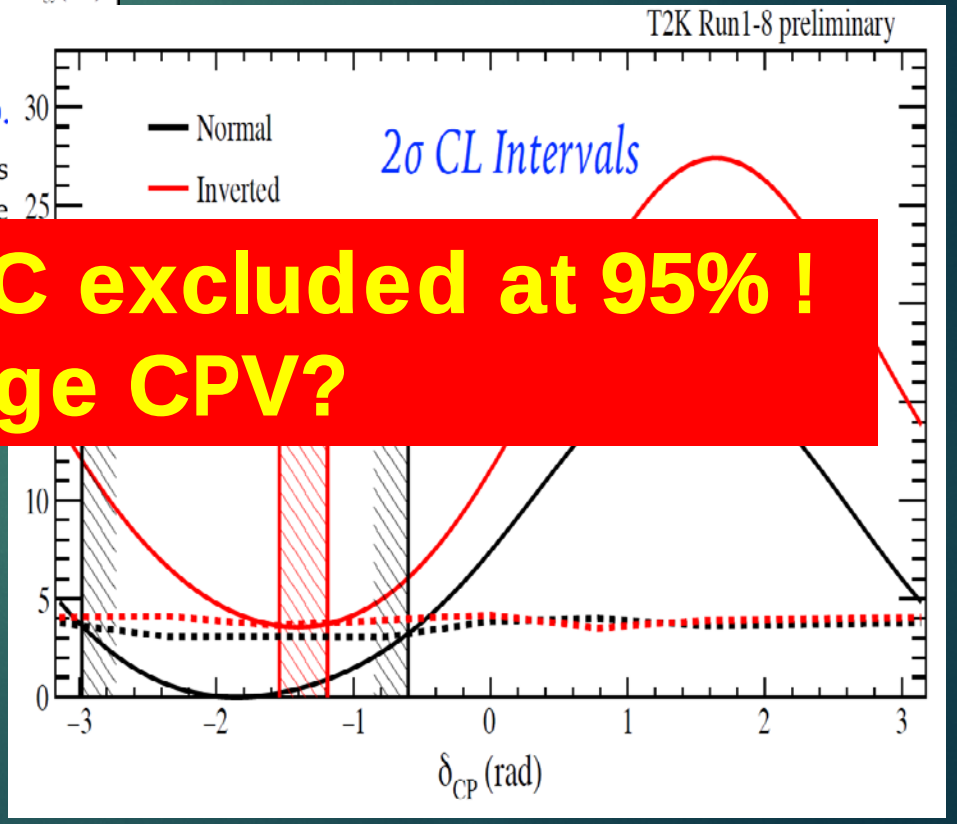


T2K results (2017)





p-value = 0.
calculated us
posterior pre



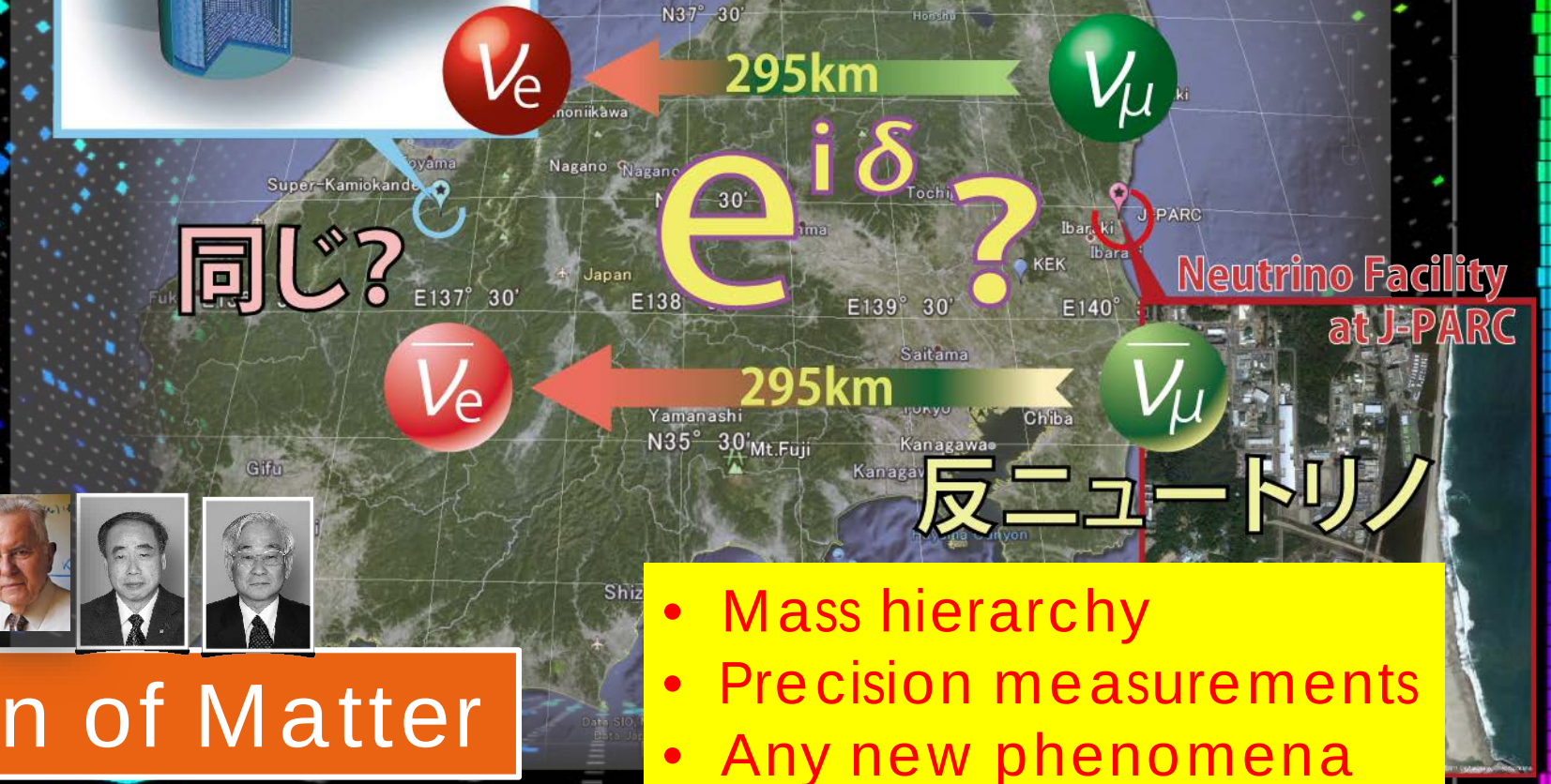
CPC excluded at 95% !
Large CPV?

Posterior probabilities (with reactor constraint)

	$\sin^2\theta_{23} < 0.5$	$\sin^2\theta_{23} > 0.5$	Sum
NH ($\Delta m^2_{32} > 0$)	0.193	0.674	0.868
IH ($\Delta m^2_{32} < 0$)	0.026	0.106	0.132
Sum	0.219	0.781	

Next big goal: CPV

Neutrino and anti-neutrino behave same?



Origin of Matter

- Mass hierarchy
- Precision measurements
- Any new phenomena

Near and middle term future

T2K-II (T2K extension)

		T2K goal	T2K-II goal
Beam power	: (470kW→)	750kW	→ **1300** kW
POT goal	: (2.25×10^{21}→)	7.8×10^{21}	→ **20×10^{21} (now x9)**
Eff improve	: **+ 50% stat (+10% by horn current + Analysis)**		

- Physics
  - **Evidence of CP violation at > 3σ ($\delta = -\frac{\pi}{2}$)**
  - Contribution to mass hier. determ.
  - Neutrino int. cross sec.
- Proposal submitted to PAC, stage-1 status granted

https://arxiv.org/abs/1609.04111

Upgrade to 1.3MW (also for Hyper-K)

- Strategy

+22%

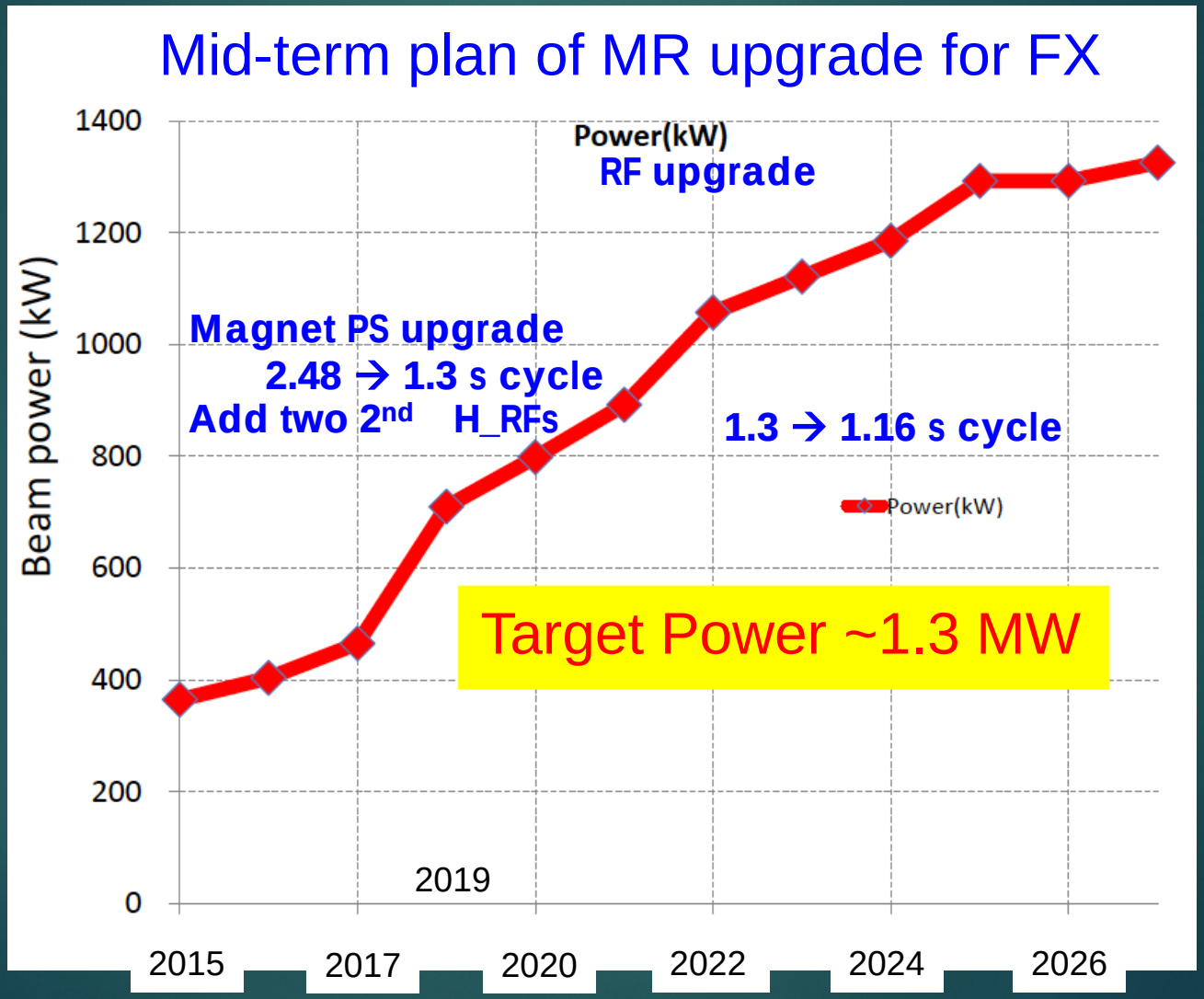
Beam Power (kW)	470 (Achieved)	897	Demonstrated 510kW eq	1326 (Goal for T2K-II)
#p/p(10^{12})	243	243	264	320
Rep T (s)	2.48	1.3	shots	1.16

+13%

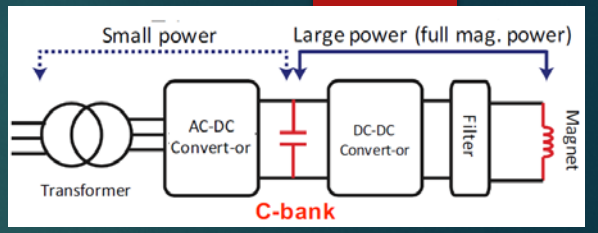
- Method
  - Higher rep rate: **Funding started**
    - MR magnet power supply upgrade
    - MR RF upgrade (High grad/PS)
    - MR Fast Extraction Kicker upgrade
  - Higher #p/p
    - MR RF upgrade (PS)
    - MR Beam monitor upgrade
      - Precise beam control for Higher ppp

After funding for 750kW design power is secured, No big step to >1.3MW

J-PARC MR Upgrade – Mid-Term Plan

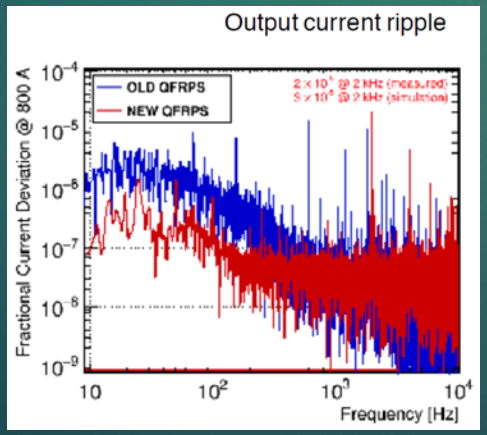


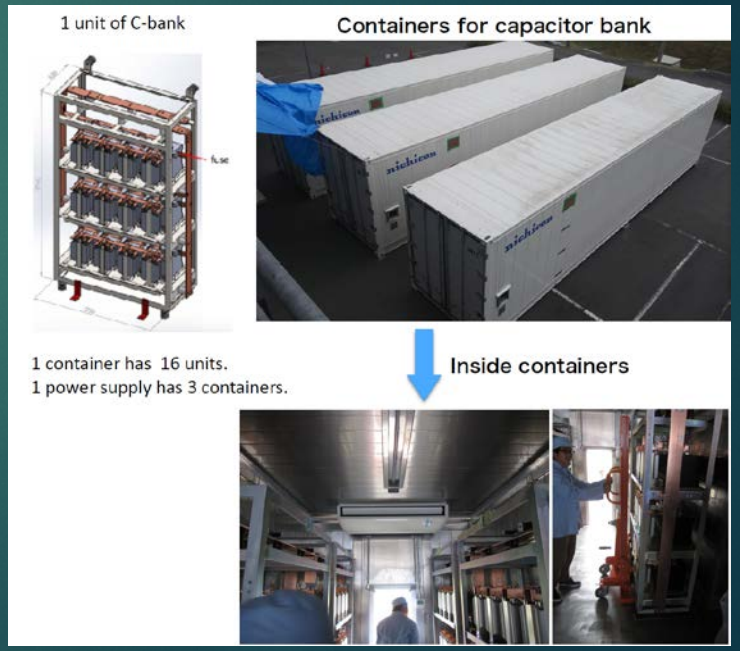
MR magnet power supply upgrade for higher rep rate



- Large capacitor bank for energy recovery
- Construction started
  - Buildings to be completed in 2017
  - First mid scale PS installed and being operated successfully
  - First full size PS to be tested in this winter

Budget for three buildings of the magnet PS's and starting mass production of the PS's have been approved by the government in JFY2016.





Neutrino beam facility upgrade

- Original design principle/specification
  - 750kW for replaceable components
  - >3MW for irreplaceable parts (Decay volume, Dump, etc)
  - 750kW = 30GeV x **(330Tp/5us pulse)** x (2.10s cycle)
- Goal
  - 1.3MW = 30GeV x **(320Tp/5us pulse)** x (1.16s cycle)
    - Similar impulse thermal shock!
- Main upgrades
  - Horn current 250kA → 320kA (+10% nu flux)
  - Cooling power
  - Radio-active waste (water,..) processing power

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.

KEK Project Implementation plan (KEK-PIP)

- Prioritization of projects which require new funding requests
- External review (May 22,23, 2016)
  - Recommendations
  - https://www.kek.jp/ja/About/OrganizationOverview/Assessment/Roadmap/KEK-PIP_Evaluation.pdf
- KEK-PIP taking into account the recommendations
  - https://www.kek.jp/ja/About/OrganizationOverview/Assessment/Roadmap/KEK-PIP.pdf

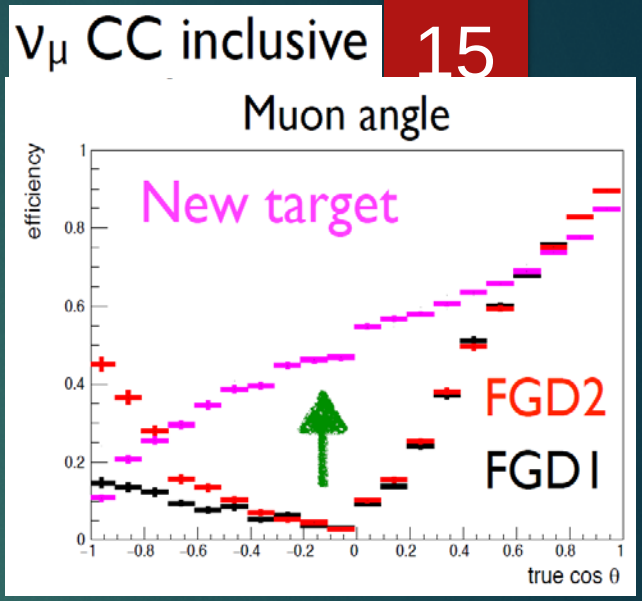
Project to be prioritized:
- COMET II
- J-PARC upgrade for Hyper Kamiokande
- Hadron Hall Extension
- H-line and g-2/EDM
- LHC and ATLAS
- Super Computer
- RNB

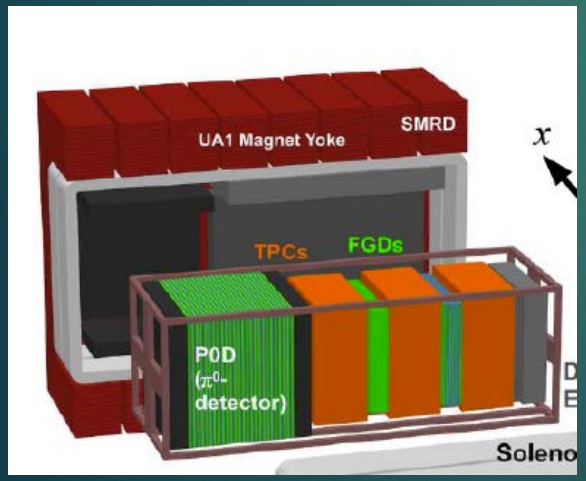
Separate prioritization
- Light Source

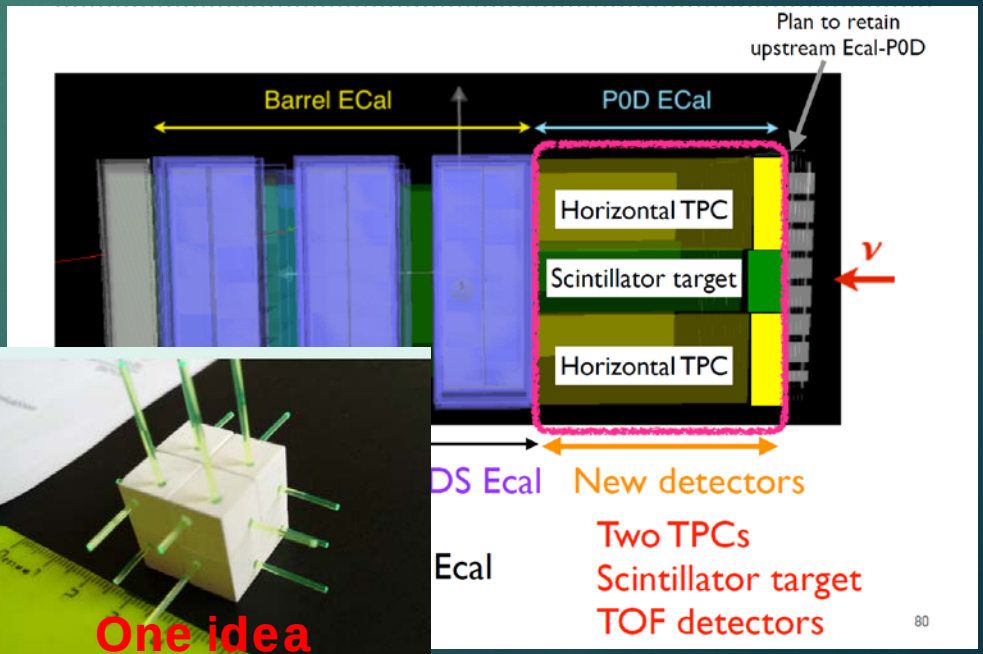
Upgrade of J-PARC for Hyper-K is highest priority

Improving cross section errors: Near detector upgrades

- Present near detector (280m) working fine
  - Producing many cross section data
- But low efficiency for large angle tracks
- Upgrade 280m det for T2K-II
  - Increase acceptance
- Status
  - Conceptual baseline design
  - Detailed design under discussion and R&D
- Workshop for TPC near detector
  - https://indico.cern.ch/category/8511/

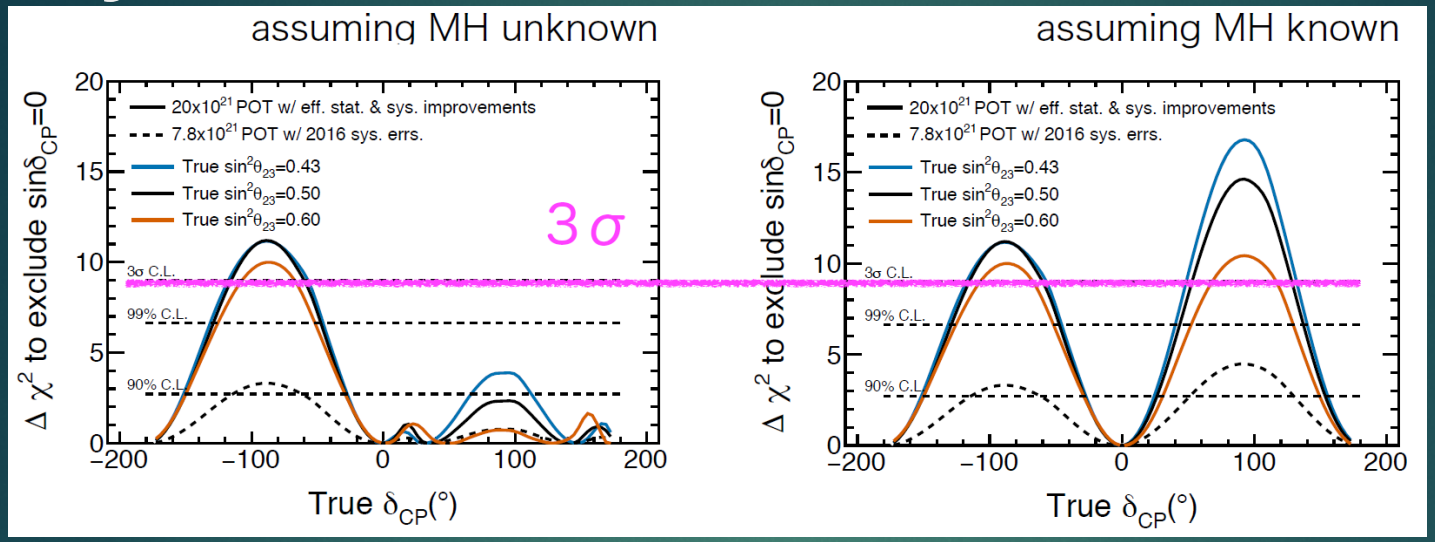


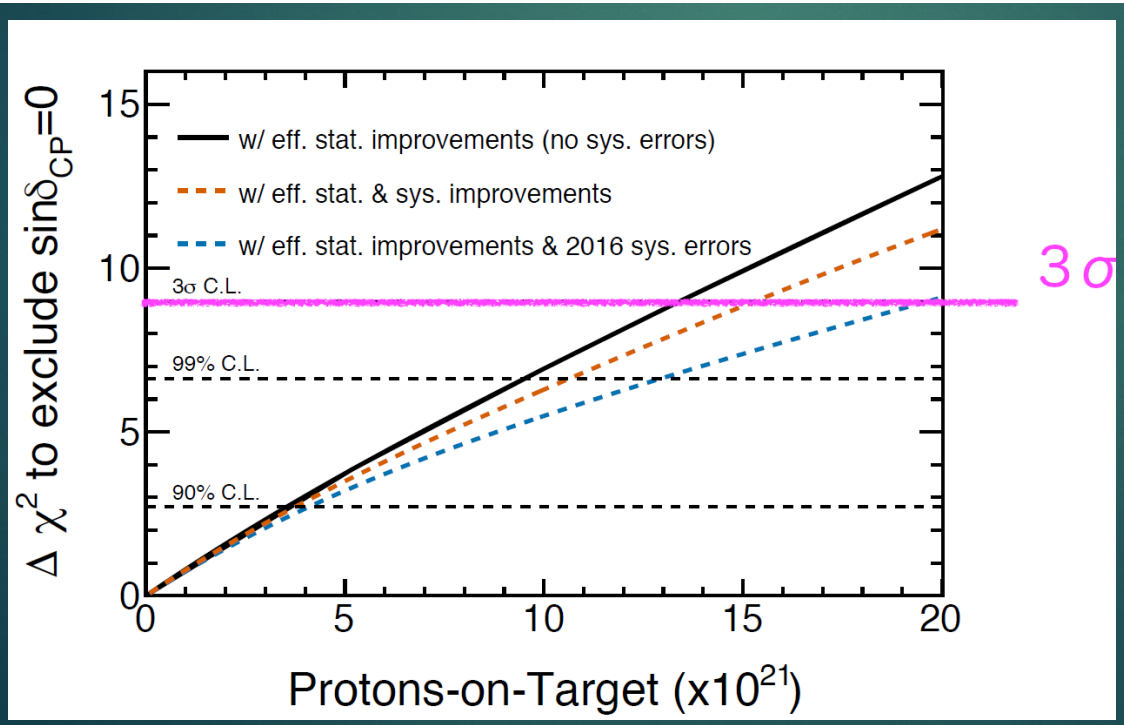




With CERN SPSC EoI-015 https://cds.cern.ch/record/2240188/files/SPSC-EOI-015.pdf

Physics sensitivities of T2K-II



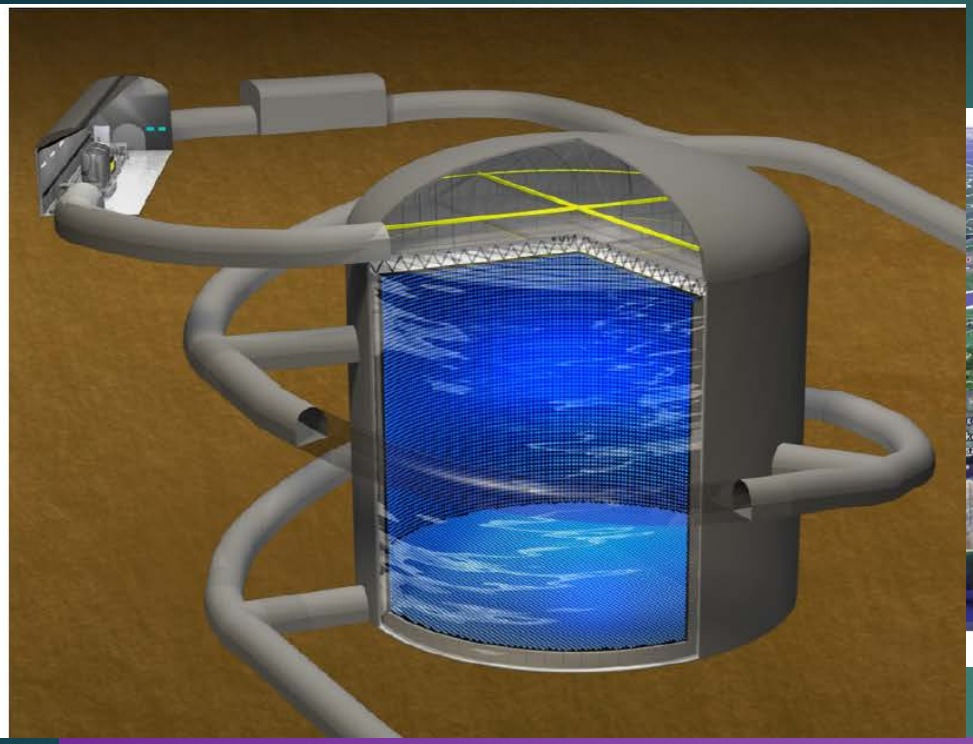


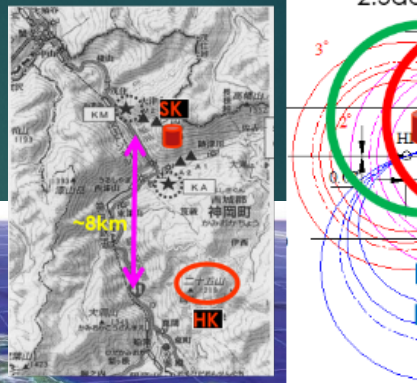
>3σ evidence

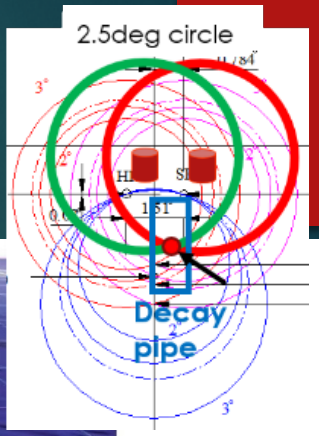
If maximally violated!

Next generation experiment: Hyper-Kamiokande

Hyper-Kamiokande



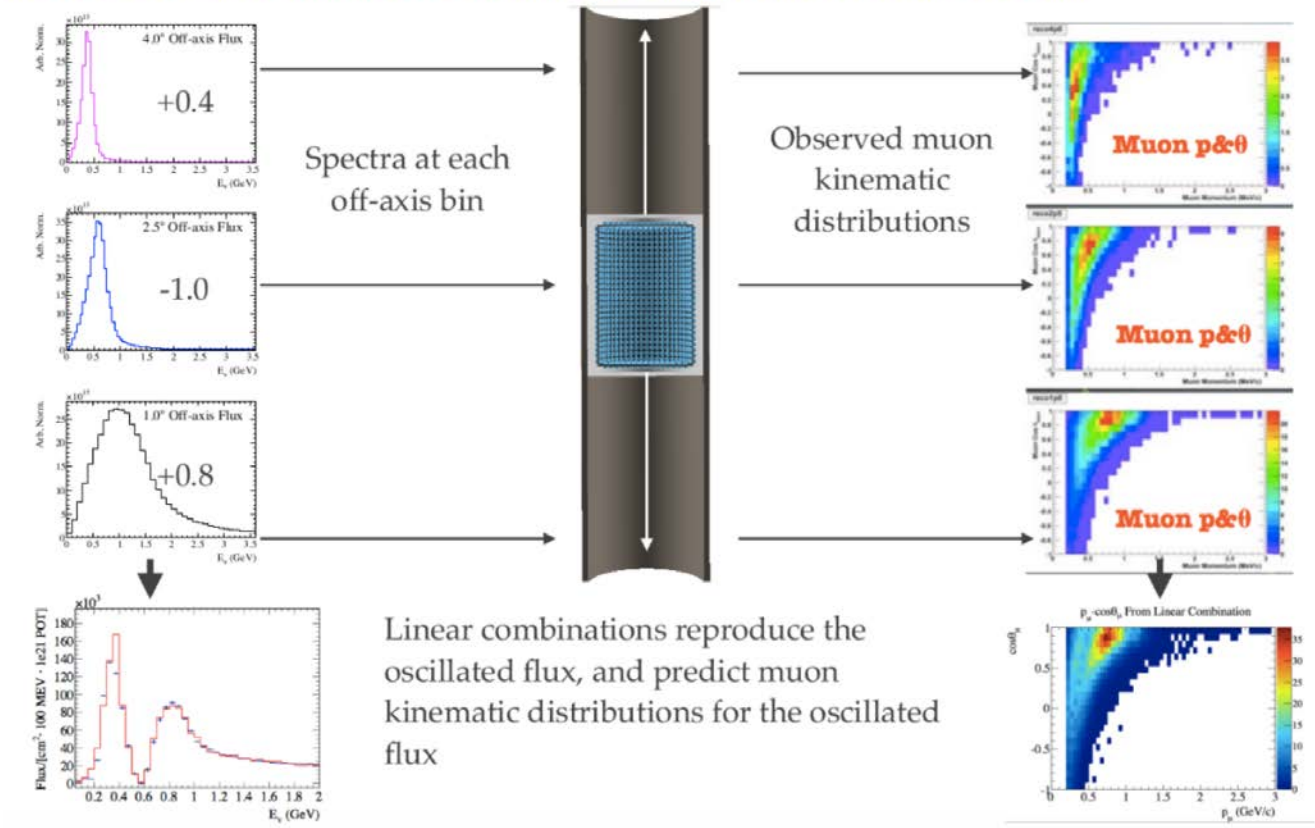




- Upgraded J-PARC with >1.3MW
- Hyper-Kamiokande
  - 260kt (D74mxH60m),190kt fiducial mass
  - 40,000 PMTs with x2 eff.
- Option to place 2nd detector in Korea in the future
- **Physics goals**
  - **Acc nu: CPV**
  - **Atm nu: mass hierarchy**
  - **Astronomical nu: SN, solar nu**
  - **Discover Proton decay!**

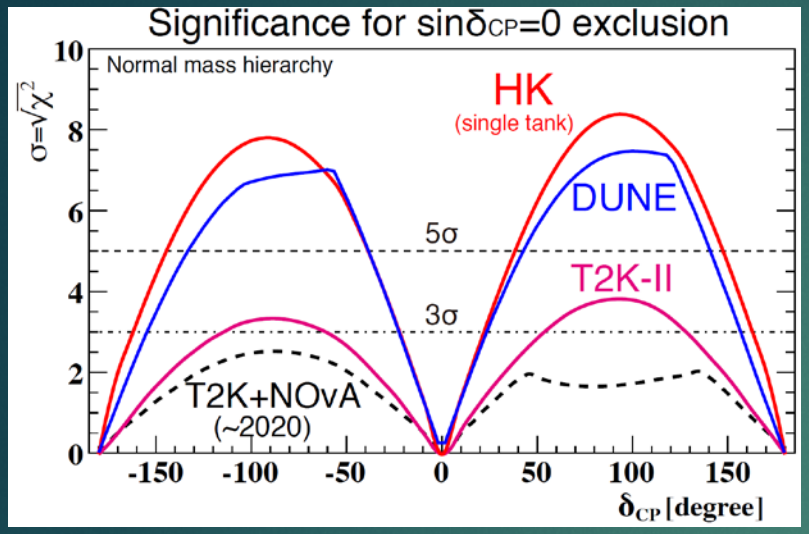
Possible intermediate Water Cherenkov detector option

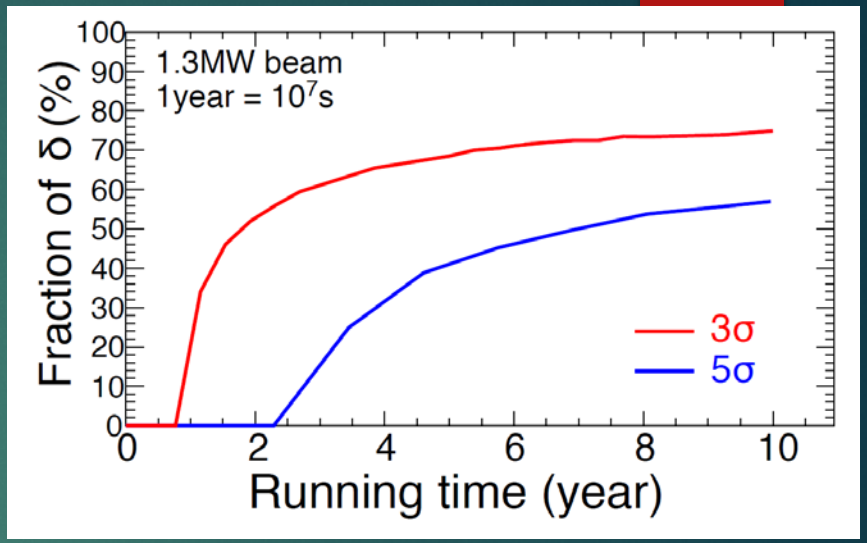
- Measure ν+H_2O events at varying off-axis angles (i.e. varying known ν spectra) @1~2 km, reducing systematics together with ND280 upgrade
- Superpose and predict interaction at Hyper-K (after oscillation!)
- Proposed as J-PARC E61 with international collaboration

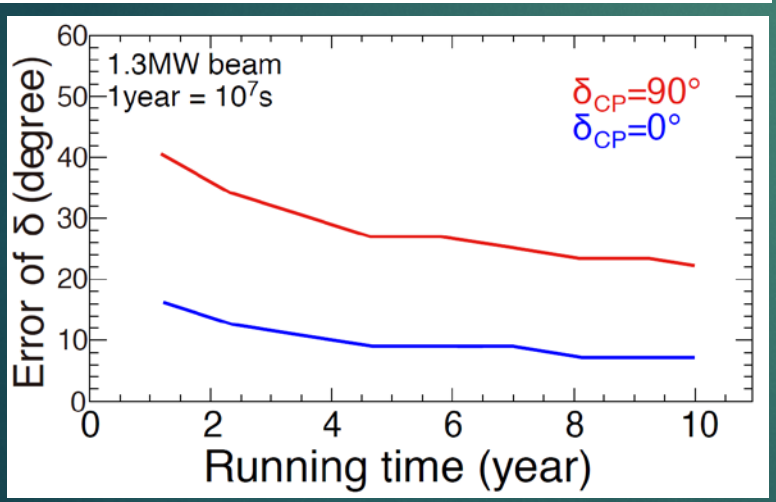


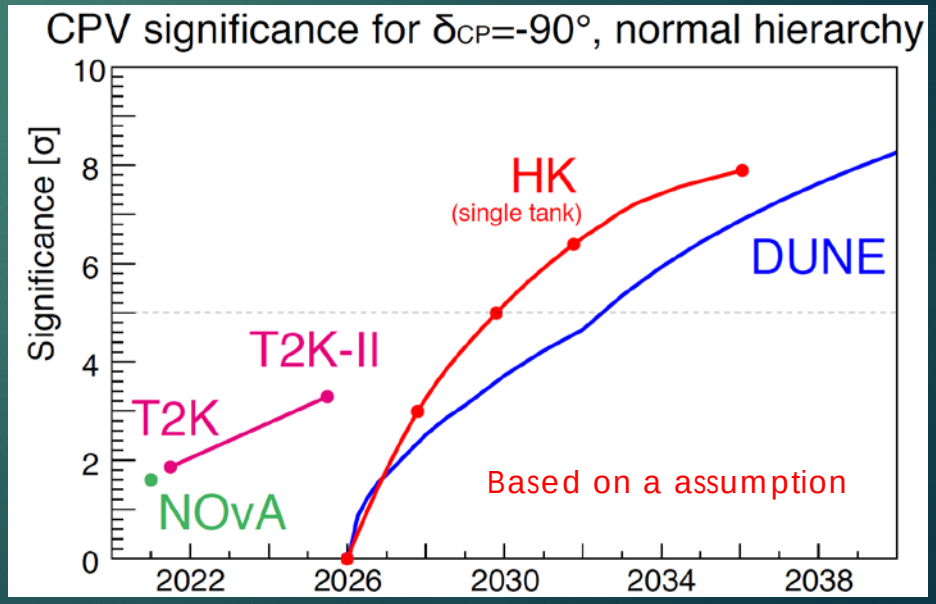
Sensitivities on CPV

1.3MWx10x10^7s
Nu:anti-nu=1:3







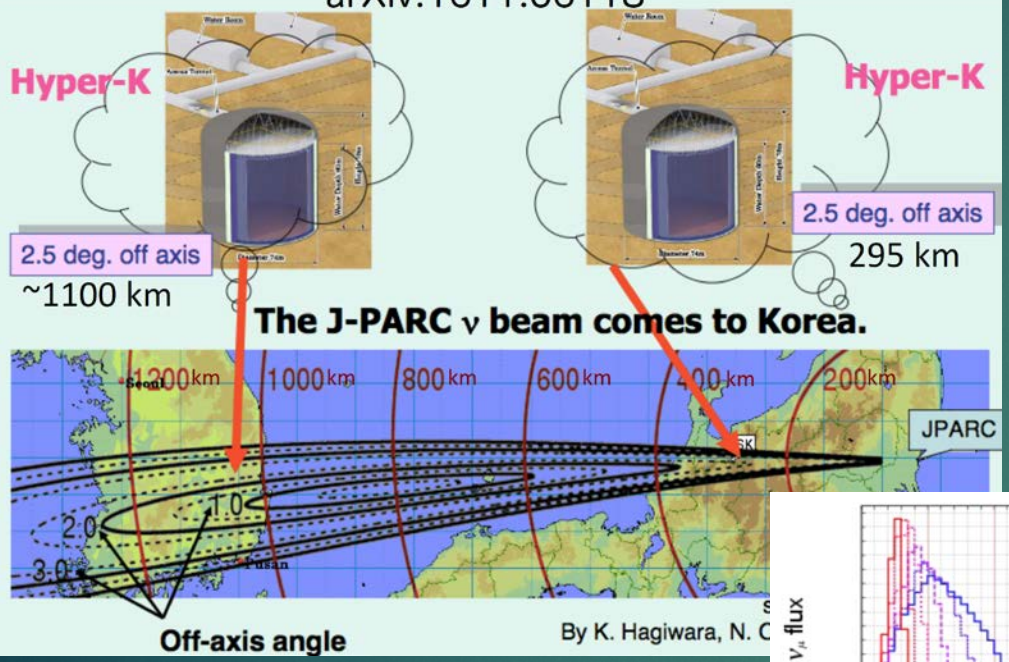


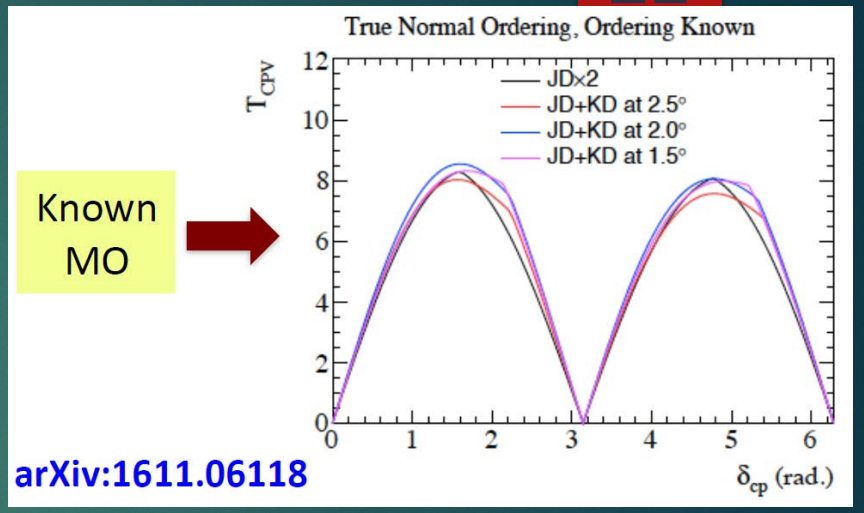
Configuration	$(\sin\delta_{CP}=0)$ exclusion $>3\sigma$	$>5\sigma$	68% uncertainty of δ_{CP} $\delta_{CP}=0°$	$\delta_{CP}=90°$
1 tank	76%	57%	7.2°	23°

Possible future option of 2nd detector in Korea

The 2nd Hyper-K Detector in Korea

arXiv:1611.06118

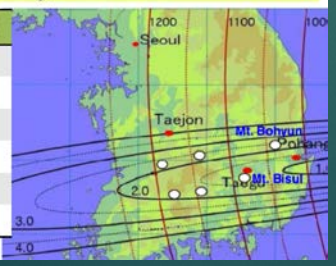


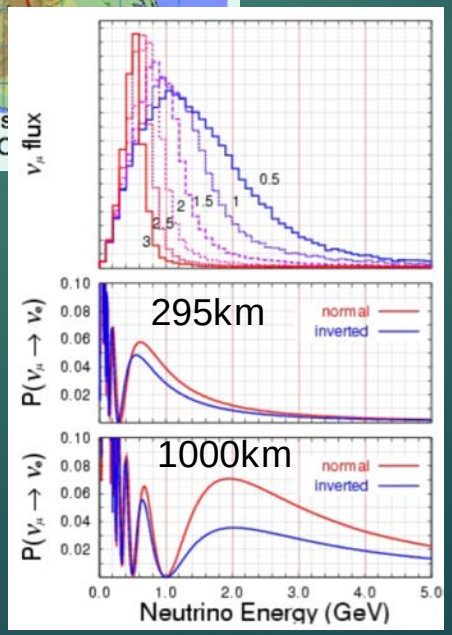


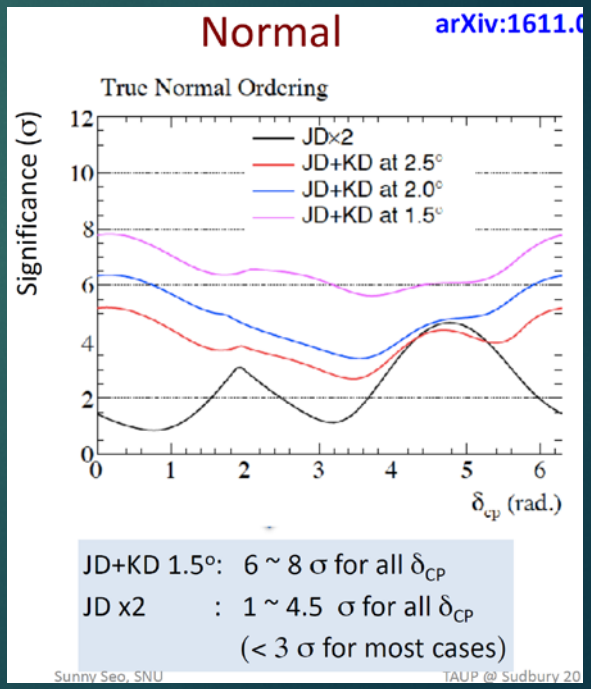
Some Candidate Sites

Site candidates for a 2nd osc. maximum detector in Korea
- -- Baselines with 1,000~1,200 km
- -- 2.0~2.5° or 1.5~2.0° off axis beam directions
- -- >1,000 m high mountains with hard granite rocks

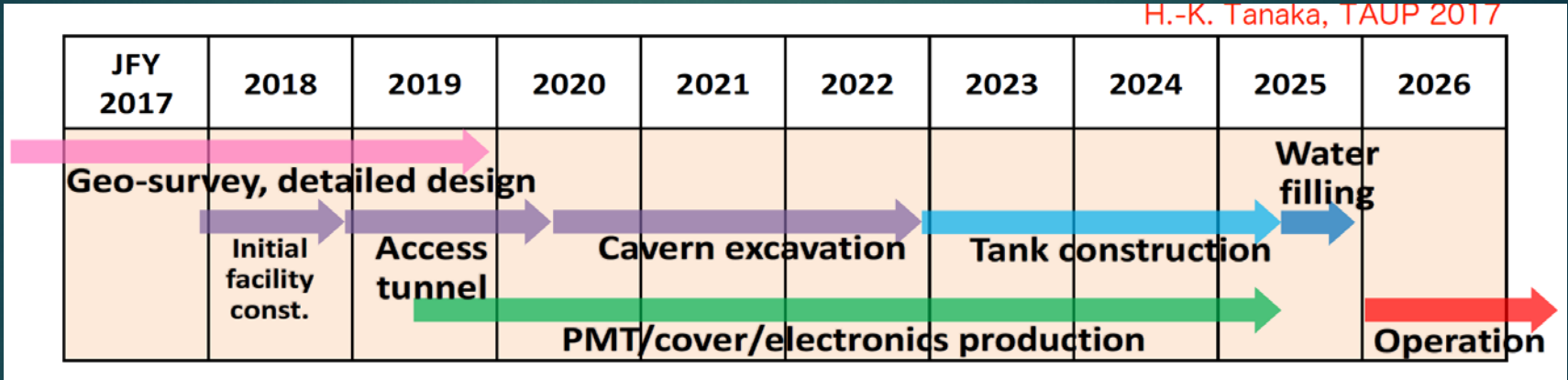
Site	OAB	Baseline [km]	Height [m]
Mt. Bisul	~1.3°	1088 km	1084 m
Mt. Hwangmae	~1.8°	1140 km	1113 m
Mt. Sambong	~1.9°	1180 km	1186 m
Mt. Bohyun	~2.2°	1040 km	1126 m
Mt. Minjuii	~2.2°	1140 km	1242 m
Mt. Unjang	~2.2°	1190 km	1125 m







Project status and plan

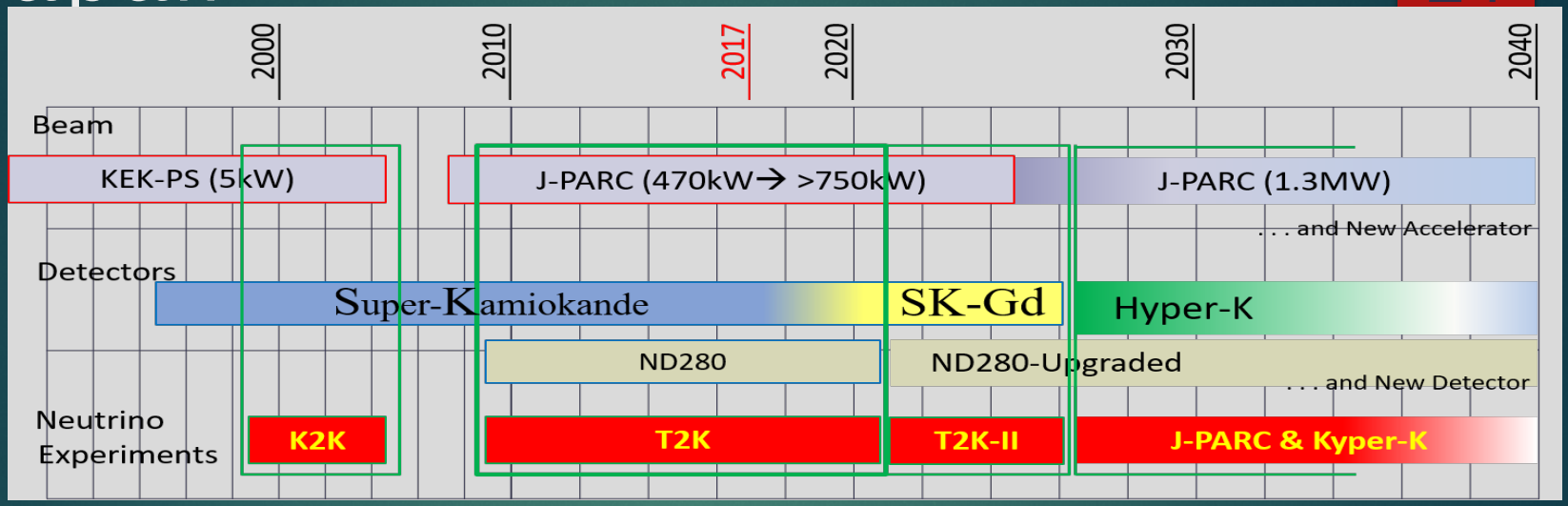


- Aim to start operation ~2026
- Proto-collaboration formed since 2015
  - 300 members from 15 countries (70% overseas)
- Selected by Science Council of Japan as a top-priority large-scale project (Master Plan 2017)
- Selected by MEXT in Roadmap 2017 on promotion of large research projects
- Budget request submitted to start const. 2018

Summary

- T2K started to seek CPV
- J-PARC plan to upgrade to 750kW and then 1.3MW
  - **Highest priority in KEK-PIP**
- T2K-II plan to accumulate 2e22POT by around 2026
  - >3sigma sensitivity for maximum CP violation!
  - Stage-1 status given by PAC
- Hyper-Kamiokande
  - 8sigma CPV, x10 sensitivity on proton decay, mass hierarchy determination
  - Aim to start operation in 2026
- **Seamless program in Japan**

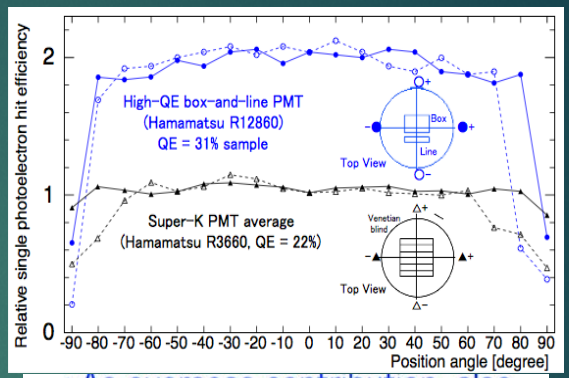
Accelerator-based neutrino program in Japan

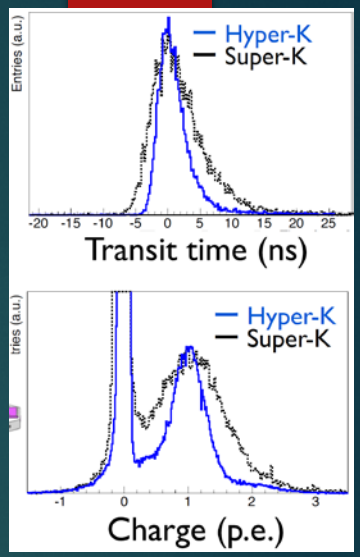


Hyper-Kamiokande (260kt)

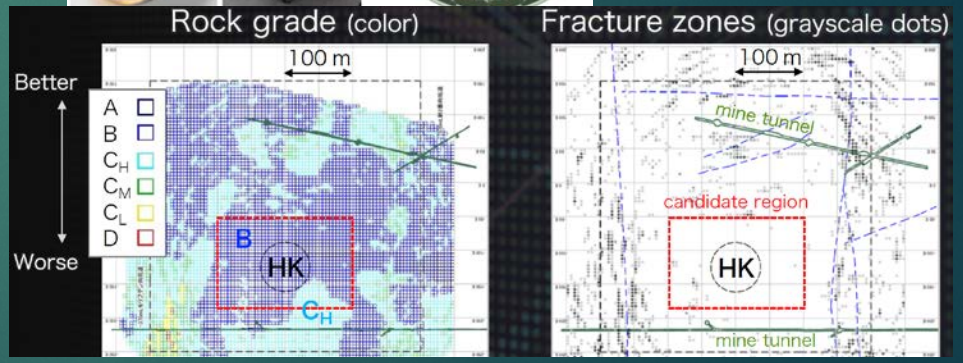
Technology ready to go

- Mature technology of Water Ch with long experiences in construction, operation and analysis
  - Mass: 260kt = SK(50kt)**x5.2**
    - $\sqrt[3]{5.2} = 1.7$
    - Fid mass: 190kt=SK**x8.4**
- Further improvements since SuperK after >20yrs of development
- Huge cavern & tank
  - Experts' committee concluded to be feasible
- Photo sensors
  - 1st half: x2 efficiency PMT developed, to be chosen
  - 2nd half: R&D including multi-PMT on-going as foreign contribution





• As overseas contribution, also multi-PMT modules are in R&D



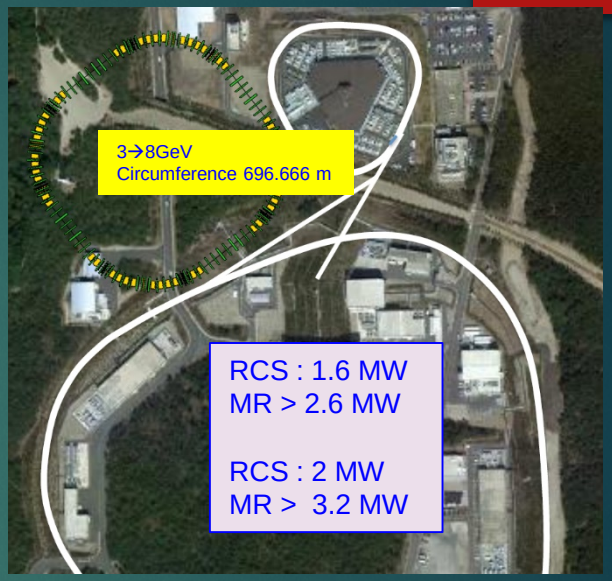
Report from cavern and tank sub-committee meeting

Jiro Yamatomi, Professor Emeritus, The University of Tokyo

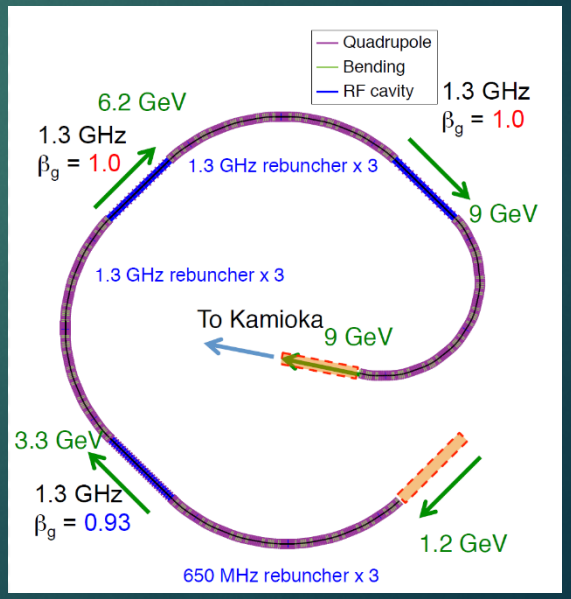
- **And the Sub-Committee concluded that the level of the feasibility of cavern and water tank constructions for the Hyper-Kamiokande Project is now satisfactory.**

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



Nucleon decay search