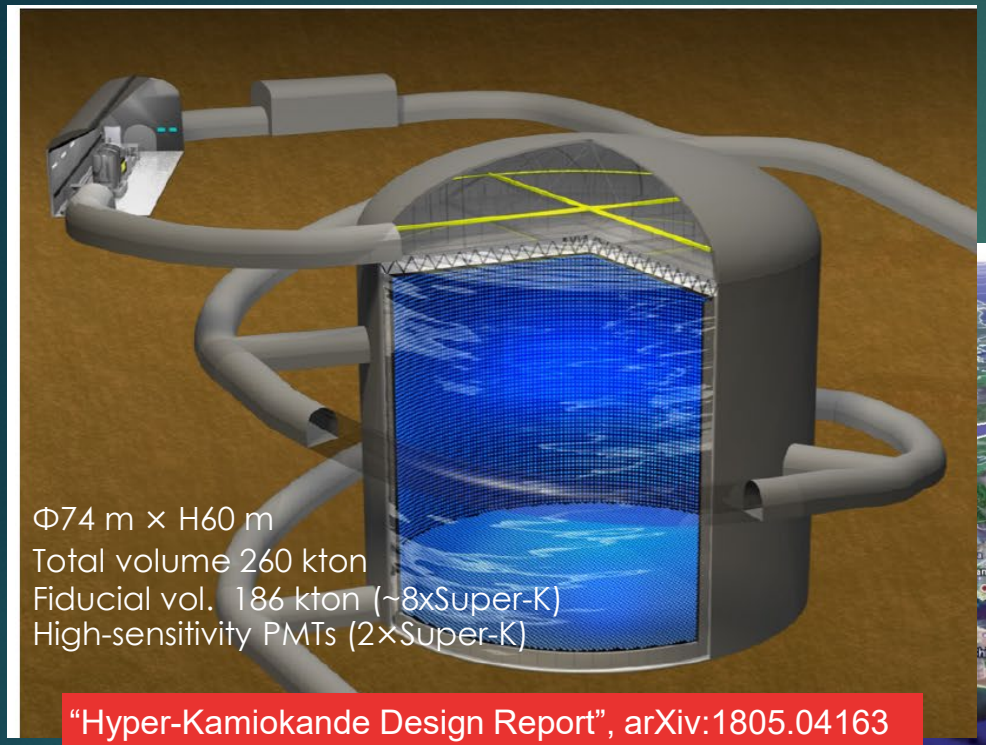
Aug.30,2019
Nufact2019

Hyper-Kamiokande

TAKASHI KOBAYASHI

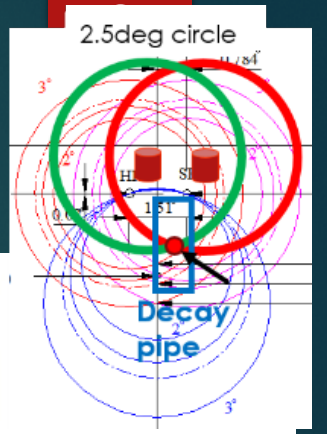
IPNS/KEK, J-PARC

The “Hyper-Kamiokande” project



Φ74 m × H60 m
Total volume 260 kton
Fiducial vol. 186 kton (~8xSuper-K)
High-sensitivity PMTs (2×Super-K)

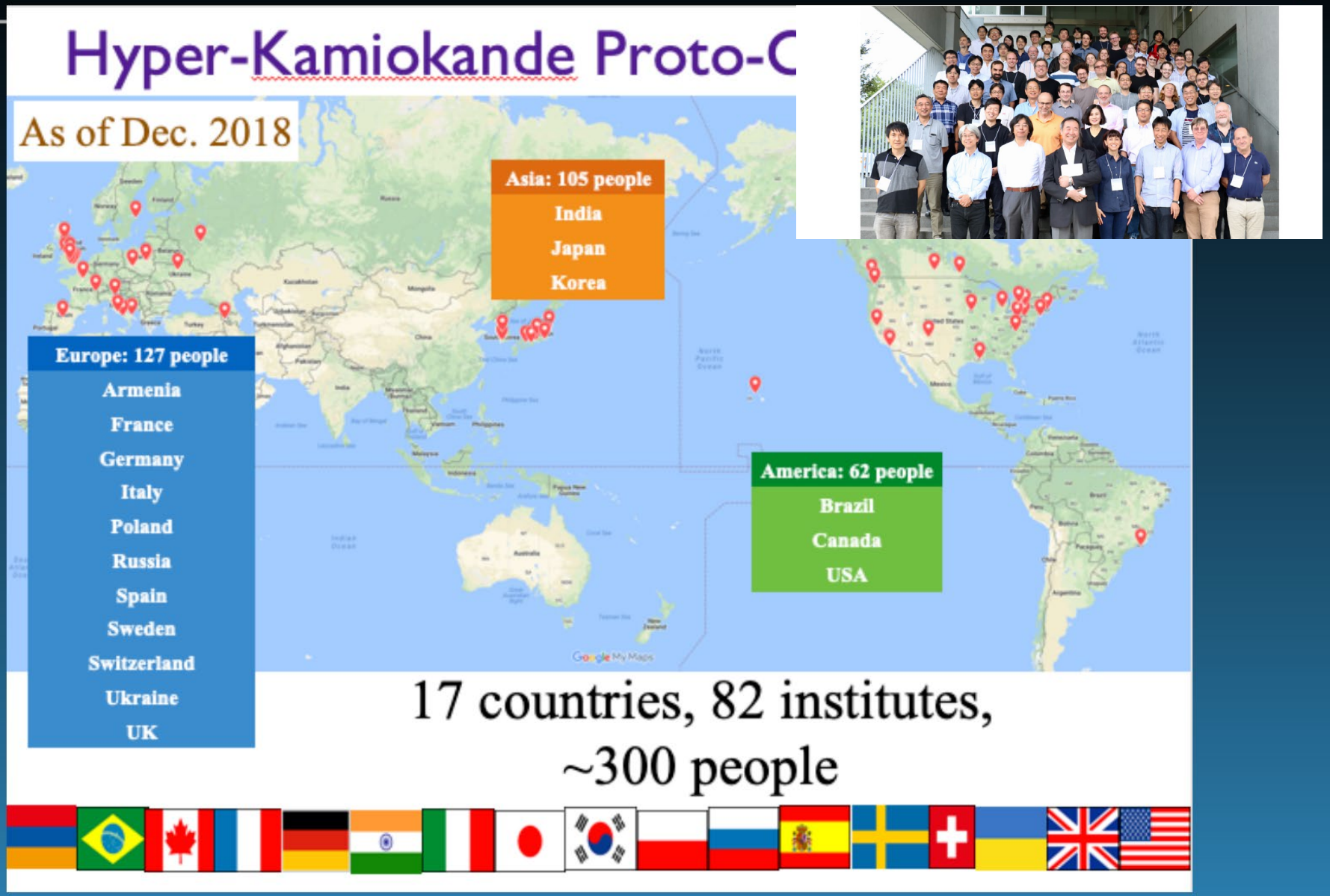
“Hyper-Kamiokande Design Report”, arXiv:1805.04163



J-PARC Main Ring
(KEK-JAEA, Tokai)

- Hyper-Kamiokande detector
  - 190kt fiducial mass (SK:22.5kt)
  - 40,000 photo sensors
- J-PARC upgrade
  - Upgrade to 1.3MW J-PARC beam
  - Near/intermediate detector complex
- Aim to start construction in 2020 and start operation in 2027

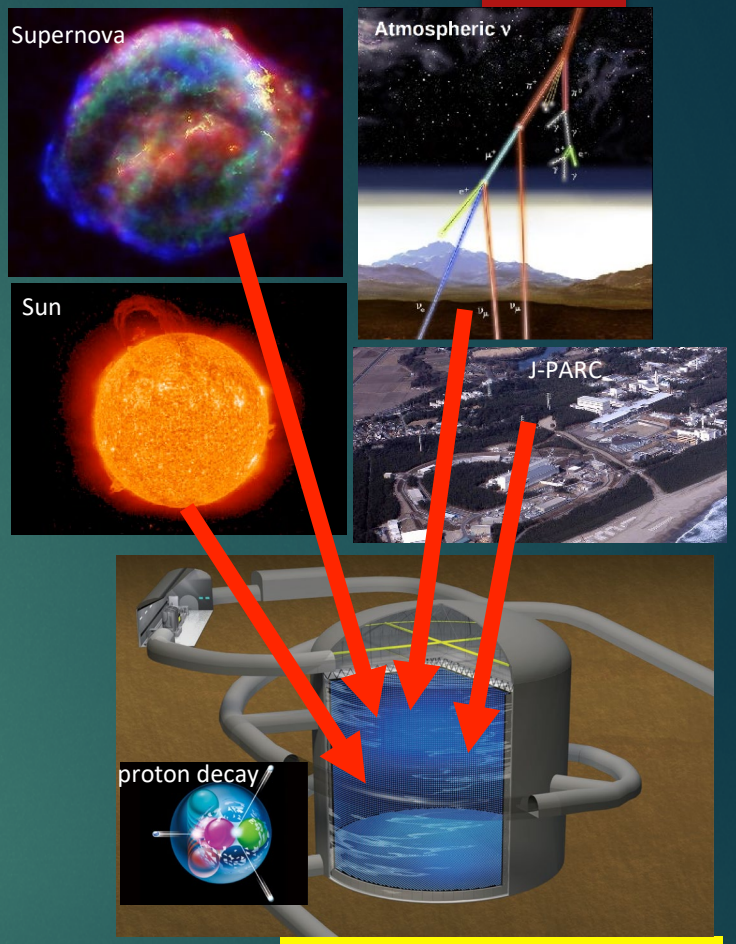
HYPER-KAMIOKANDE PROTO-COLLABORATION



International community corresponds to ~75% of the total.

Broad science program with Hyper-K

- Neutrino oscillation physics
  - Comprehensive study with beam and atmospheric neutrinos
- Search for nucleon decay
  - Possible discovery with ~×10 better sensitivity than Super-K
- Neutrino astrophysics
  - Precision measurements of solar ν
  - High statistics measurements of SN burst ν
  - Detection and study of relic SN neutrinos
- Geophysics (neutrino oscillography of interior of the Earth)
- Maybe more (unexpected)



Solar
Supernova
Accelerator
Proton decay
DM search

MeV to TeV with a single detector

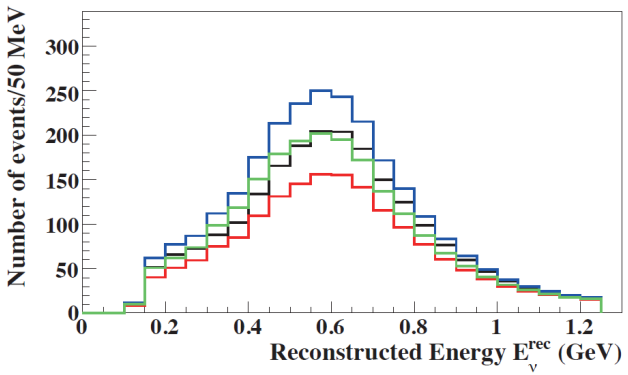
~3.5MeV ~20 ~100MeV ~1GeV TeV

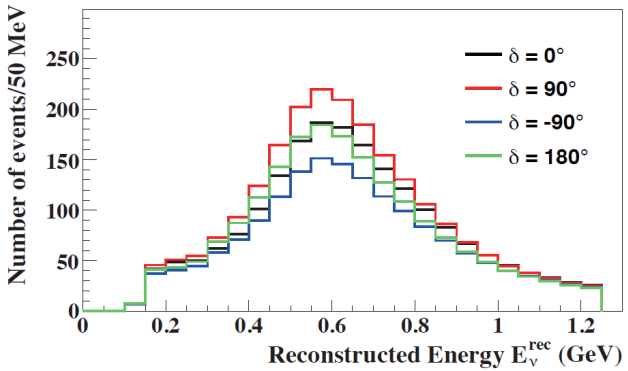
Atmospheric

Physics sensitivities: CPV

Expected observations

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





Expected number of ν_e appearance signal and background

	Appearance signal	Wrong sign signal	Beam ν_e background	NC background
Neutrino mode	1600	20	260	130
Antineutrino mode	1200	200	320	200

Assumed syst err

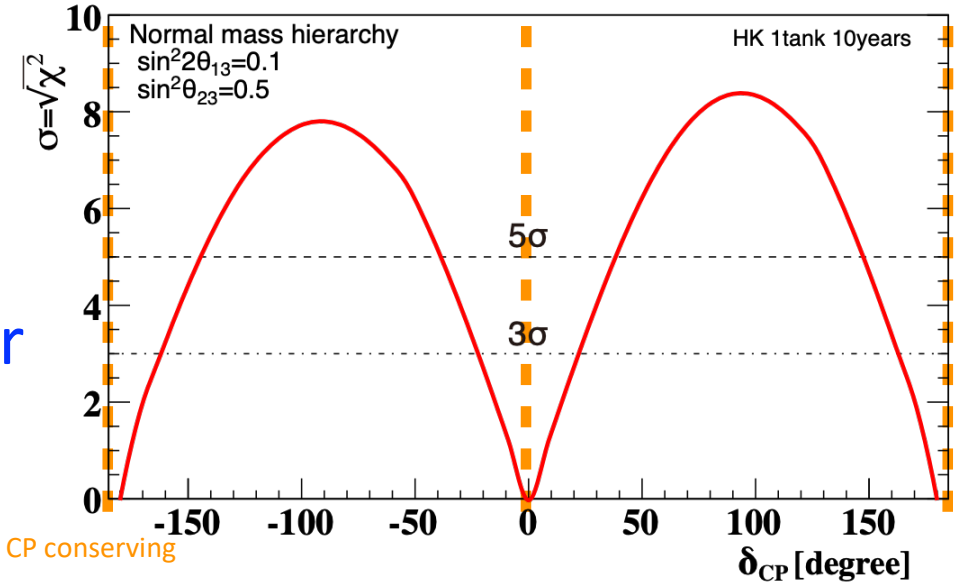
		Flux & ND-constrained cross section	ND-independent cross section	Far detector	Total (T2K)
ν mode	Appearance	3.0%	0.5%	0.7%	3.2% (6.1%)
	Disappearance	3.3%	0.9%	1.0%	3.6% (4.4%)
$\overline{\nu}$ mode	Appearance	3.2%	1.5%	1.5%	3.9% (6.5%)
	Disappearance	3.3%	0.9%	1.1%	3.6% (3.8%)

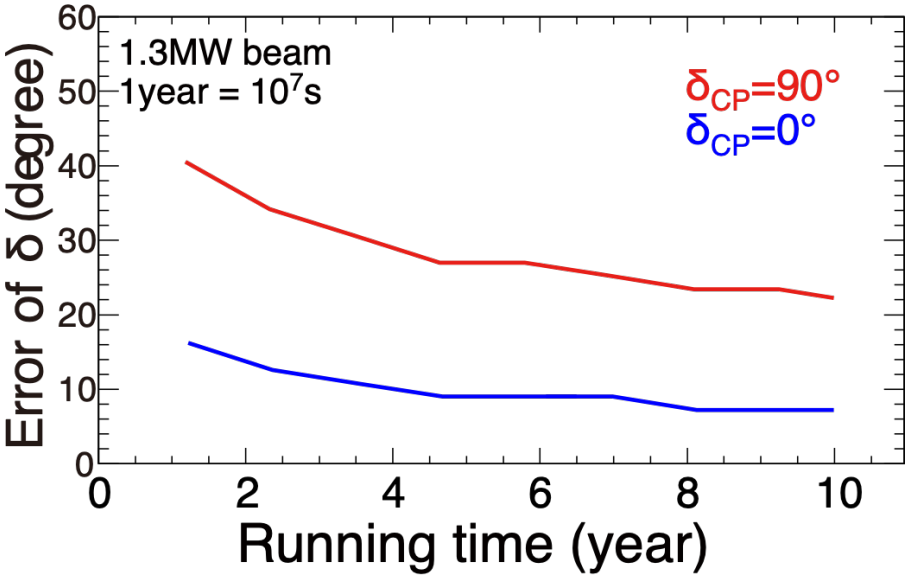
Sensitivity to CP violation

- Exclusion of $\sin\delta_{CP}=0$
  - ~8σ(6σ) for $\delta=\pm90°(\pm45°)$
  - >3σ(>5σ) significance for ~76%(57%) of δ_{CP} space
- δ_{CP} resolution:
  - 23° for $\delta_{CP}=\pm90°$
  - 7° for $\delta_{CP}=0°$or 180°

Enhanced further by combination with atmospheric ν

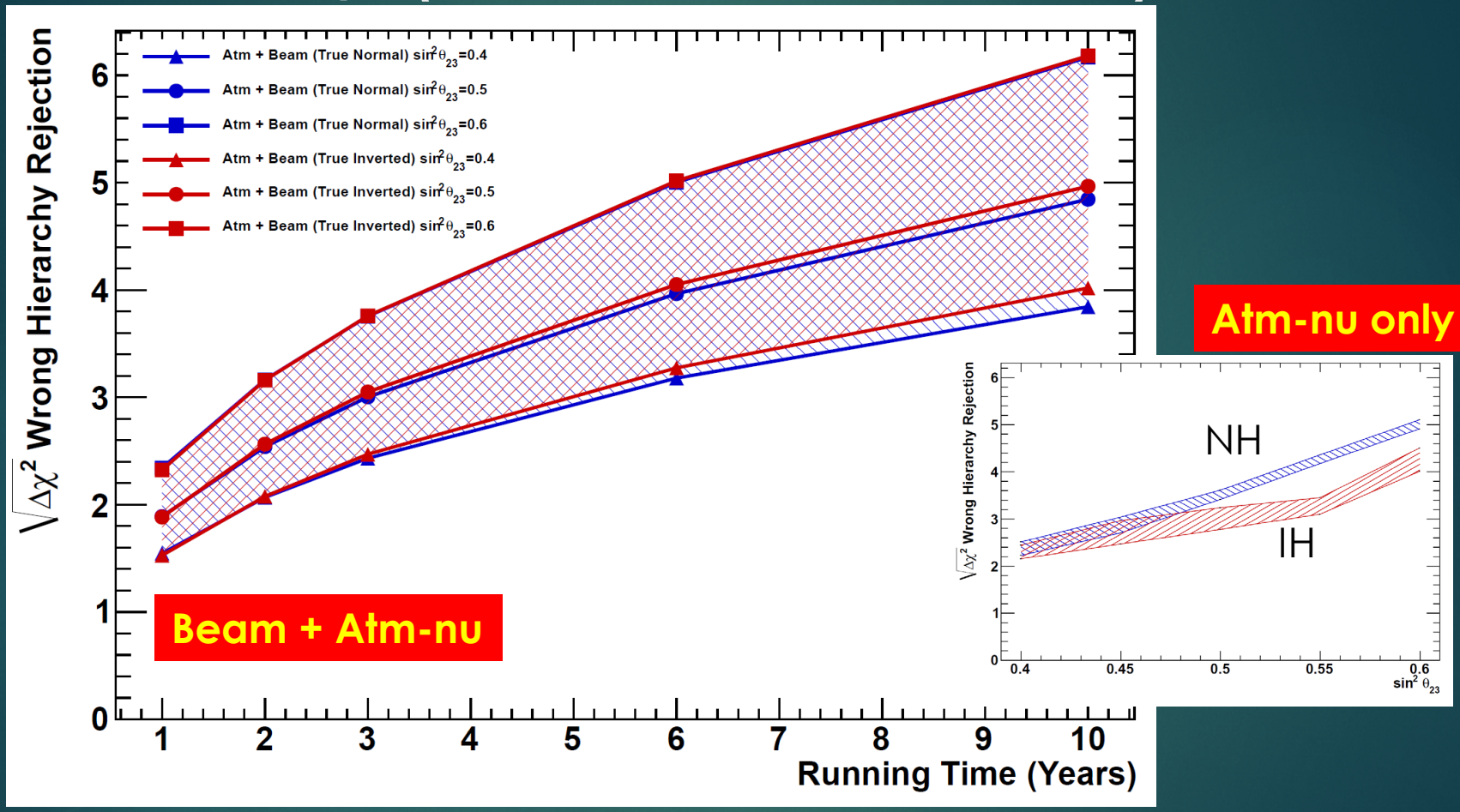
Possibility of 2nd tank in Korea under discussion





arXiv:1611.06118, PTEP **2018** 063C01

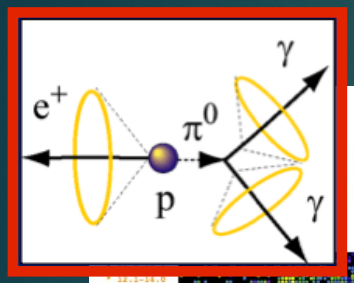
Sensitivities on mass hierarchy (beam + atm nu)

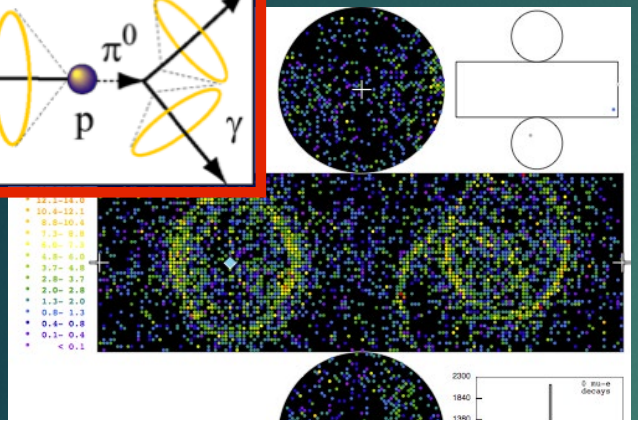


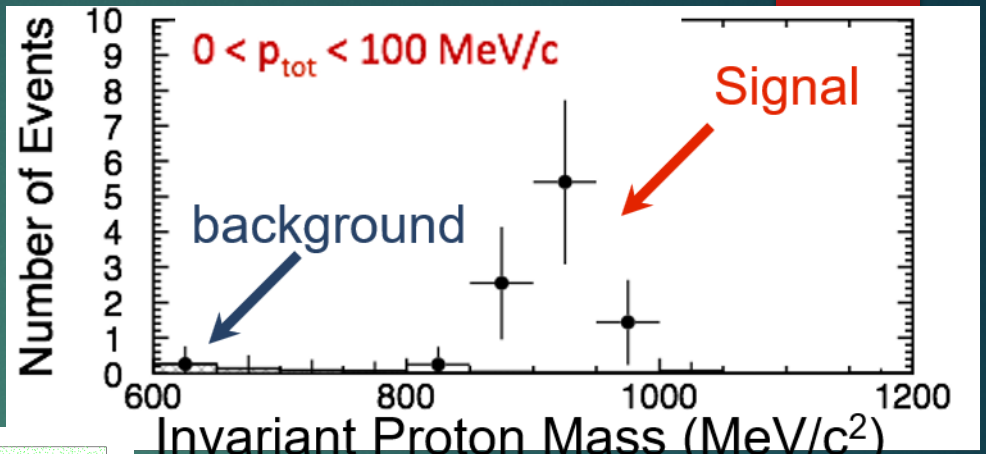
- ~ 4sigma in 10yrs by combination of beam and atm-nu
  - While Atm-nu only 2~4 sigma

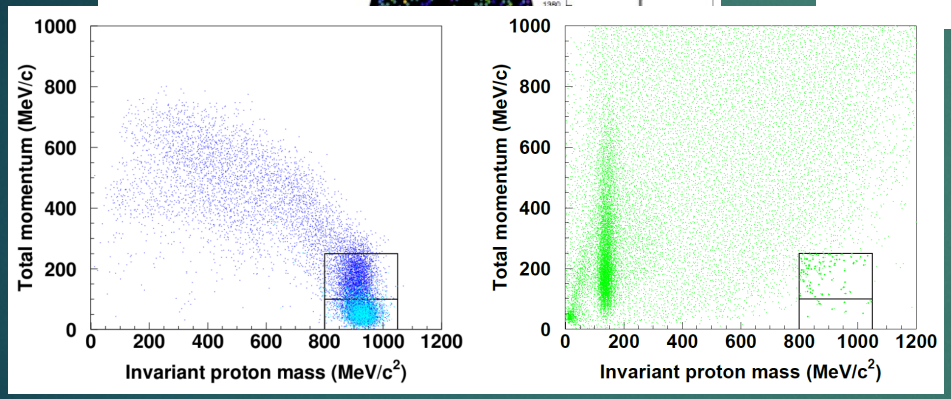
Proton decay search

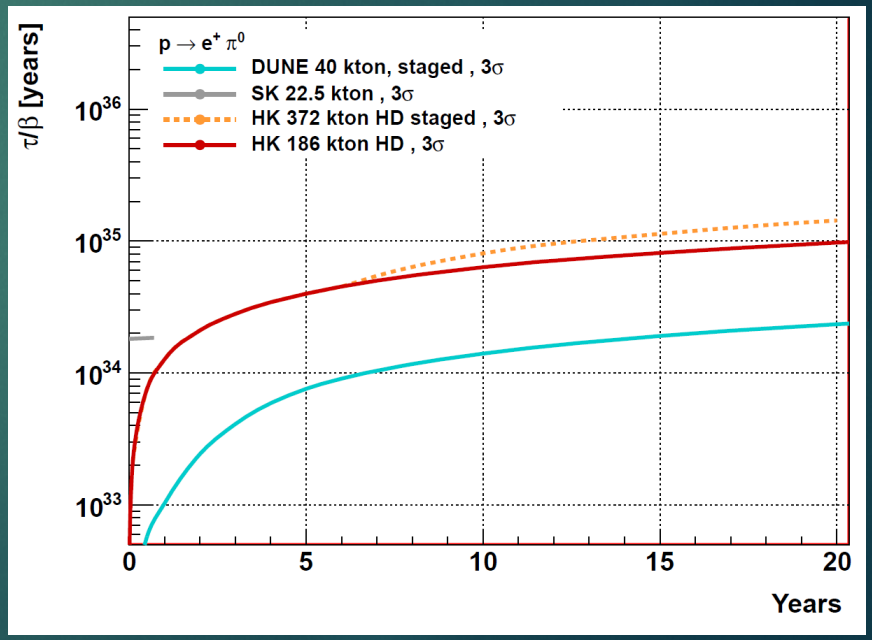
$p \rightarrow e^+ \pi^0$









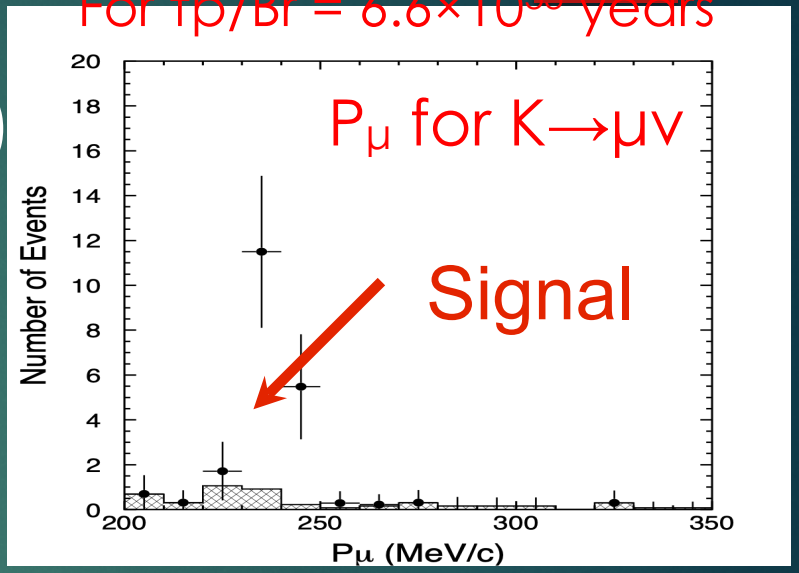


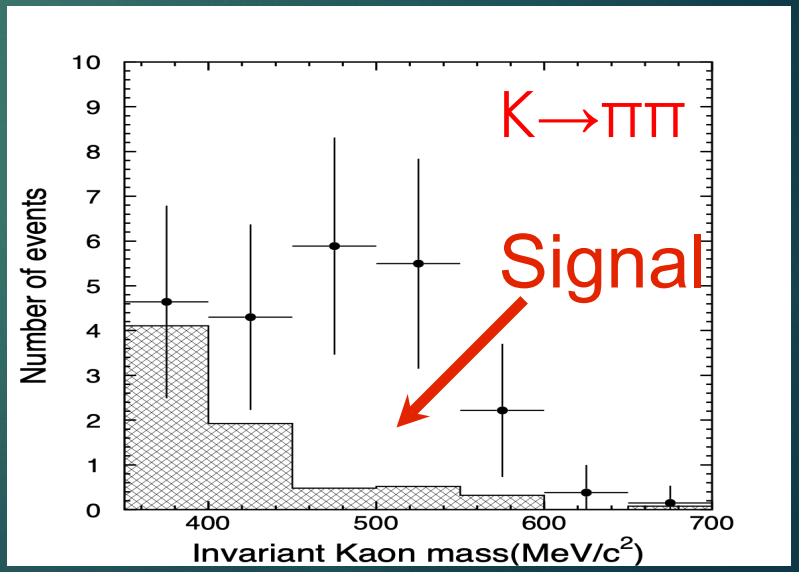
- Clear signal expected just beyond present limit
- 3σ discovery potential will reach ~10^{35} years!
- Extend present reach by factor 10

Proton decay (p→nuK)

- K is below Ch. threshold, identified by daughter particles (established by SK)
  - Monochromatic muon (K→ μν)
  - K → π+π0
- Enhanced sensitivity thanks to improved photosensors (photon efficiency and timing)
- Discovery reach >3×10^{34} years

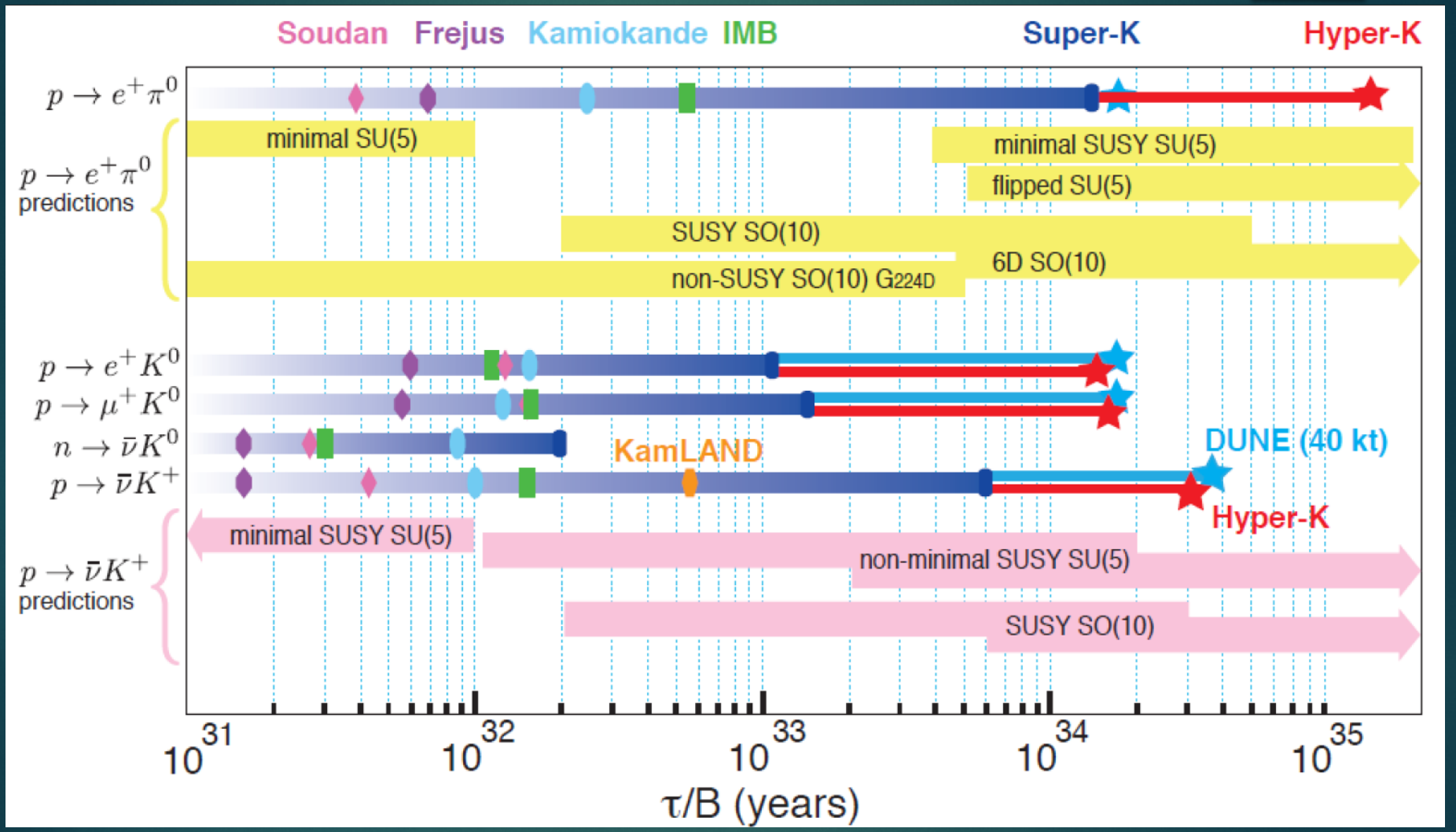
For τp/Br = 6.6×10^{33} years





	Prompt γ		π+π0	
	Eff(%)	BG (/Mtyr)	Eff(%)	BG (/Mtyr)
HK	12.7	0.9	10.8	0.7
SK 4	8.5	1.0	9.0	0.9

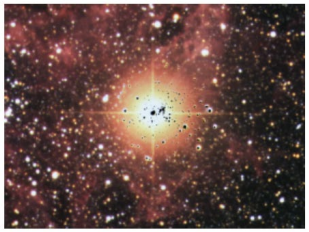
Nucleon decay search

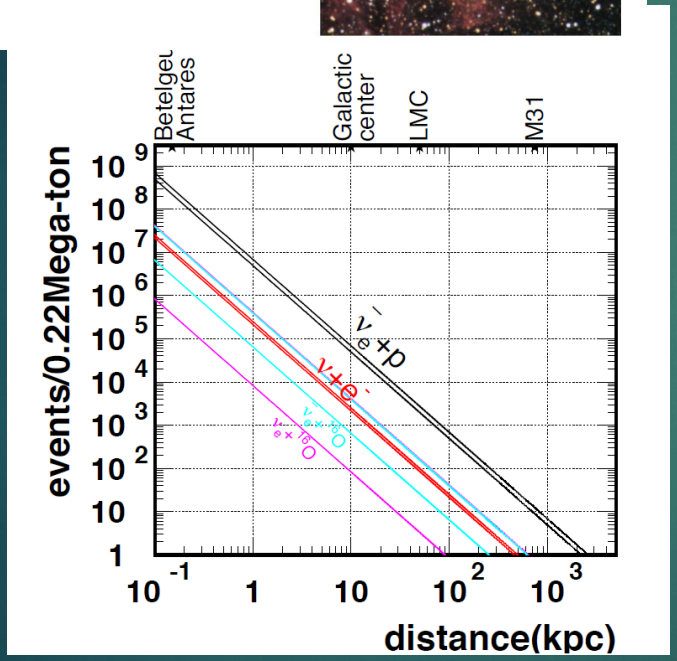


Astroparticle physics

- SN exprosion

First multi-messenger event: neutrinos and light from SN1987



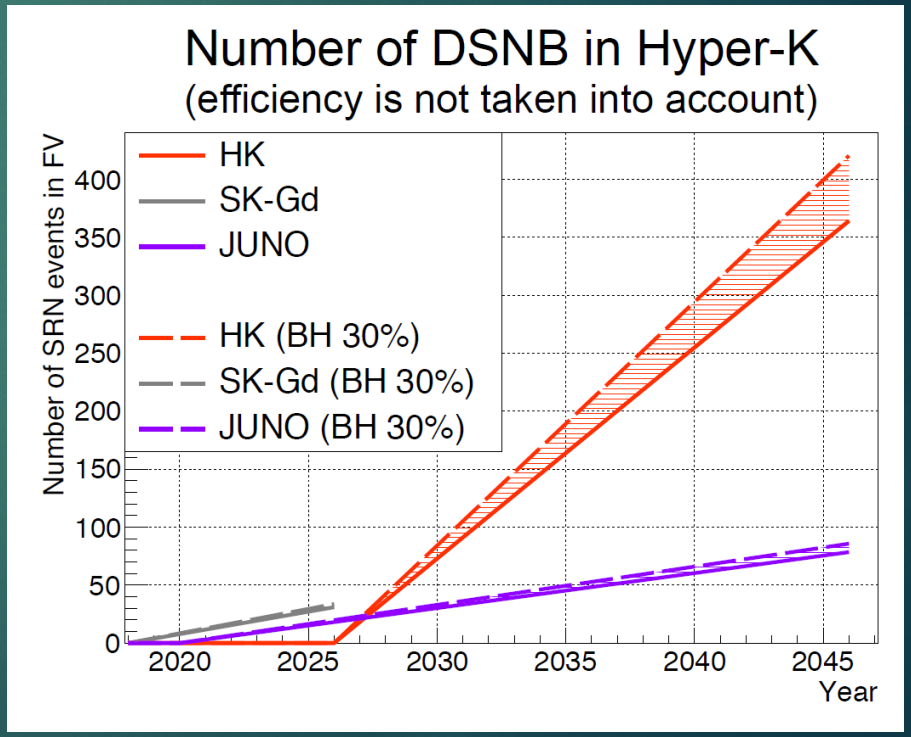


54,000-90,000 evts @ 10kpc

Reaching Andromeda

Diffuse supernova nu BG (SN relic neutrino)

- Good chance for precise flux and energy spectrum measurement



Japan Proton Accelerator Research Complex : J-PARC

J-PARC Facility (KEK/JAEA)

South to North

181MeV Linac
→400MeV

3 GeV RCS

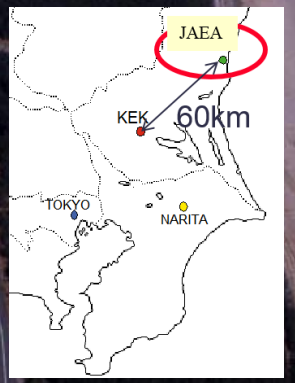
Neutrino Beams
(to Kamioka)

Materials and Life Experimental Facility

Design intensity
RCS for MLF: 1MW
MR for PN : 750kW

30GeV MR

Hadron Exp. Facility



CY2007 Beams
JFY2008 Beams
JFY2009 Beams

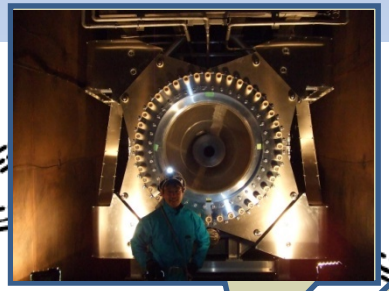
Bird's eye photo in January of 2008

Neutrino facility at J-PARC

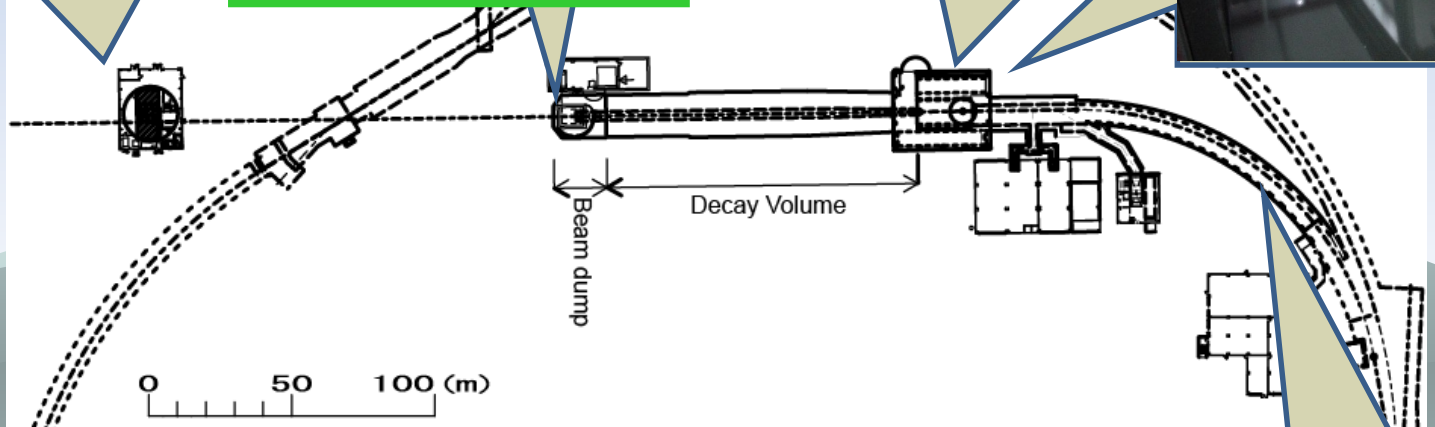
Neutrino monitor bld.

Muon monitors

Electromagnetic horn



Target



- Fast Extracted (FX) beam from MR @ 30GeV
  - 8 bunches 581ns apart
- Proton beam transport
  - Superconducting combined function magnets
- Graphite target (26mmϕx90cm)
- 3 horns @ 250kA
- 117m of decay volume (from target)
- SK direction is given by GPS survey at 2μrad precision

Primary beamline (superconducting

Upgrade to 1.3MW

- Strategy

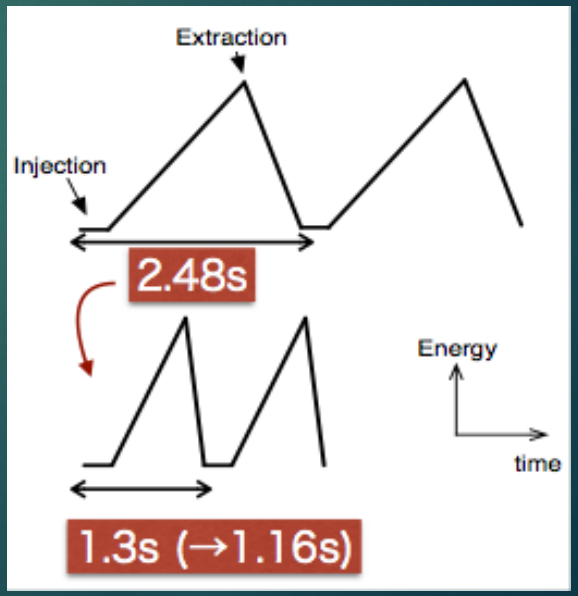
Beam Power (kW)	490 (Achieved)	(940)	1,300
#p/p(10^{12})	250	250	320
Rep T (s)	2.48	1.28	1.16

+25%

Funding started

-10%

- 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)

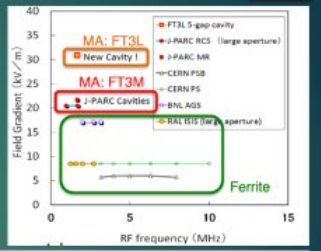


Status of accelerator power upgrade

- MR power supply will be replaced in FY2021
- RF cavities:
  - High gradient cavity developed
  - current 7(fund.)+2(hh) → 11 + 2 around early 2020s
- High intensity trial: 520kW 1 shot succeeded
  - Equivalent to ~1.1 MW when 1.16s cycle with the beam loss of 2.1 kW.

RF upgrade status and plan

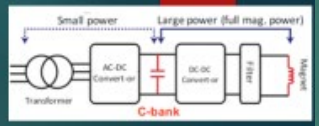
- All 9 cavities are FT3L now
  - 7 for fundamental
  - 2 for 2nd H.
- For 1.3MW 600 kV accelerating voltage needed for 1.16 s operation.
  - 11 accelerating systems
  - 2 2nd harmonic Needed
- Anode power supply upgrade required to increase output current

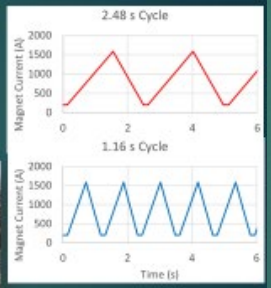


JFY	2018	2019	2020	2021	2022	202X
Events				Long shutdown	MR 1.3-sec operation	MR 1.16-sec operation
FT3L 4GAP Cavity	7	7	7	9	9	9
additional 4GAP Cavity	-	-	-	-	-	2
2nd Harmonic Cavity	2	2	2	2	2	2
Accelerating Voltage	300-390kV	300-390kV	300-390kV	510kV	510kV	600kV
2nd Harmonic Voltage	110kV	110kV	110kV	120kV	120kV	120kV

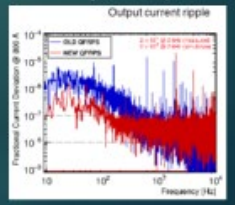
MR magnet power supply upgrade for higher rep rate

- Large capacitor bank for energy recovery
- Construction started
  - Buildings completed
  - First mid scale PS installed and being operated successfully

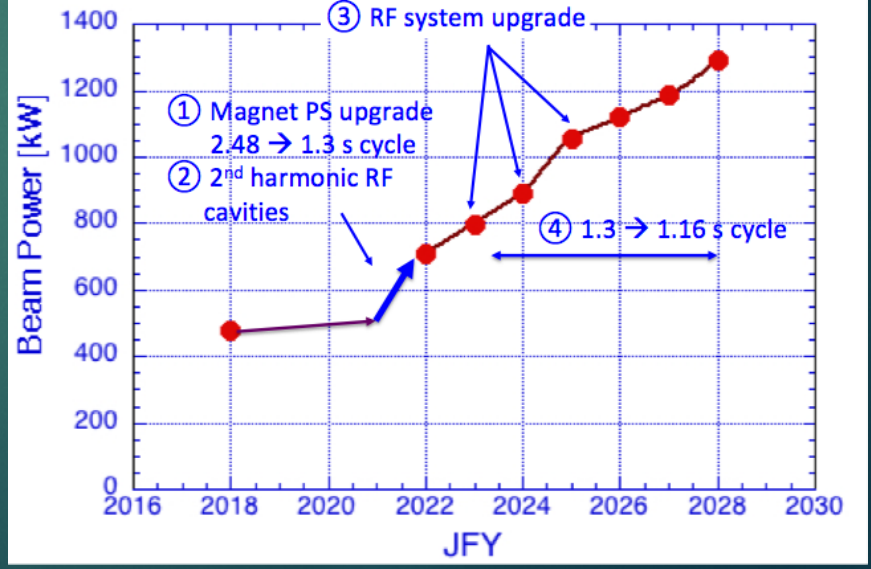




New Power Supply for Rapid Cycle



Upgrade plan of MR

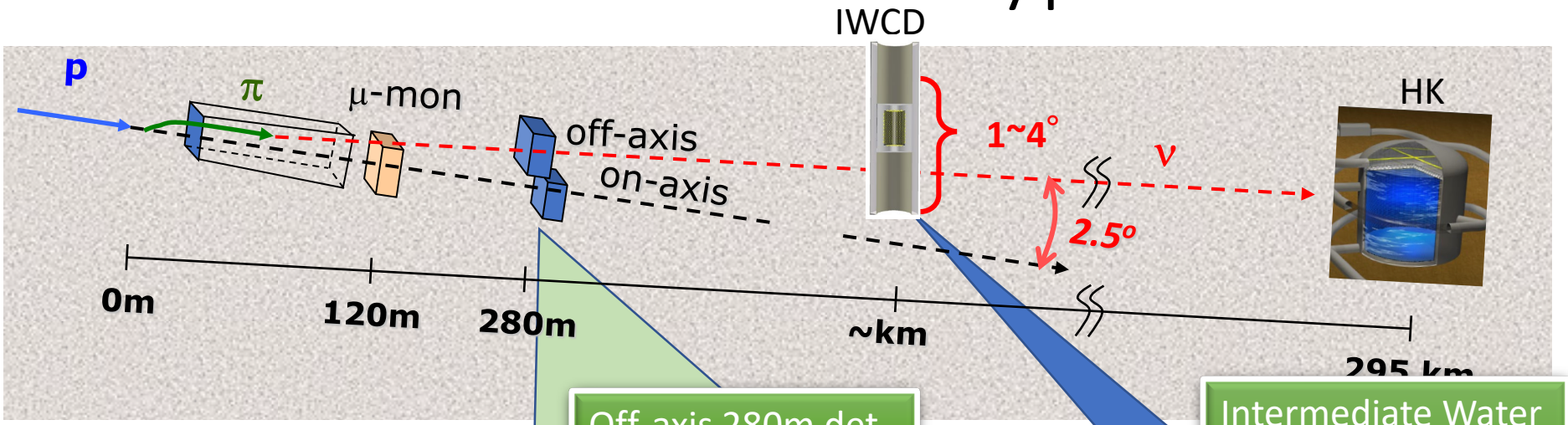


Neutrino beam facility upgrade

- 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
  - Accepting high repetition rate (~1Hz) beam

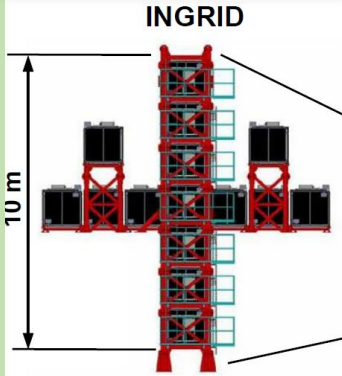
Beam Power	# of protons/pulse	Rep. rate
350 kW (achieved)	1.8×10^{14}	2.48 sec.
750 kW (proposed) [original plan]	2.0×10^{14} [3.3×10^{14}]	1.30 sec. [2.10 sec.]
1.3 MW (proposed)	3.2×10^{14}	1.16 sec.

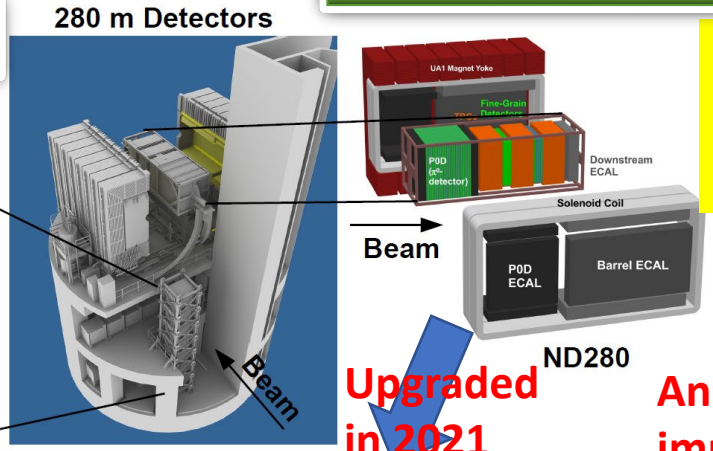
Near detector suite for HyperK



Off-axis 280m det

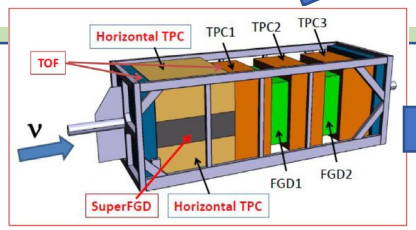
On-axis INGRID



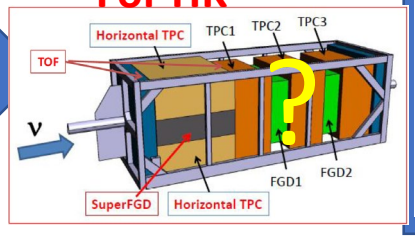


ν Int
ν flux
ν_e xsec

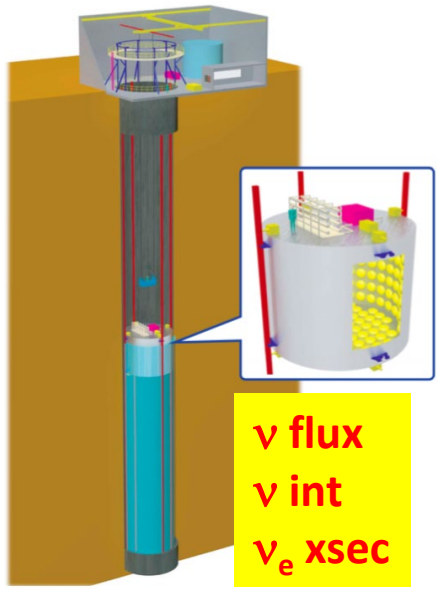
Upgraded in 2021



Another improvement For HK



Intermediate Water Charenkov Detector (IWCD)



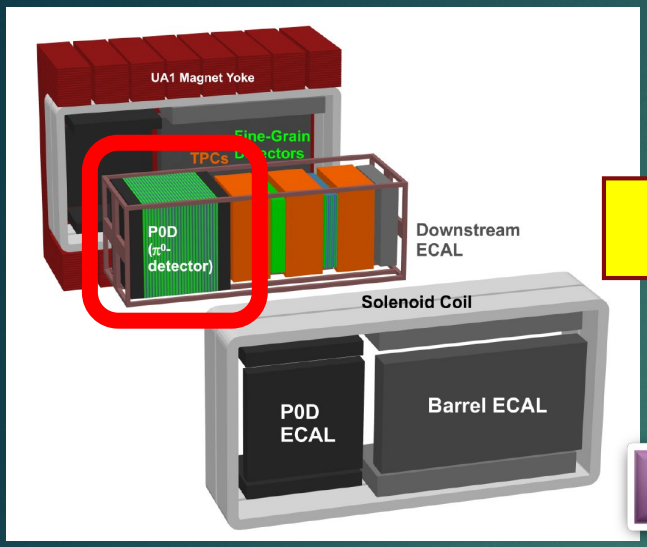
ν flux
ν int
ν_e xsec

ν Beam dir.
ν Beam prof.

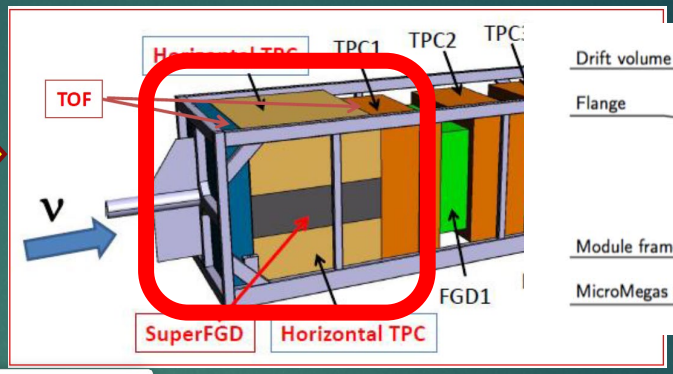
Need at least refurbishment (elec…)

280m off-axis magnetized detector

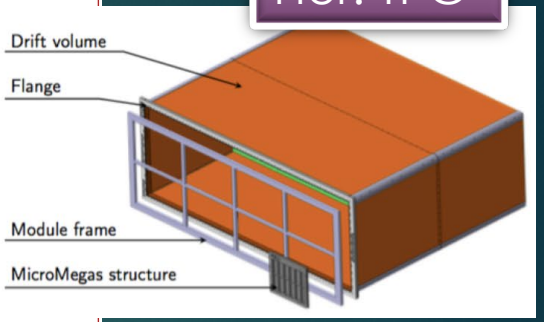
SPSC-TDR-006
arXiv:1901.03750



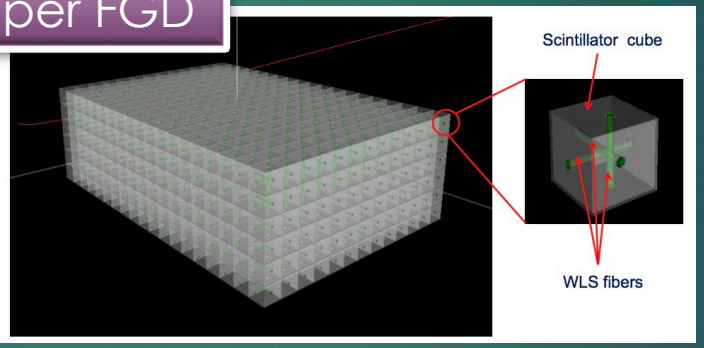
Upgrade for T2K

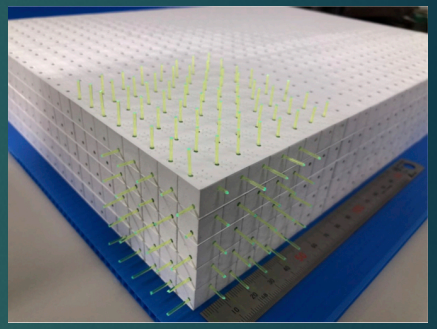


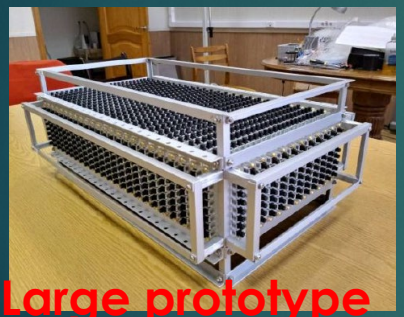
Hor. TPC



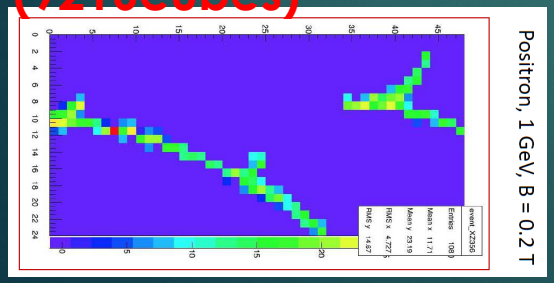
Super FGD







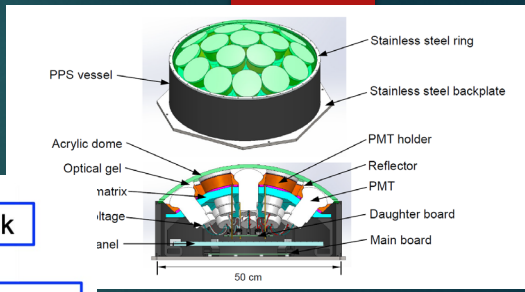
Large prototype (9216cubes)

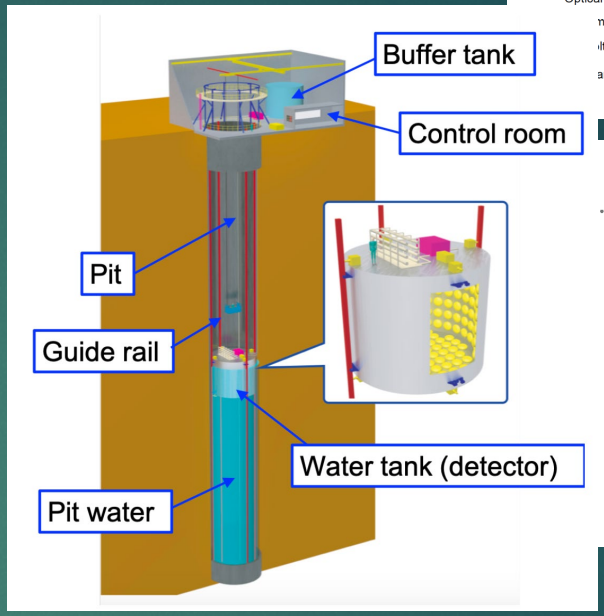


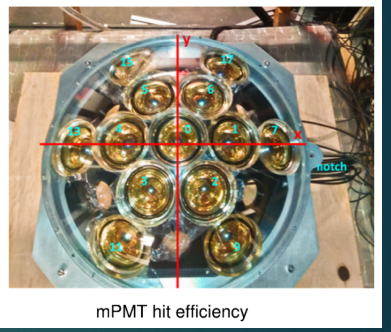
- **Only magnetized det.: Essential for CP meas.**
- Being upgraded for T2K
  - SuperFGD/Horizontal TPCs
  - To be installed in 2021
- **Another improvements needed for HyperK era**
  - **New ideas are welcome**

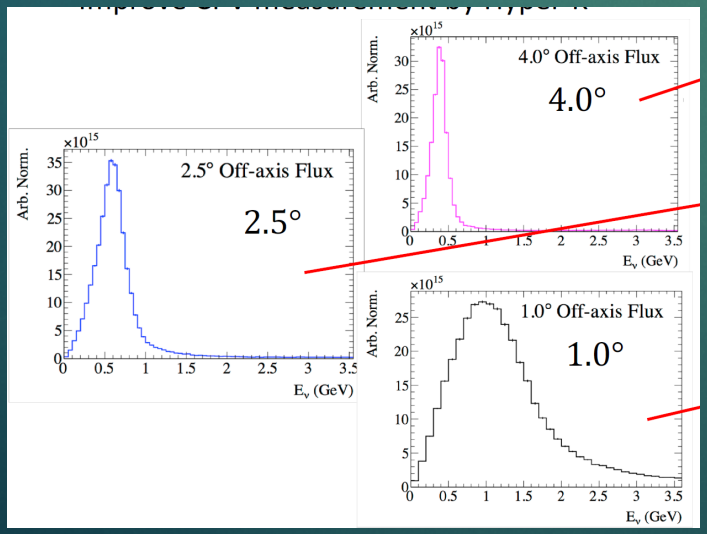
New intermediate Water Cherenkov detector

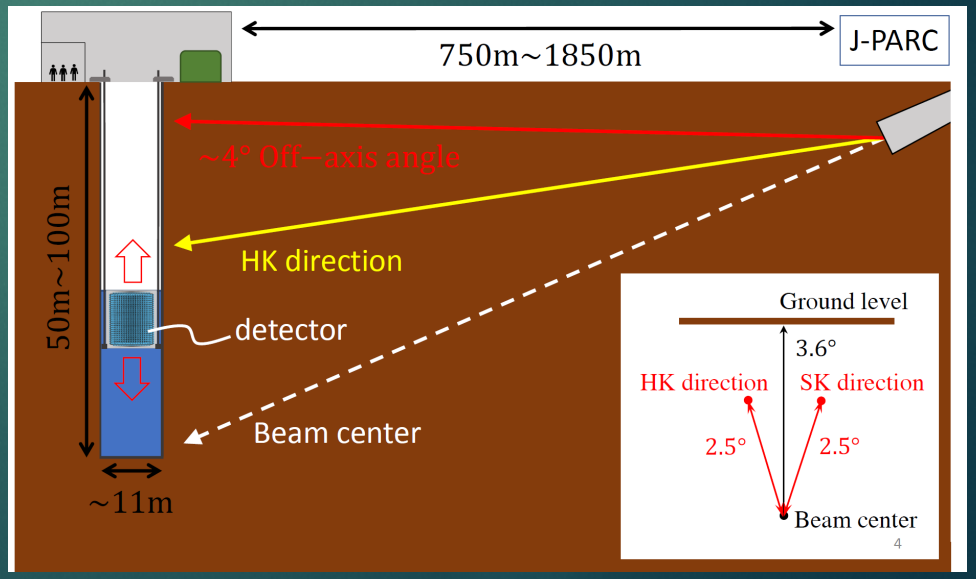
- ~1kt Water Cherenkov detector at ~km from nu source
- Measure the neutrino beam at different off-axis angles to resolve neutrino-nucleus scattering kinematics
  - Improve systematic error on CPV measurement by Hyper-K → Essential to reach final precision
- mPMT being developed by foreign countries to improve reconstruction






mPMT hit efficiency

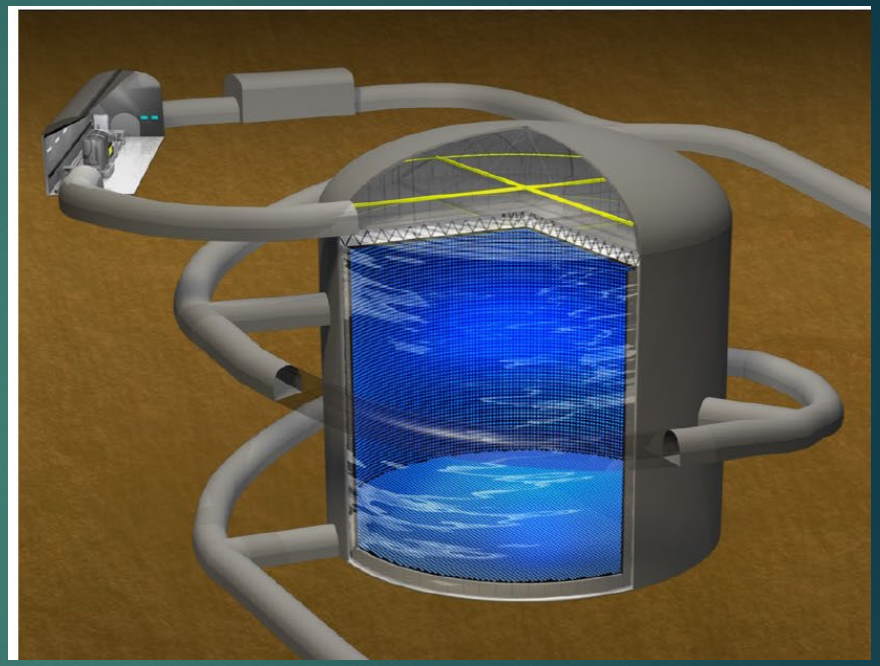




The Hyper-Kamiokande detector

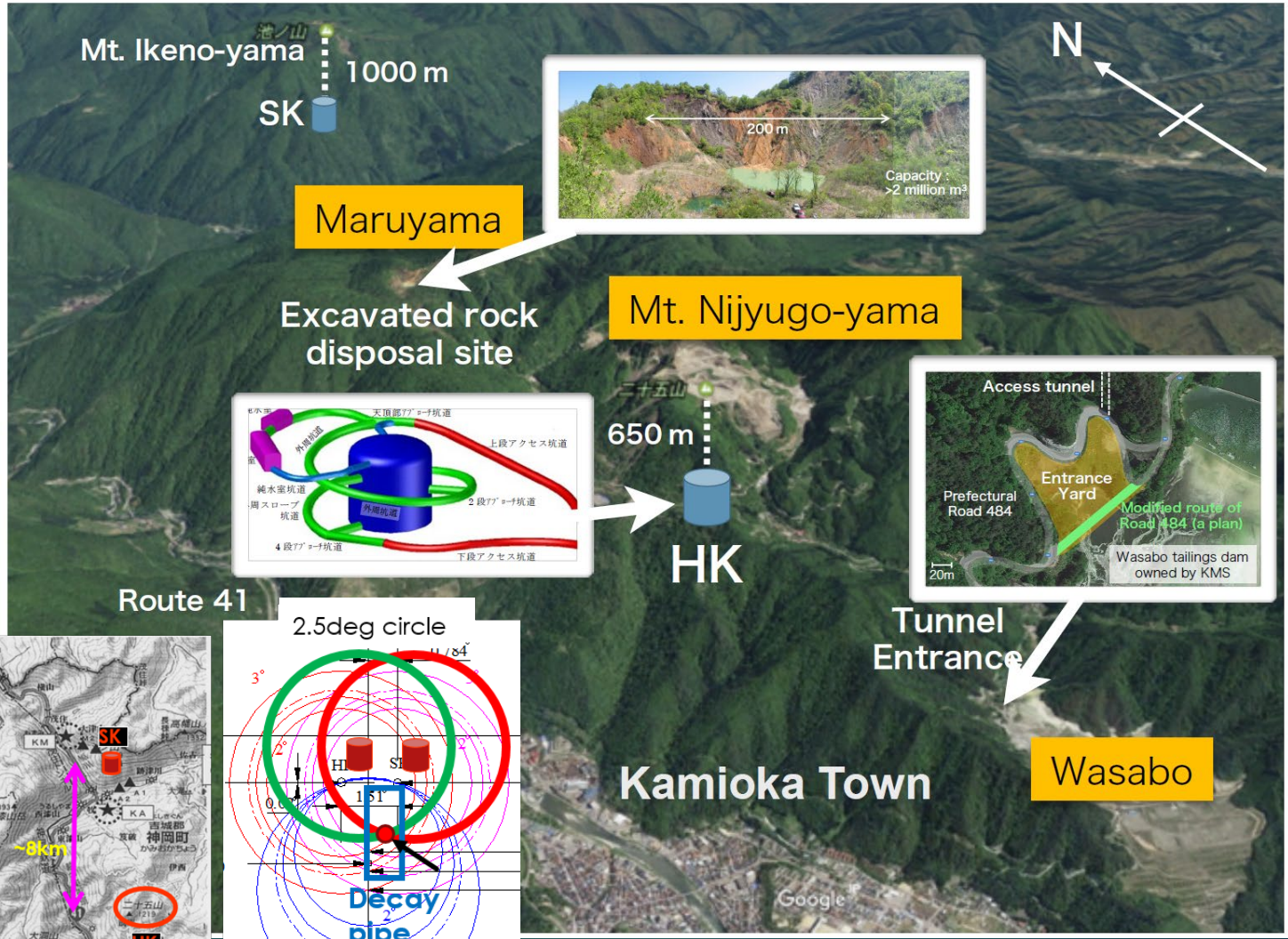
- 260kt(190kt fid.mass)
- ~40,000 50cm PMTs for inner det.
  - New PMT with x2 photo eff.
  - 40% coverage with new sensor
  - ~6,700 20cm PMTs for outer det.

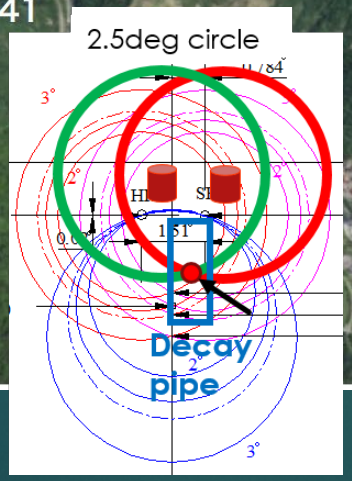
- Detector location (candidate)
  - ~8km south of SK
  - 295km from J-PARC, @ same off-axis angle
  - 650m overburden (1755m W.E.)



Candidate site

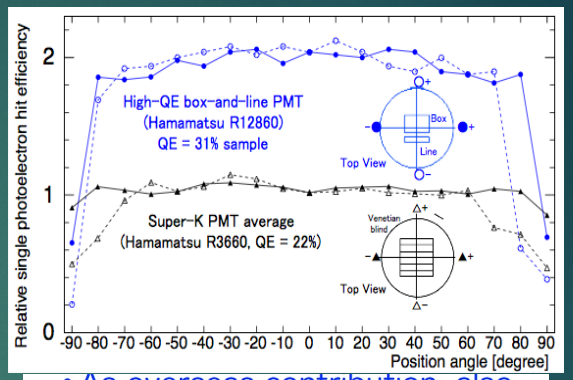
8 km south of Super-K
650 m rock overburden

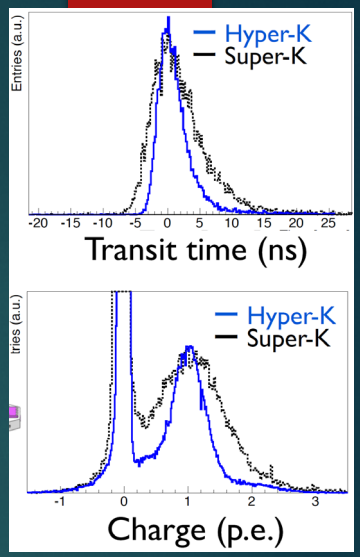




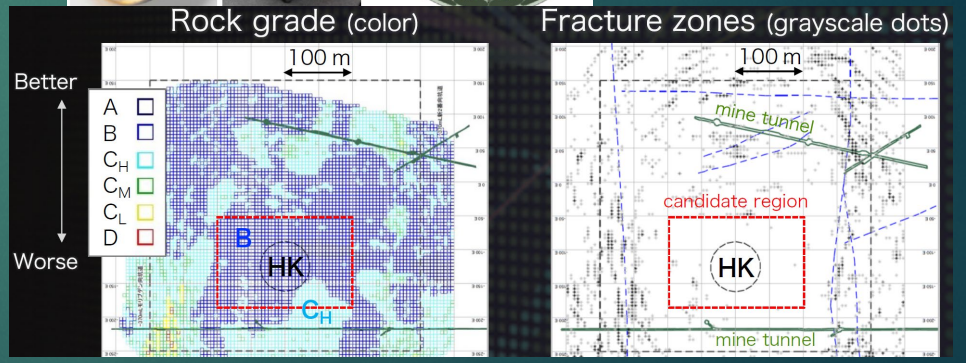
Technology development

- Huge cavern & tank
  - Experts' committee concluded to be feasible
- Photo sensors
  - x2 efficiency PMT developed
  - R&D including multi-PMT on-going as foreign contribution
- Etc
  - Electronics/DAQ
  - Analysis improvement
  - …





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

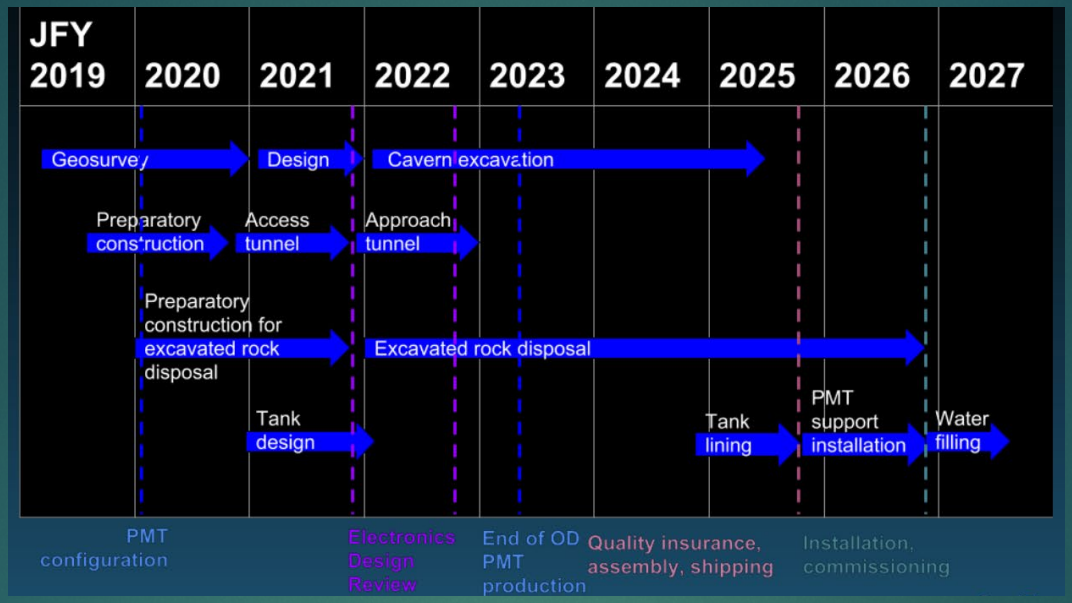


Report from cavern and tank sub-committee meeting

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.**

Project status and plan



- Aim to start operation ~2027
- 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
- Seed fund is secured in JFY2019
- Budget for JFY2020- requested to MEXT
- MEXT submit HK budget request to MOF

文部科学省
MEXT

Points of FY2020 Budget request

令和２年度概算要求のポイント

研究力向上に向けた基礎研究力強化と世界最高水準の研究拠点の形成

令和2年度要求・要望額　332,050百万円
（前年度予算額　304,712百万円）
※運営費交付金中の推計額含む

文部科学省

- イノベーションの源泉である多様で卓越した知を生み出す基盤の強化のため、**独創的で質の高い多様な学術研究**と**政策的な戦略に基づく基礎研究**を、強力かつ継続的に推進する。
- 国内外の優れた研究者を惹きつける**世界トップレベルの研究拠点**の構築を支援するとともに、**大学の研究力強化**のための取組を戦略的に支援し、世界水準の優れた研究大学群を増強する。
- 競争的研究費改革と連携して研究開発と機器共用の好循環を実現する**新たな共用システムの導入等**を推進する。

（参考）世界の学術フロンティアを先導する大規模プロジェクトの推進

大型電波望遠鏡「アルマ」による国際共同利用研究の推進や、全国の研究者・学生の教育研究活動に必須である学術情報ネットワーク（SINET）の強化、ニュートリノ研究の次世代計画である「ハイパーカミオカンデ計画」に新たに着手するなど、我が国の共同利用・共同研究体制を高度化しつつ、世界の学術研究を先導する（国立大学法人運営費交付金等に別途計上）。

令和2年度要求・要望額　40,826百万円
（前年度予算額　34,382百万円）

Start “Hyper-Kamiokande project” as a next generation project in neutrino research

http://www.mext.go.jp/component/b_menu/other/__icsFiles/afieldfile/2019/08/29/1420671_01-1.pdf
http://www.mext.go.jp/component/b_menu/other/__icsFiles/afieldfile/2019/08/29/1420671_01-2.pdf

Summary

- Hyper-Kamiokande is the Next generation Multi-purpose project
  - 190kt HyperK detector
  - 1.3MW J-PARC
- Broad science with unprecedented sensitivities
  - CP violation in neutrino
  - Proton decay
  - Astroparticle physics
  - Etc.
- Aim to start construction in 2020 and operation in 2027

- **Many interesting challenges ahead toward big goal**
- **Your challenges are welcome !**