Hyper-Kamiokande project

Outline

1. Detector construction
2. Inner detector system
3. Outer detector system
4. J-PARC beam upgrade
5. Near detector upgrade
6. Conclusions

Teppei Katori (@teppeikatori) for the Hyper-Kamiokande collaboration
King's College London
HEP seminar, Columbia University, USA, April 13, 2022

1. Detector construction

2. Inner detector system

3. Outer detector system

4. J-PARC beam upgrade

5. Near detectors

6. Conclusions

1. Hyper-Kamiokande project

Hyper-Kamiokande project includes 3 components

1. Hyper-Kamiokande detector

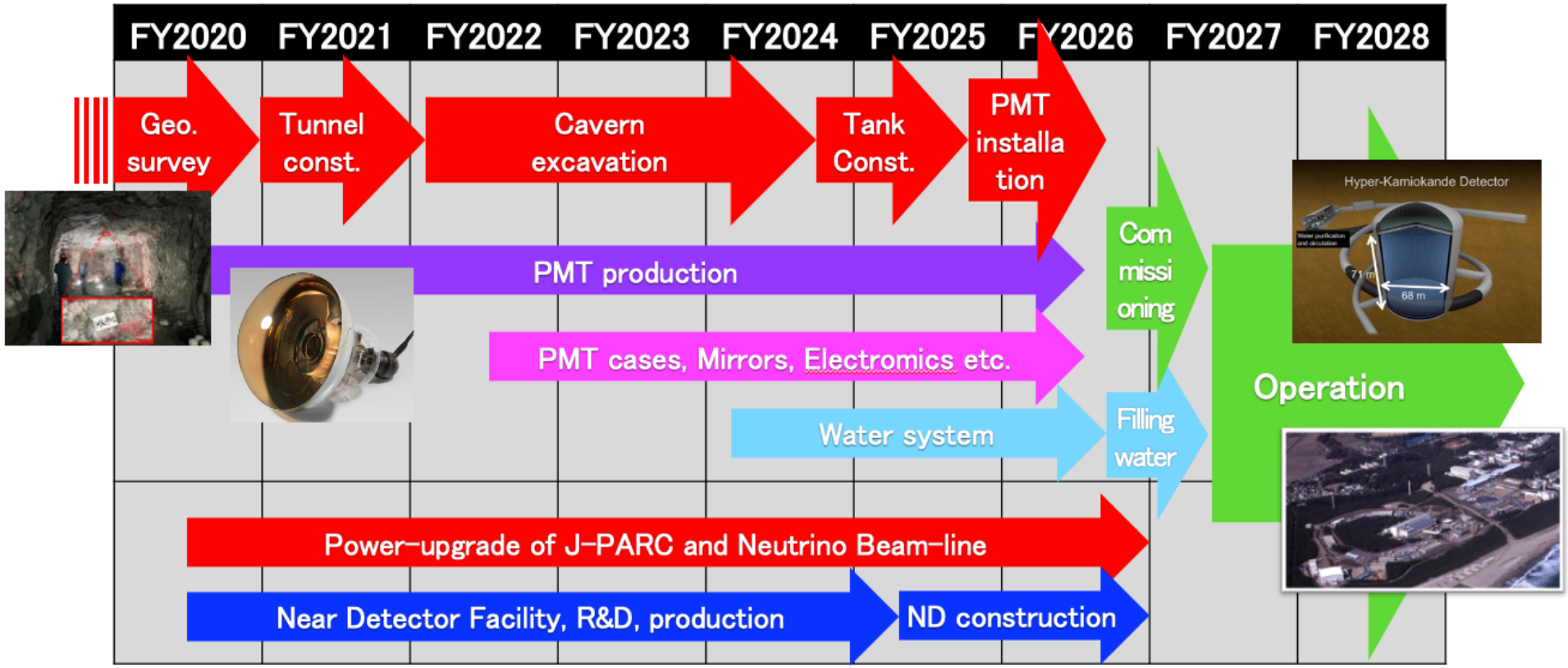
2. J-PARC beam upgrade

3. Near detector upgrade (ND280-upgrade, new near detectors like IWCD, intermediate water Cherenkov detector)

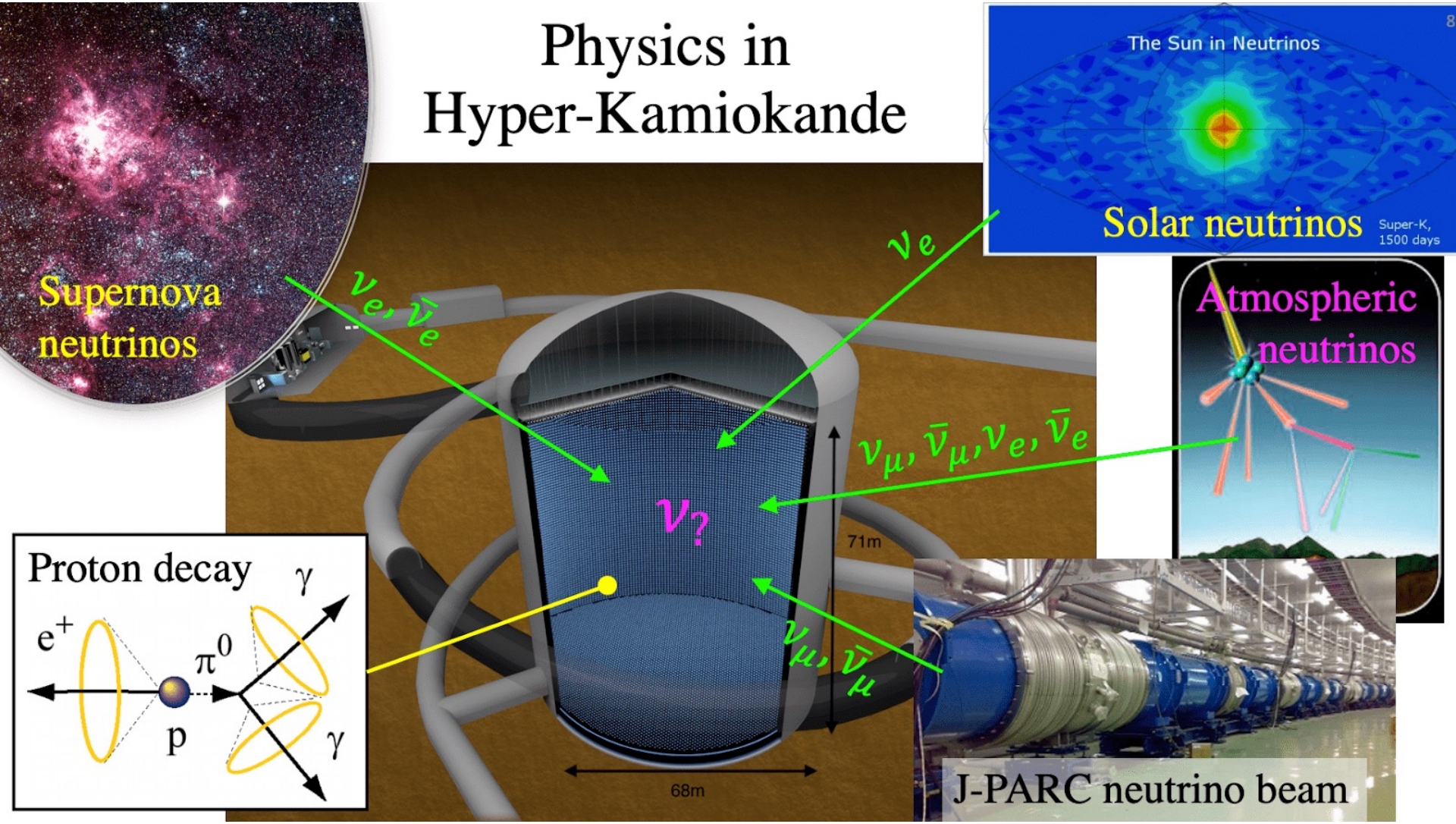
This talk mainly cover the status of (1)

1. Hyper-Kamiokande project

2027 operation start
- R&D of all stages are finishing
- Site excavation started
- PMT mass production started (already delivered, QA finished > 3,000 PMTs)

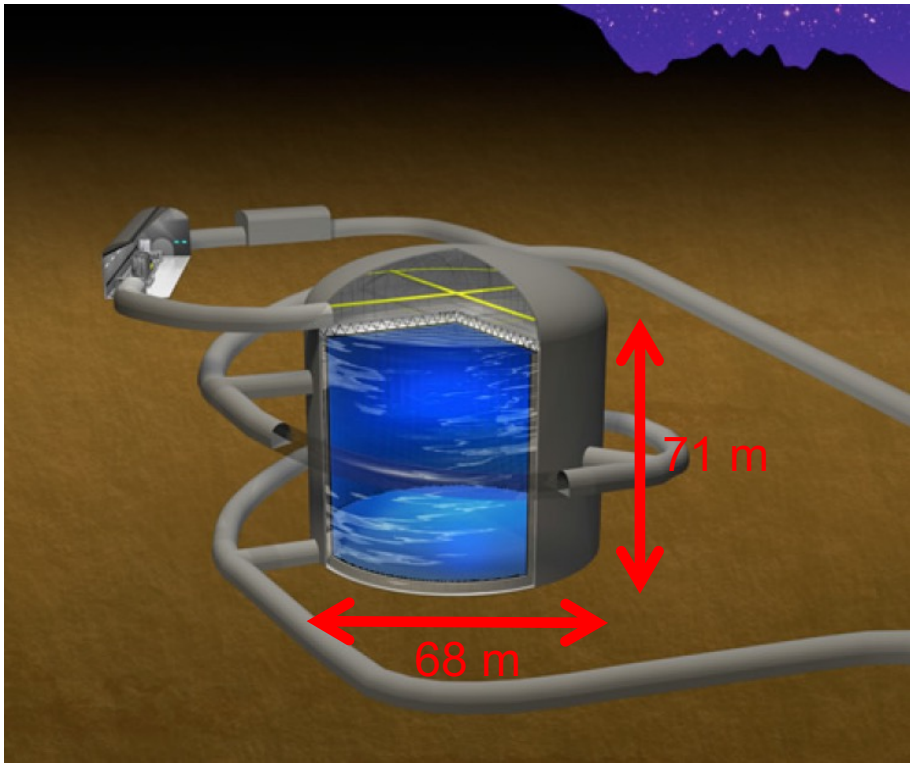


1. Hyper-Kamiokande detector

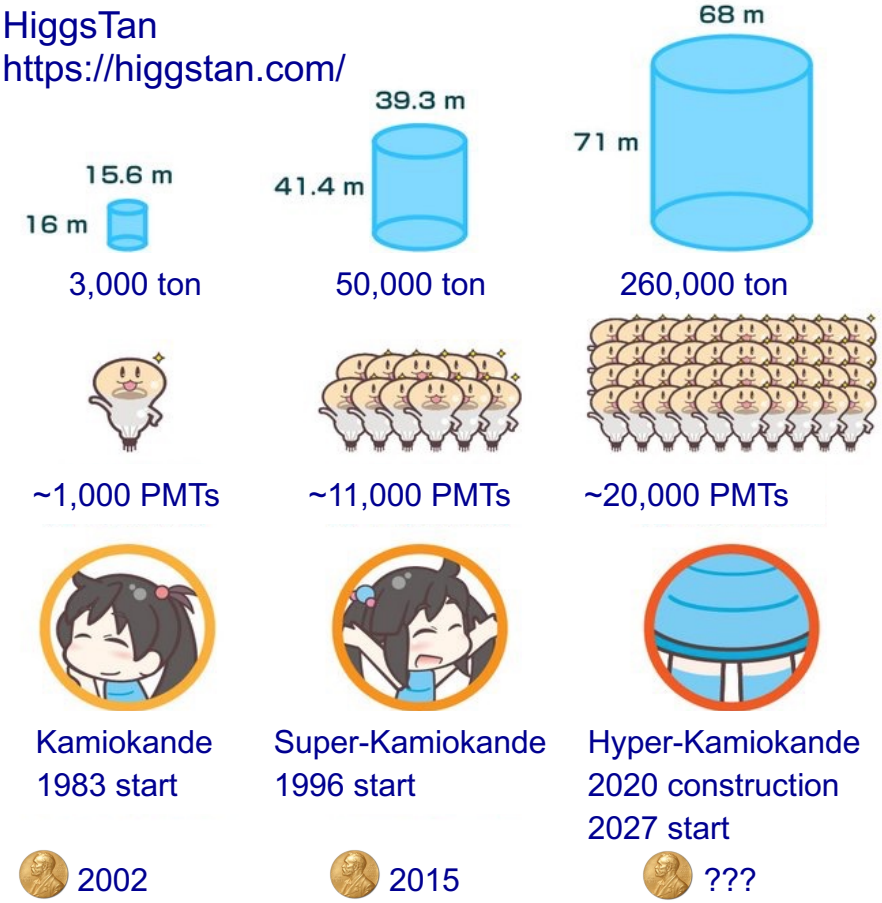


1. Hyper-Kamiokande detector

260 kton water tank
- Inner detector volume 220 kton, fiducial volume 188 kton
- At least x8.4 fiducial volume of Super-K

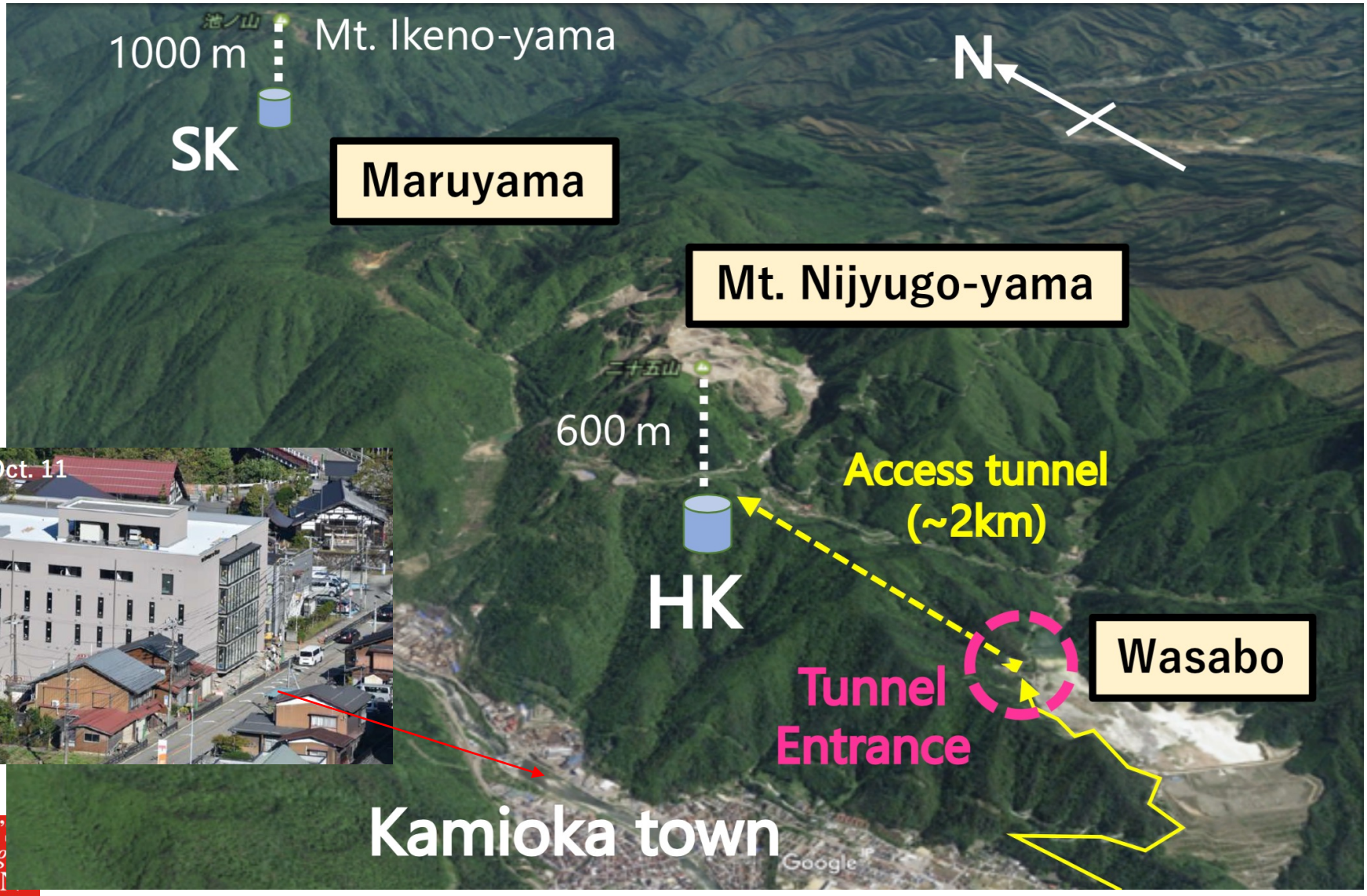


HiggsTan
https://higgstan.com/



1. Hyper-K site

Tochibora mine in Kamioka town



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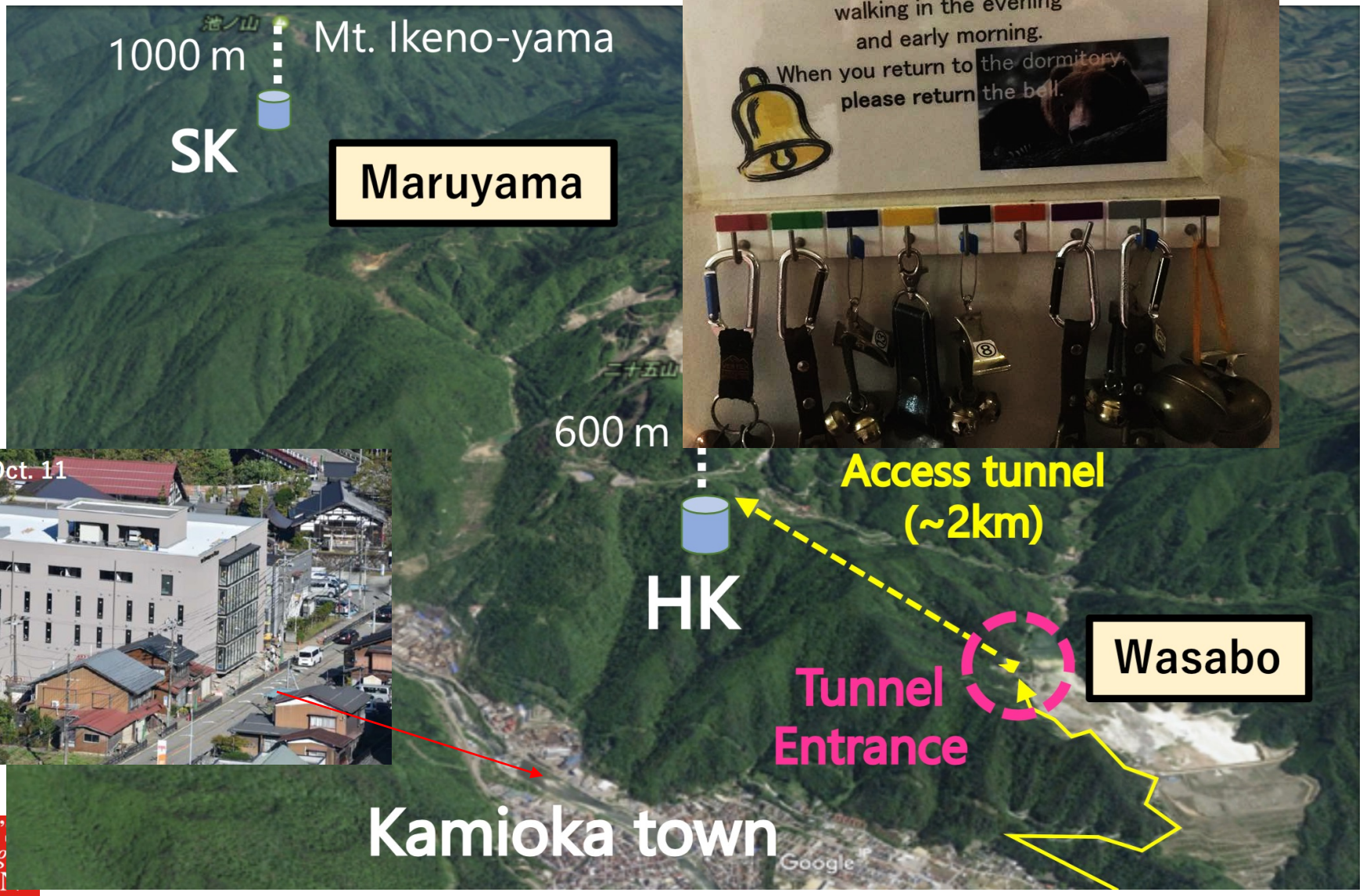
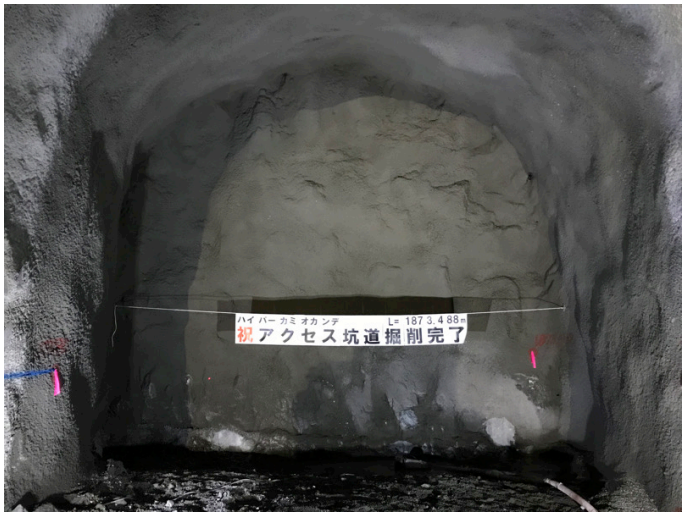
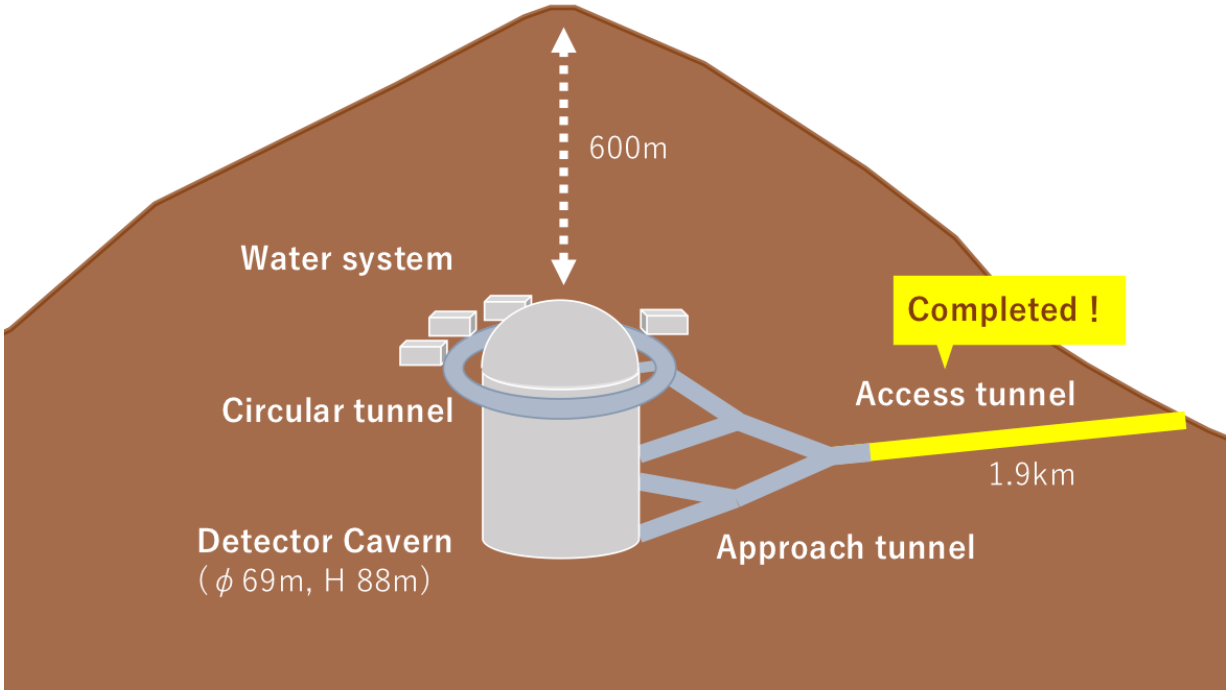


1. Tunnel construction

Horizontal access to the detector by car
- Access tunnel: completed
- Approach tunned: started
- Cavern excavation: start this year





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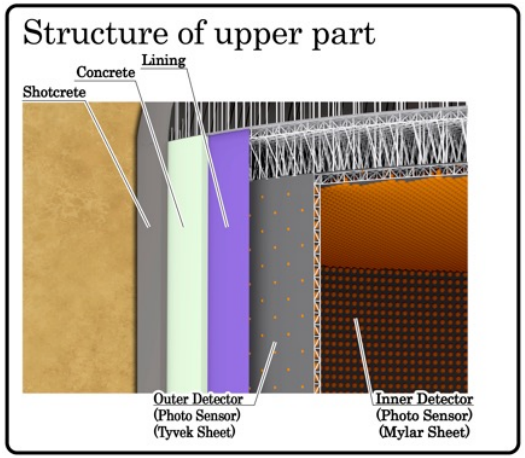
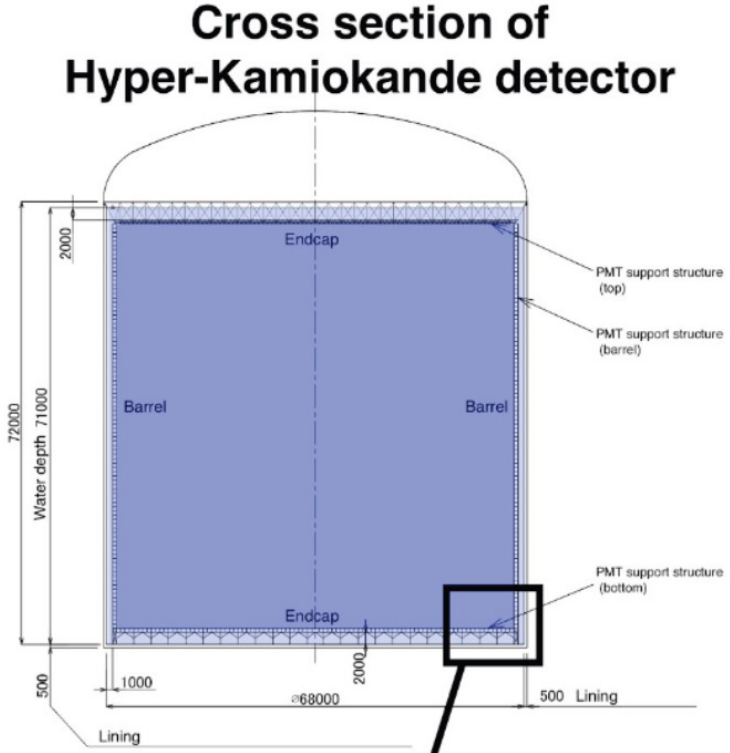
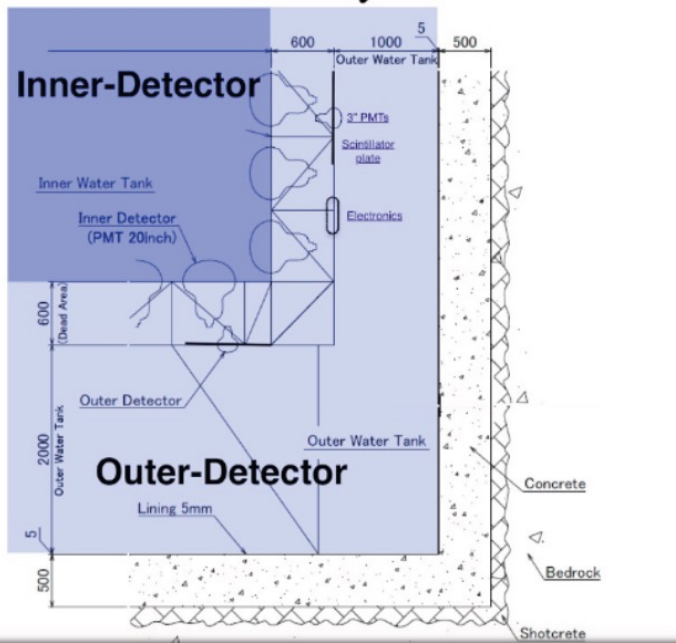
1. Hyper-K tank structure

Tank wall is protected by multiple layers

Inner detector (ID) and outer detector (OD) are optically separated by Tyvek and black sheets







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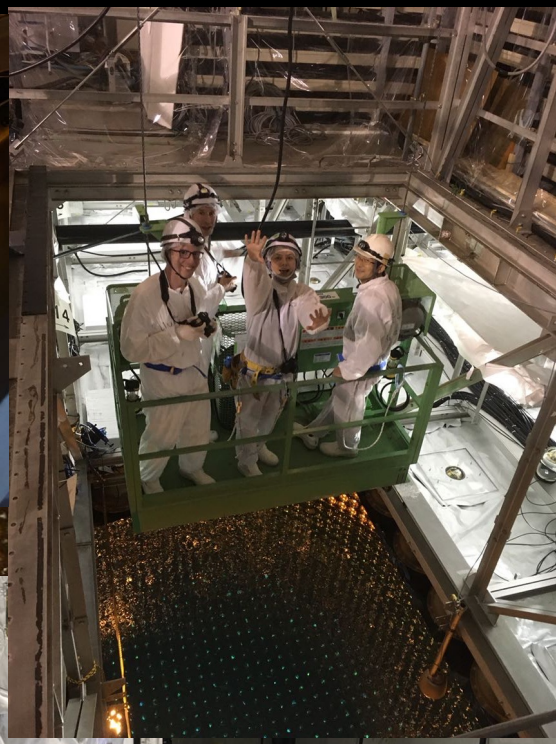
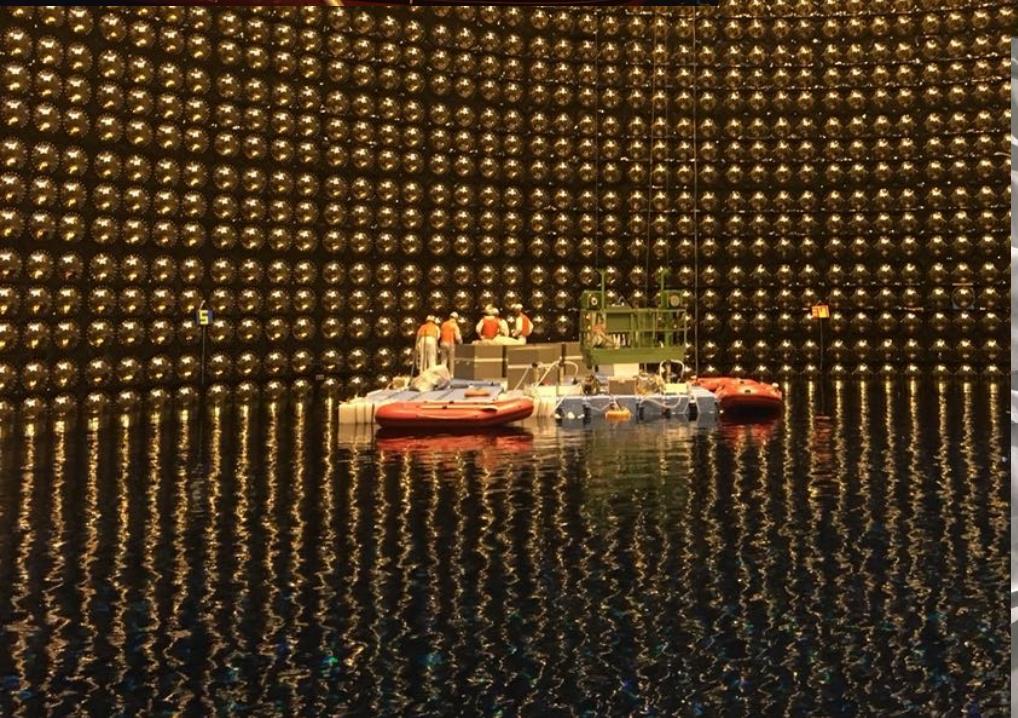
Super-Kamiokande detector refurbishment 2018





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5. Near detectors

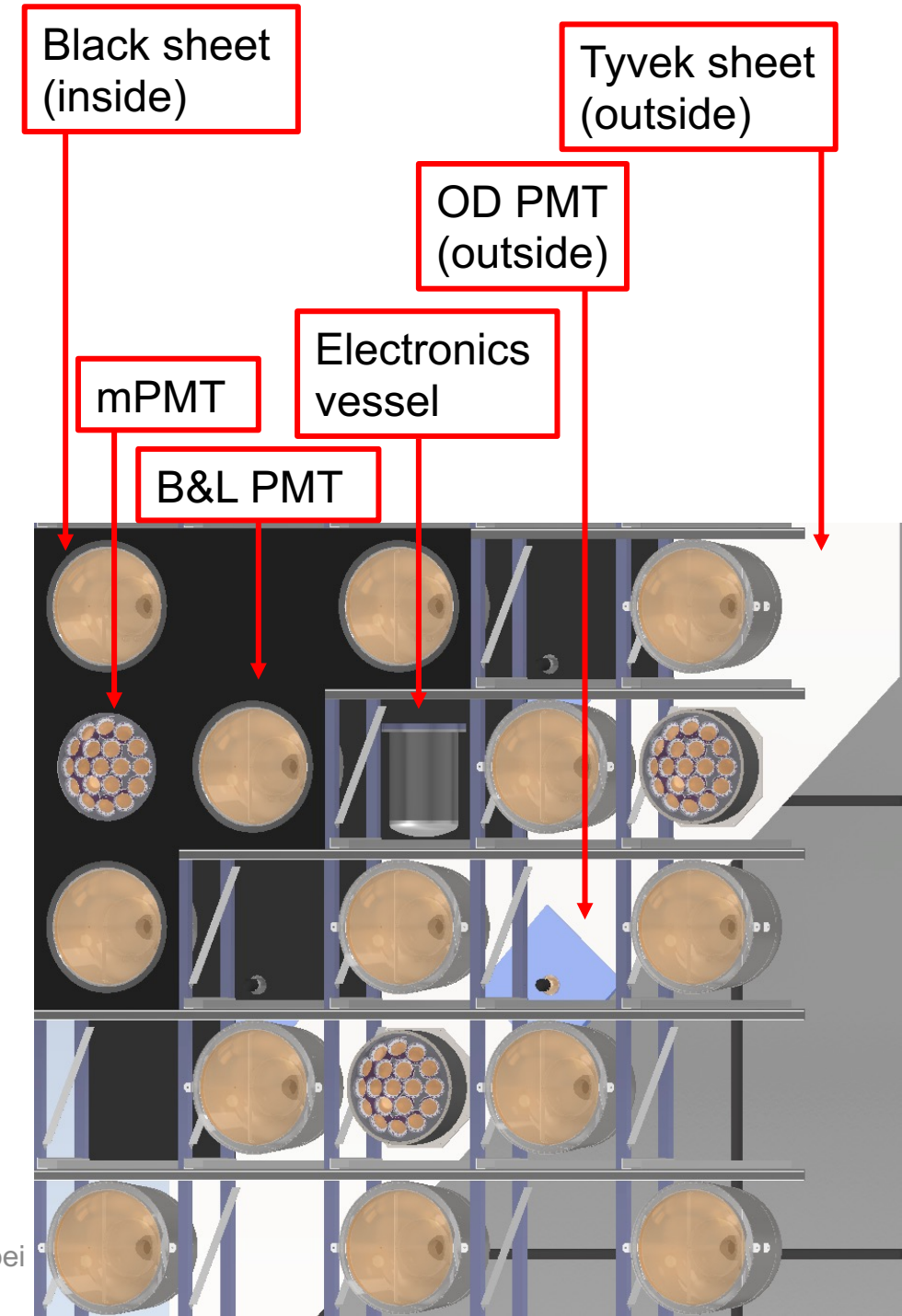
6. Conclusions

2. Hyper-K ID frame

ID PMTs, mPMTs, OD PMTs, in-water electronics, Tyvek and black sheets are all mounted on stainless streel frame

Each slot is 70cm x 70cm, and roughly 300 x 90 slots are available on barrel (70% filled)

Super-K during 2018 refurbishment

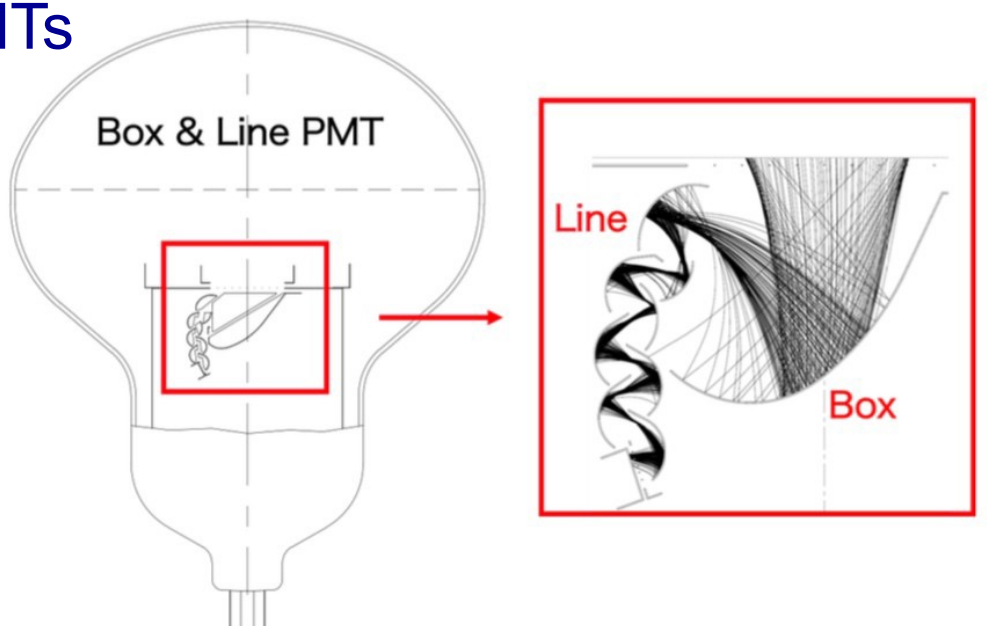


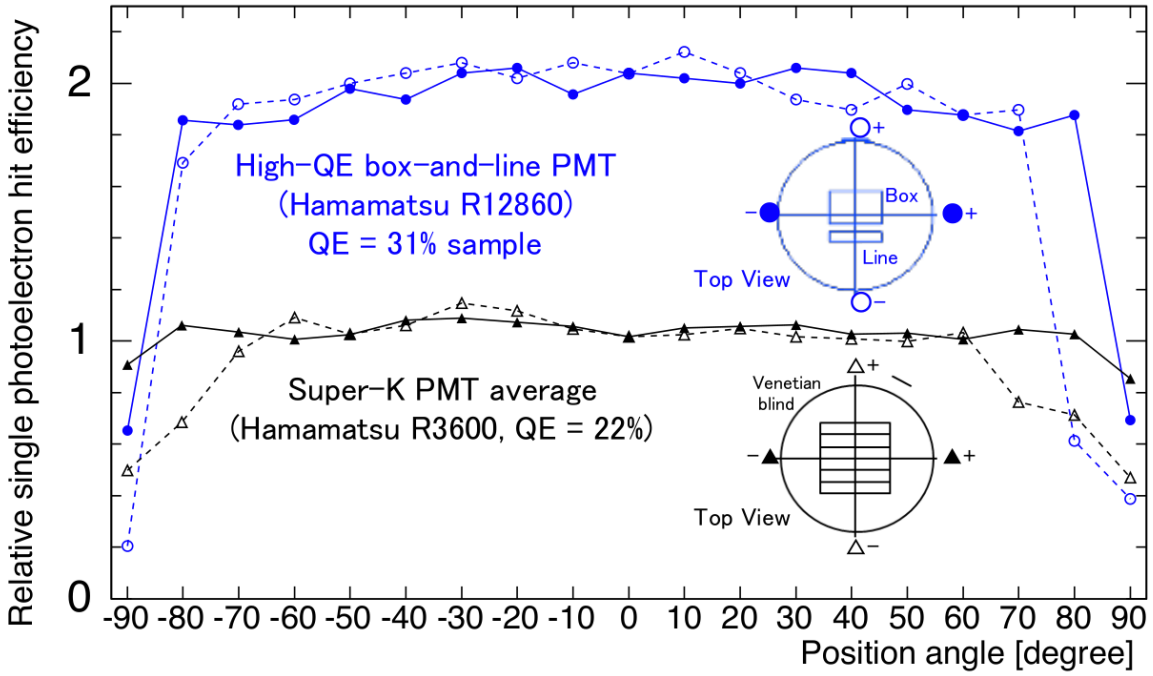
2. Hyper-K ID PMTs - B&L PMTs

R12860, new generation 50cm PMT
- Box and Line dynode structure
- 50% higher quantum efficiency (30%)
- x2 better charge resolution (30%)
- x2 better timing resolution (1.5ns)
- Stay on the same dark rate (4kHz)

We think these improvement can compensate the lower photo-cathode coverage (40%→20%)

Don't worry, this is not a real PMT





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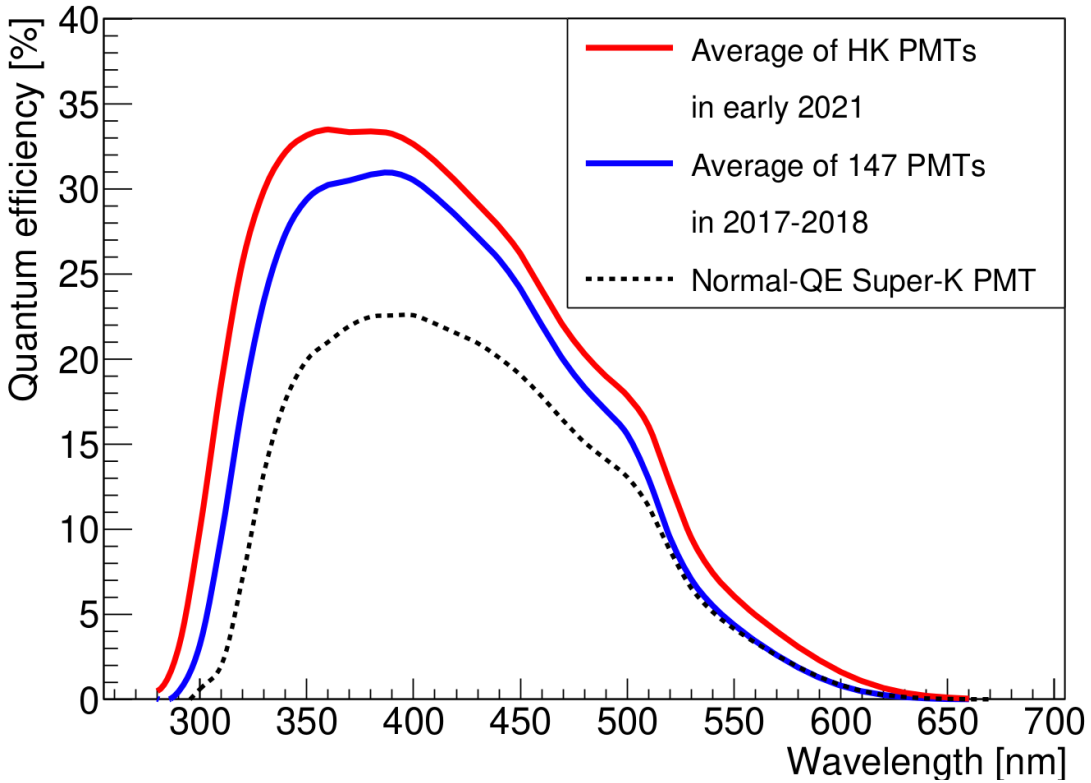
2. Hyper-K ID PMTs - B&L PMTs

Radio-isotopes in glass window are the major sources of dark current (scintillation)
- After meticulous researches, people found the origin of them
- R12860 finally achieved the 4kHz target goal!
- QE is further improved for short wavelength region

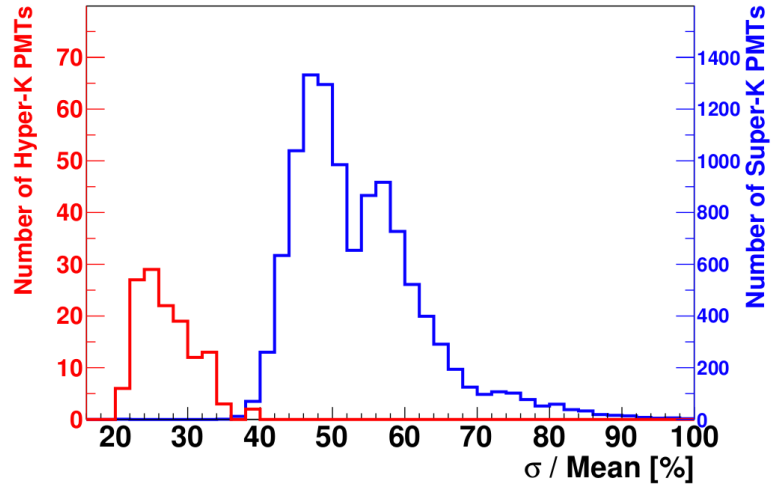
Radio isotopes in glass (Bq/kg)

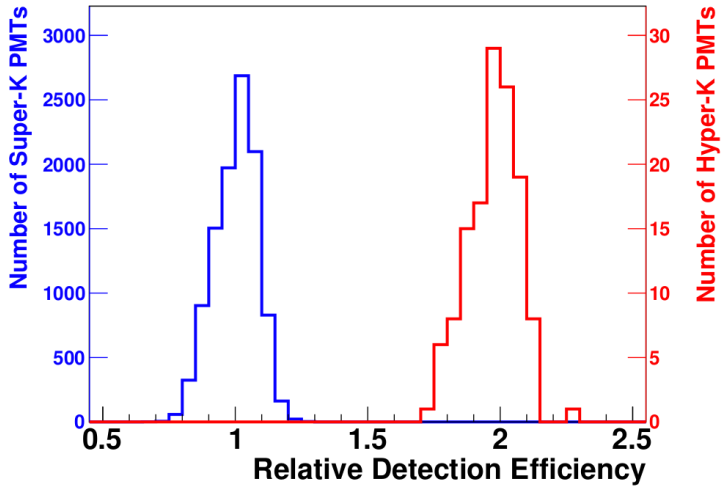
	Super-K (R3600)	R12860 (before)	R12860 (after)	R12860 (2021)
U	5.5	5.4	2.9	2.5
Th	1.8	1.8	0.95	0.7
^{40}K	18.2	1.6	2.0	1.0

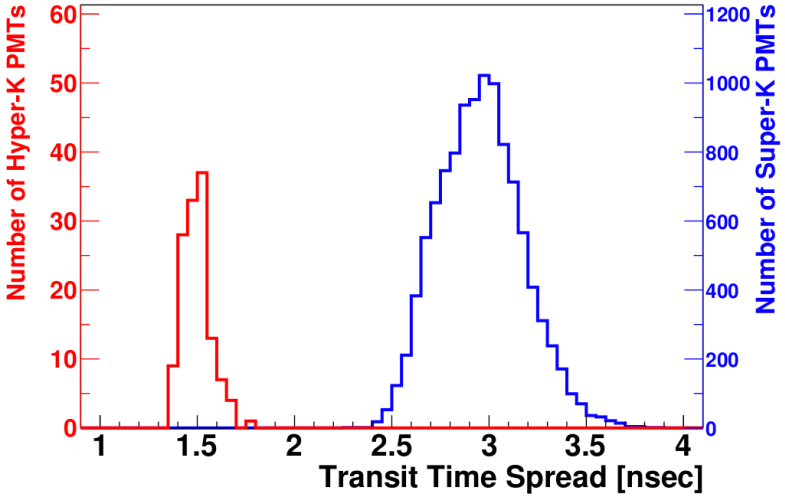


2. Hyper-K ID PMTs - B&L PMTs, in SuperK

134 of B&L PMTs were installed in SuperK (2018). Performance was confirmed in the ultra-pure water environment





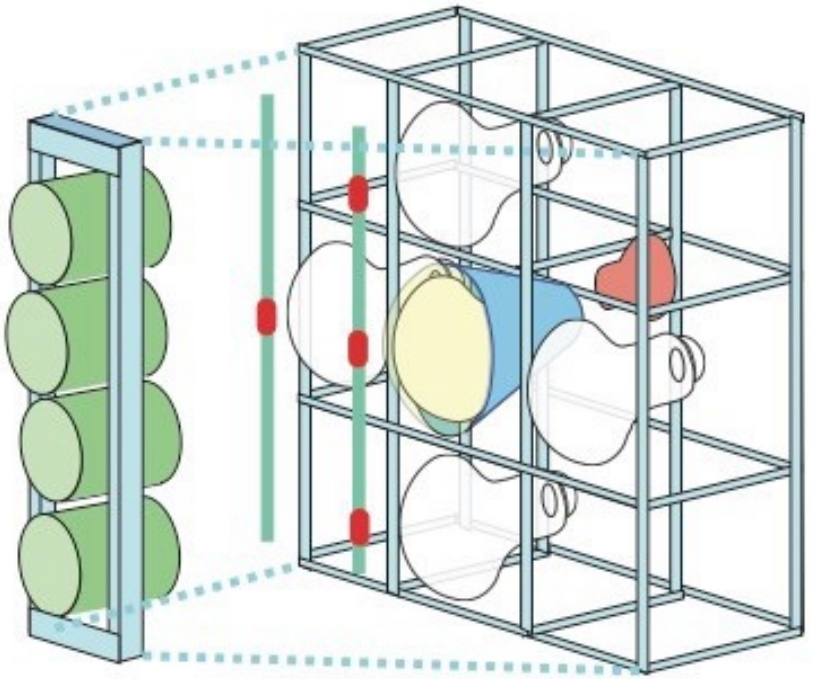


1. Hyper-K ID PMTs - B&L PMTs, cover

Pressure test: equivalent to 70m water depth
Shockwave test: man-made implosion to protect chain reaction

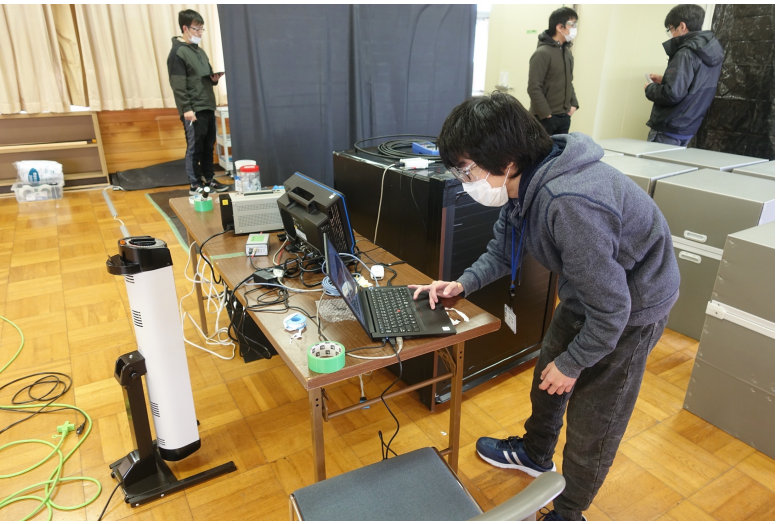
Tests are being conducted at 80m vertical tunnel in Hokkaido, Japan

Various B&L PMT cover candidates
- UV transparent acrylic front cover
- Resin or stainless steel back cover



1. Hyper-K ID PMTs - B&L PMTs, production status

B&L PMT mass production
- So far >3,000 PMTs are delivered
- QA, Signal check + visual check
- So far no major issues
- Feedback sent to Hamamatsu
- So far only done by Japanese groups



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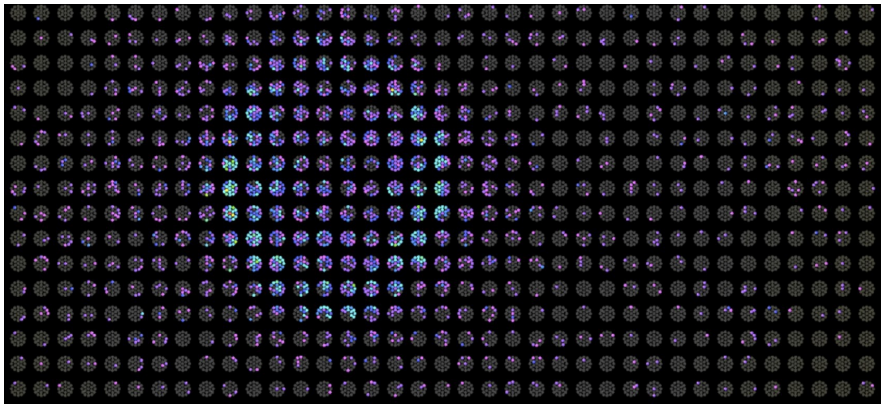
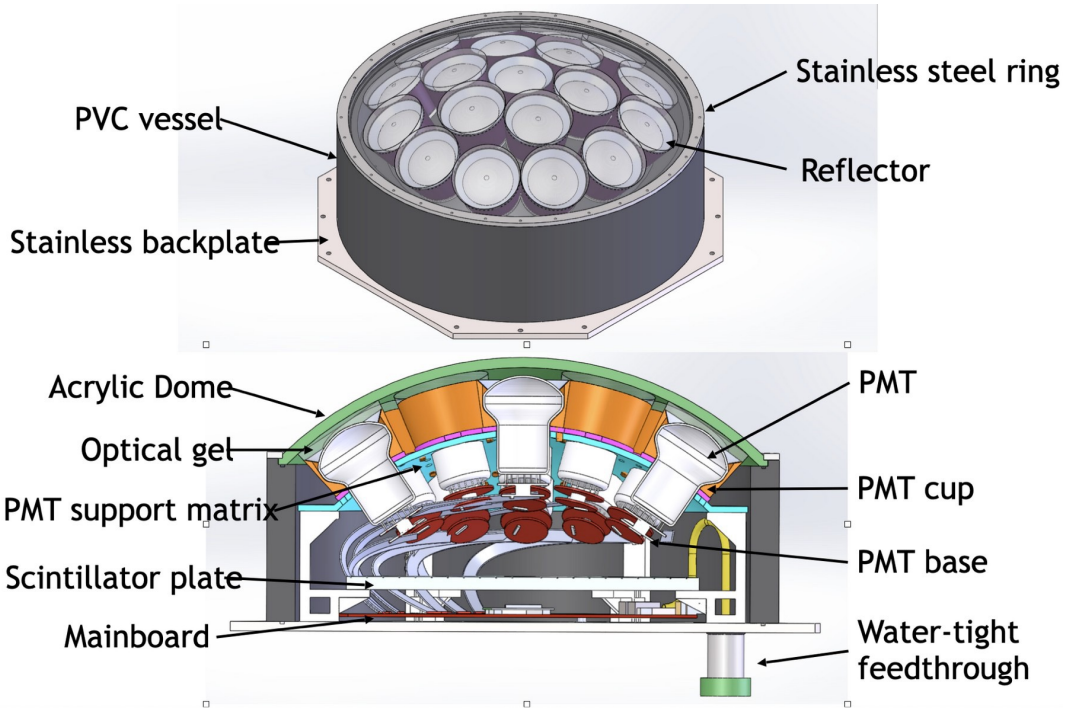
1. Hyper-K ID PMTs - mPMTs



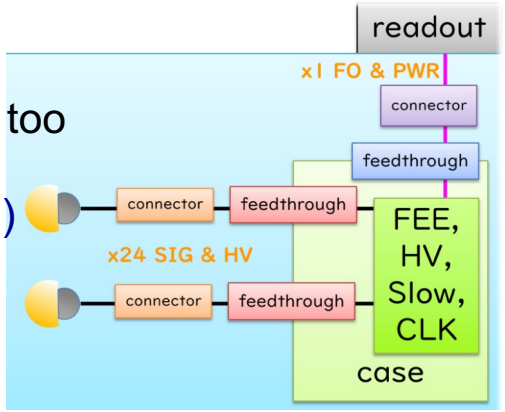
KM3NeT-based design
- 19 3-inch PMTs, lower noise
- ~half photo-cathode coverage of B&L PMT
- C-W base and electronics
- High-granularity, photon direction information

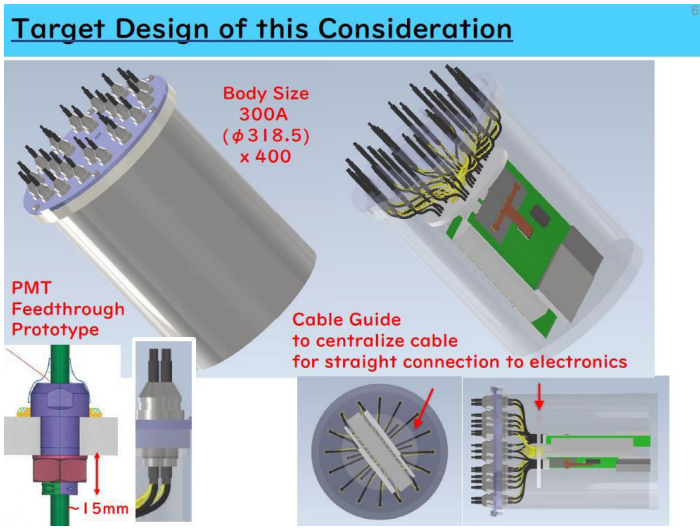


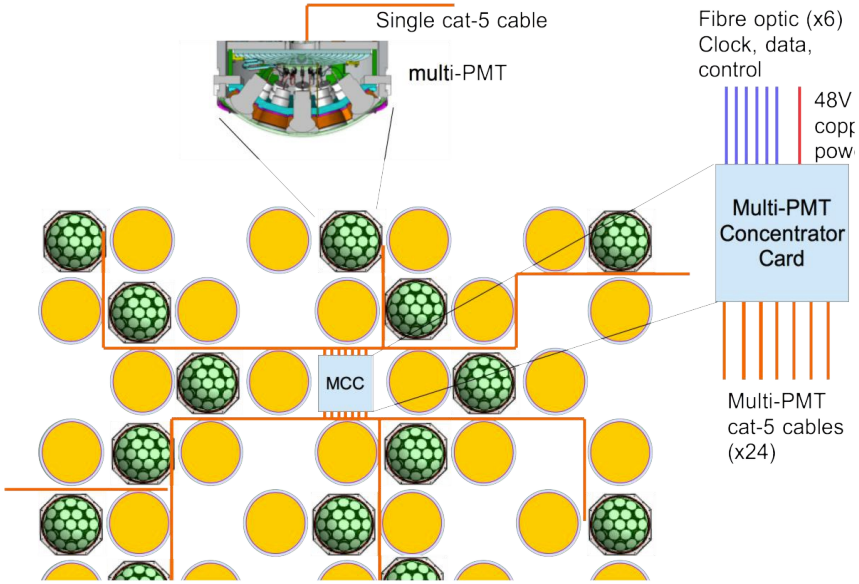
1. Hyper-K electronics

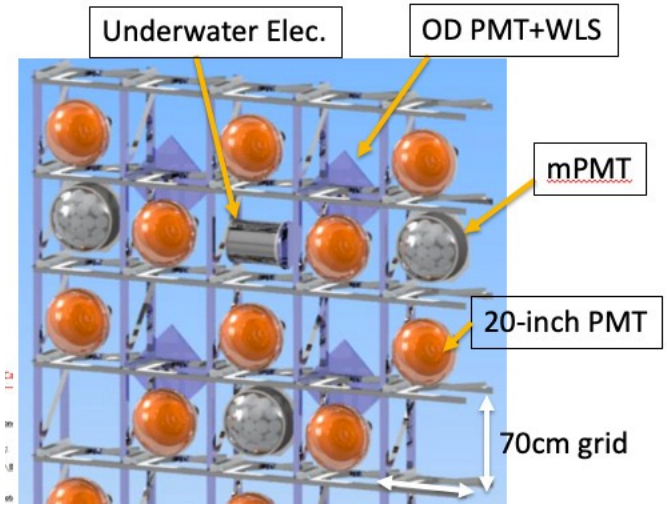
B&L PMT
- In-water electronics box (x24)
- May host OD PMT electronics too

mPMT Concentrator Card (MCC)









1. Detector construction

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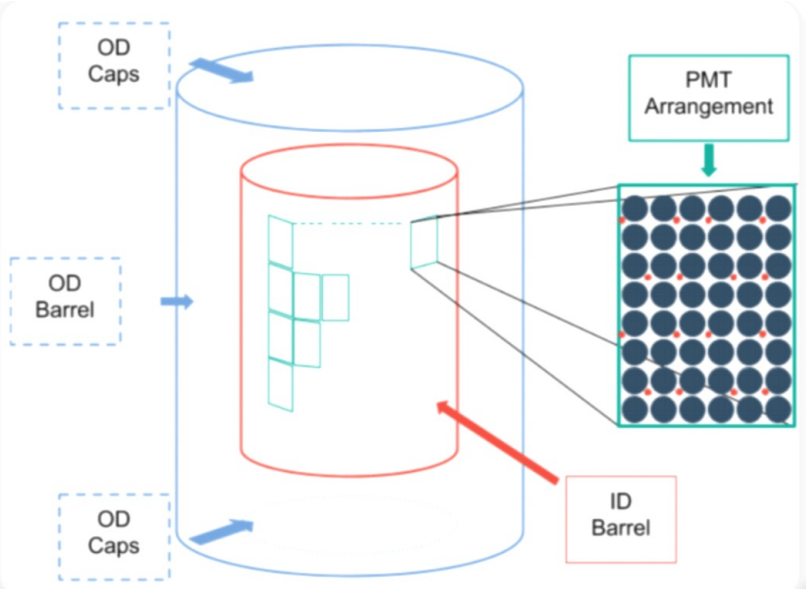
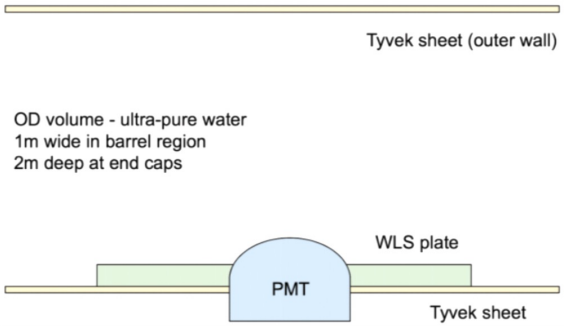
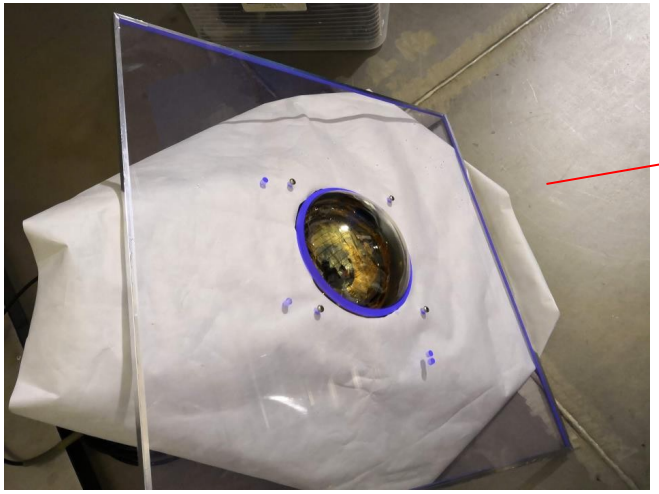
3. Hyper-K outer detector system

Cosmic ray rate 2Hz (SuperK) → 45Hz (HyperK)
- Bigger than SuperK (50kton→260kton)
- Shallower overburden than SuperK (1000m→600m
- Narrower barrel OD region (2m→1m)



Hyper-K OD PMT
- 3-inch PMT
- WLS plate
- Tyvek sheet



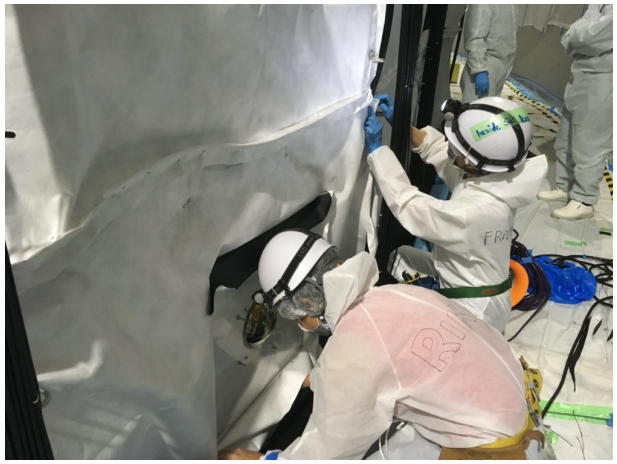


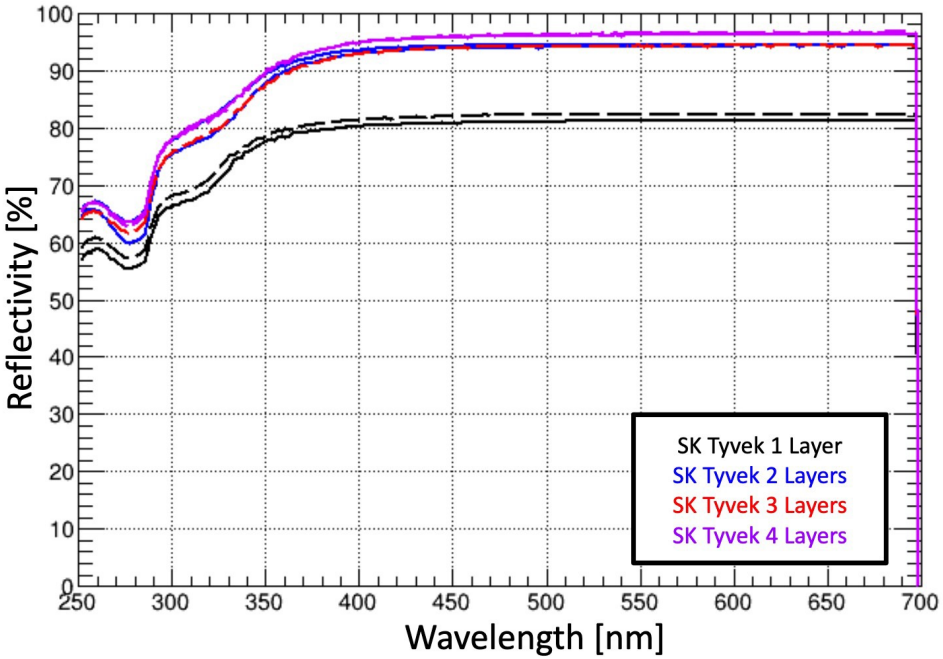
3. Hyper-K OD Tyvek

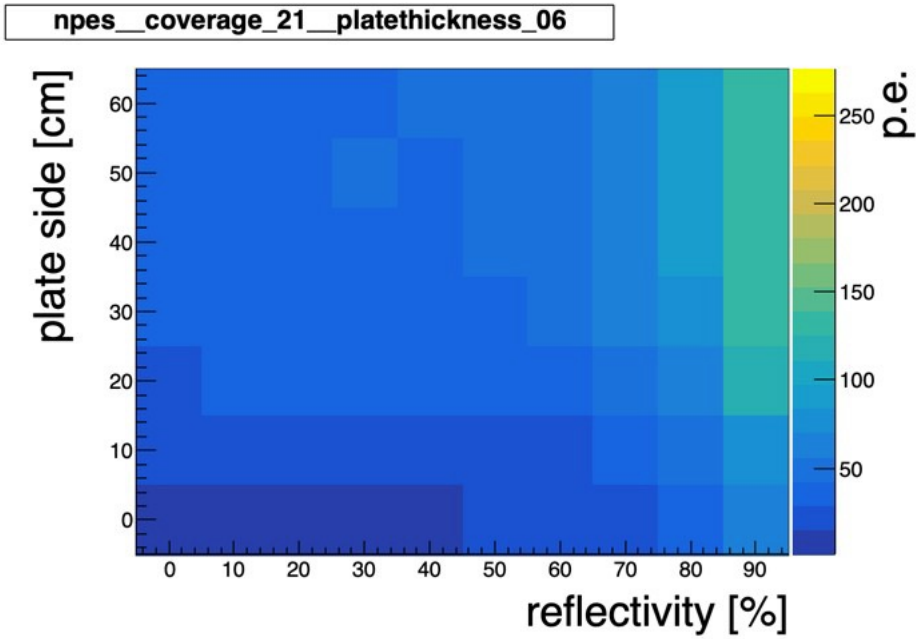
Since HyperK is huge, we mostly rely on Tyvek reflected photons for veto

High-reflective Tyvek (>90%) is the key
- Multilayer

Baseline design is >90% reflective Tyvek and 30cm WLS plate







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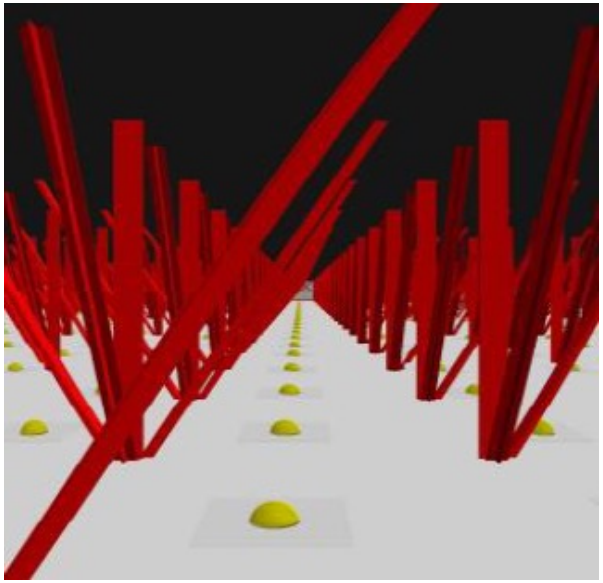
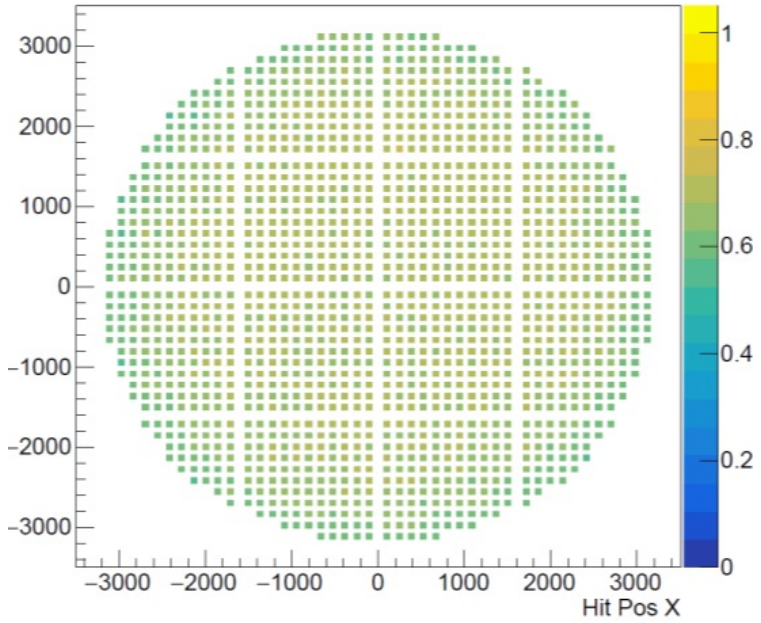
Since HyperK is huge, we mostly rely on Tyvek reflected photons for veto

The weak spots are corners, need simulation to understand effects of struts

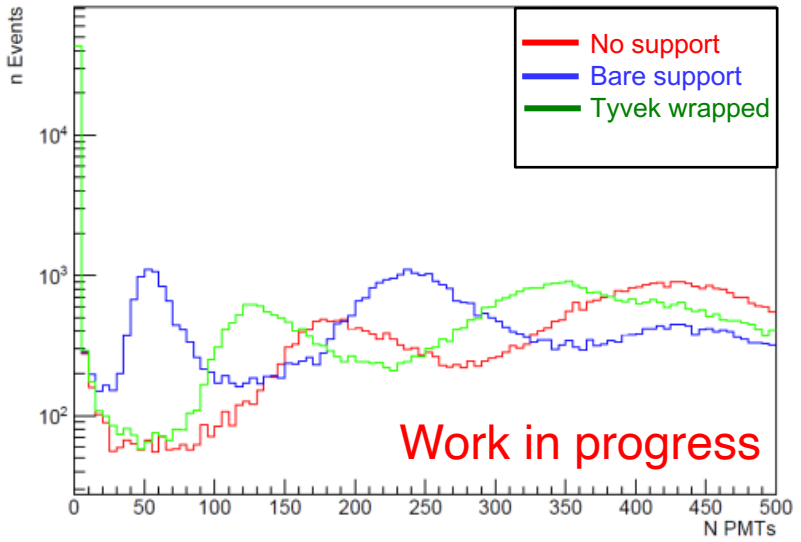


Top region of HyperK

Top OD PMT hit ratio w/ and w/o struts



OD PMT hit distribution from cosmic ray simulation



Ewan Miller

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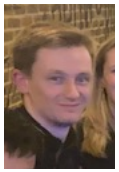
Clustering algorithm needs to be optimized for HyperK geometry
- higher rejection power for corner events
- multiple cosmic rays



George Burton

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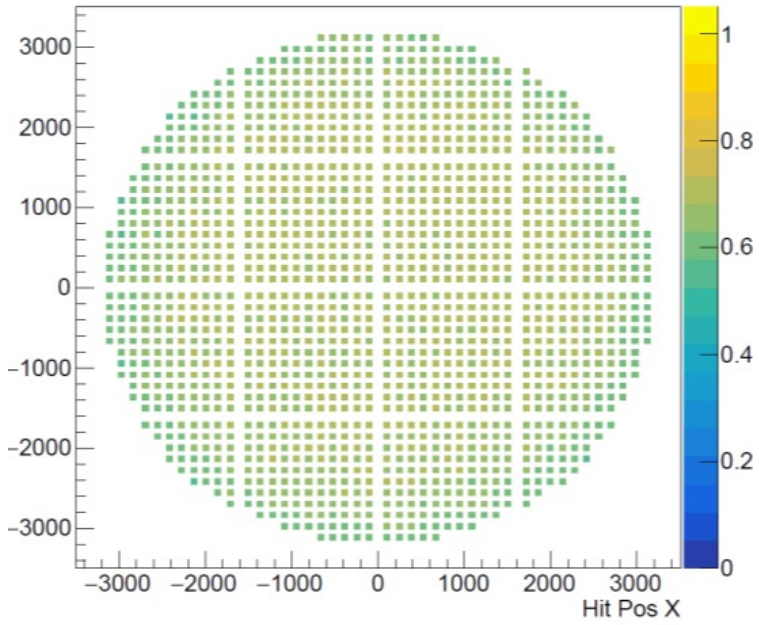
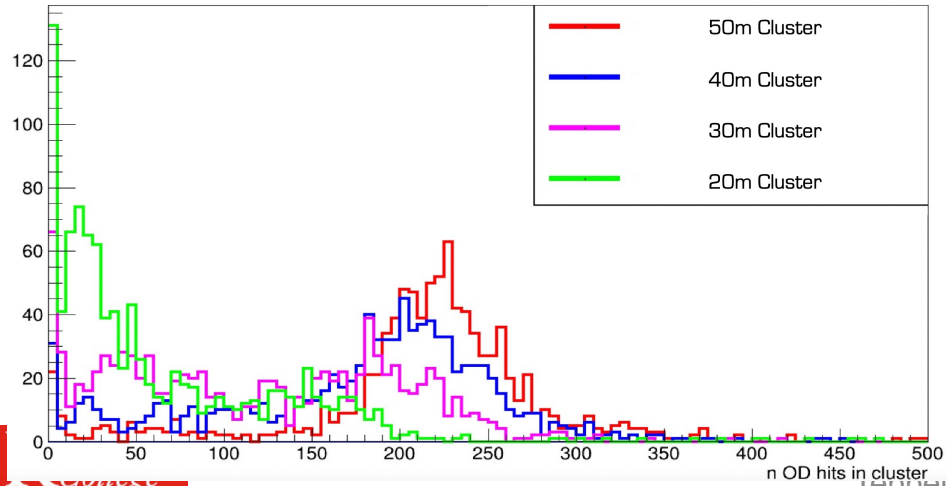


OD PMT hit in clusters



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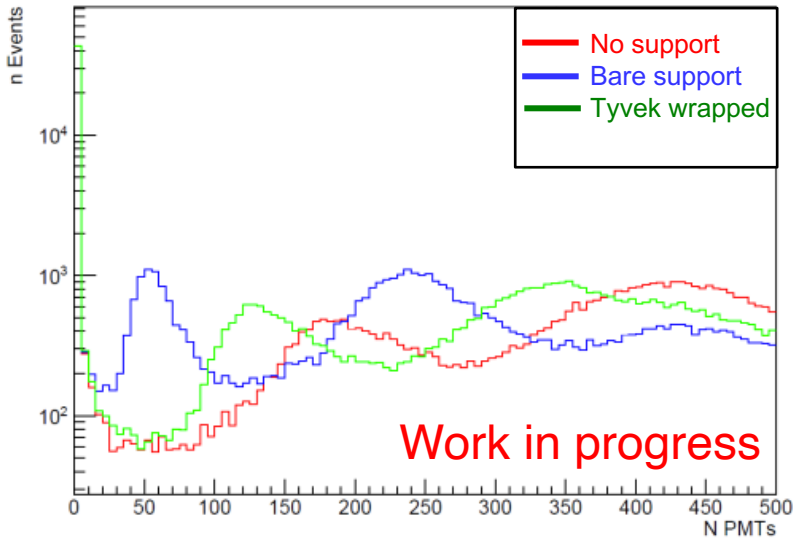


3. Hyper-K OD PMT

Zhenxiong Xie

Candidate PMTs are being tested

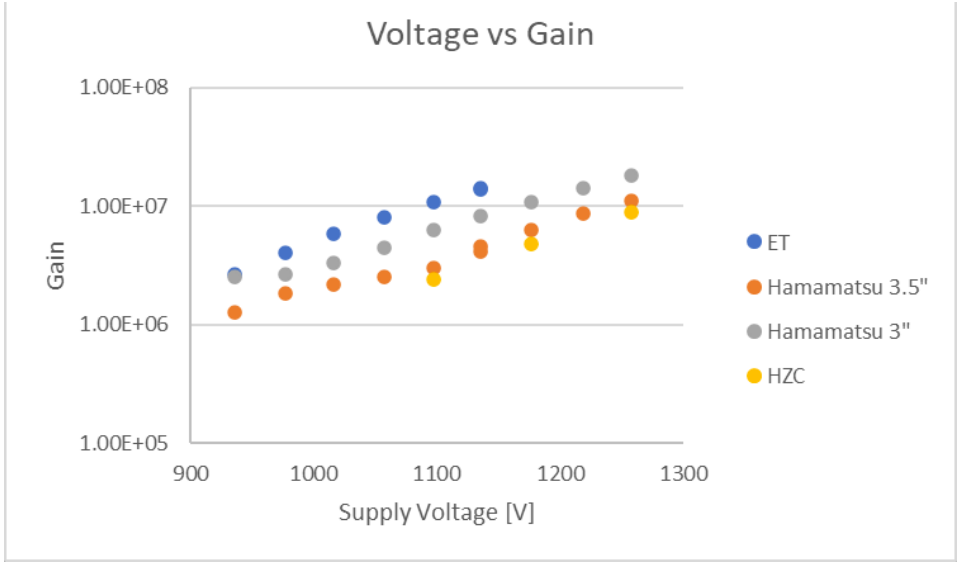
- 3-inch positive HV PMTs (1 cable operation)
- reasonable gain, efficiency, resolution, noise etc
- low failure rate is the key
  - electronics, waterproof, cable, connector

HZC XP72B2F 3”

ET Enterprises D459/2KFLB 3”

Hamamatsu R14689 3.5”

Hamamatsu R14374 3”



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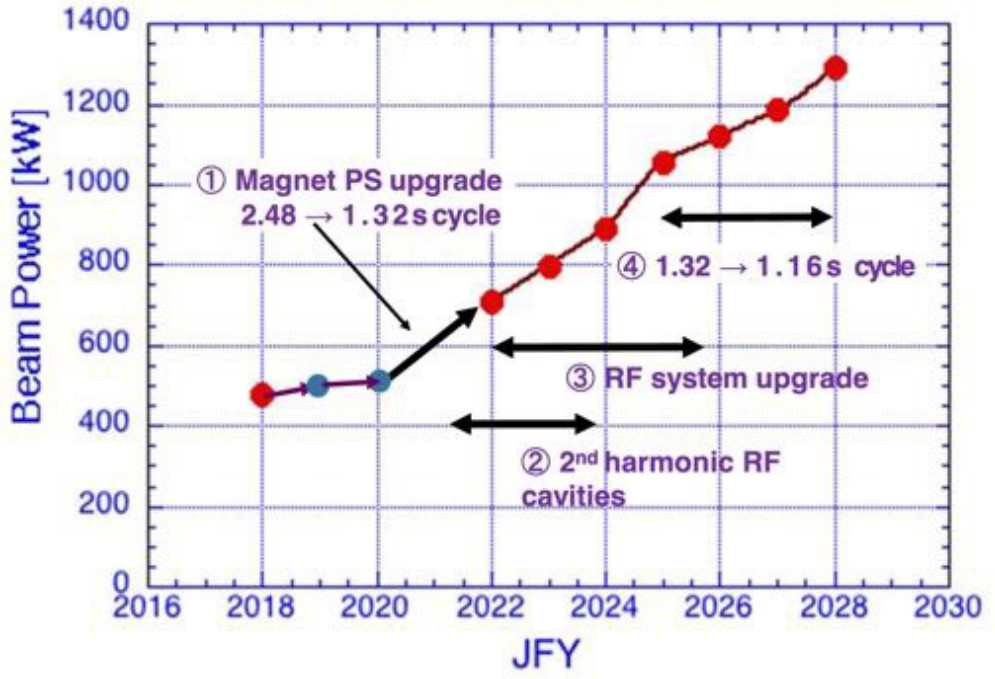
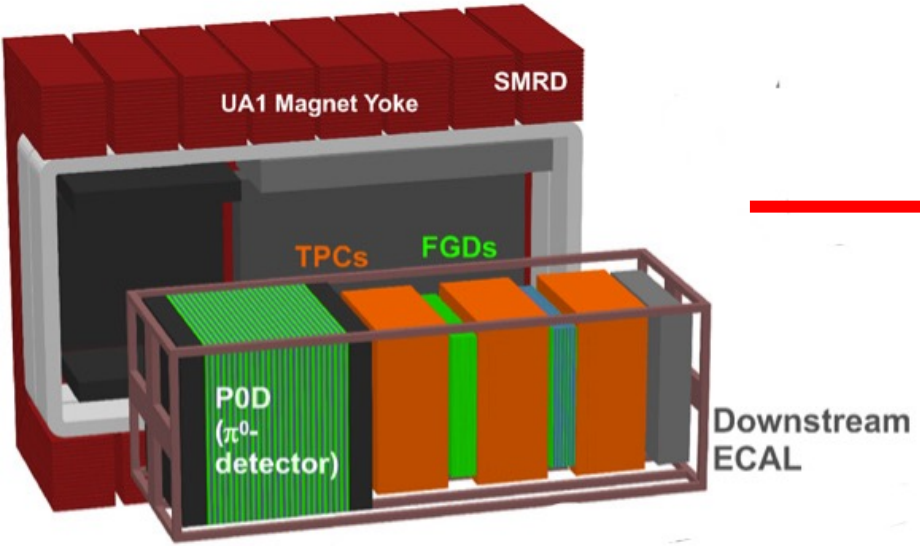
4. T2K Upgrade

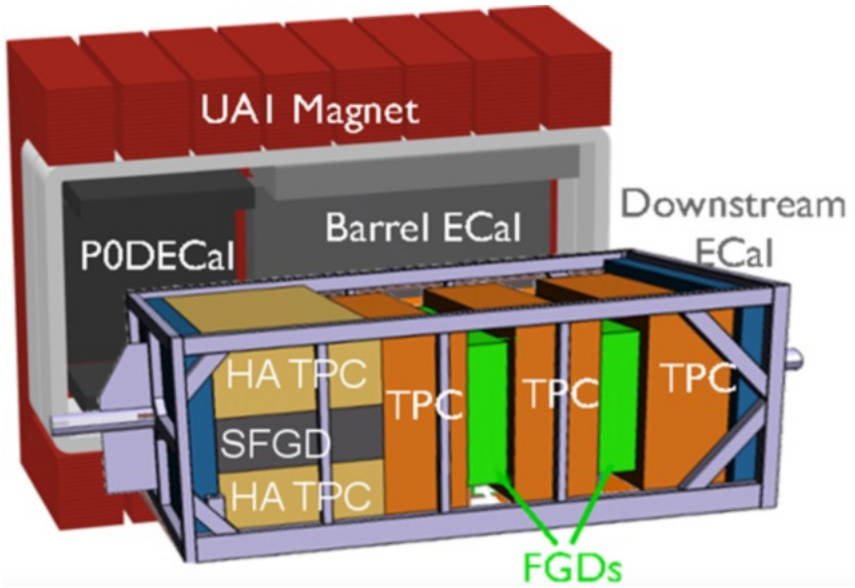
Approved project
- Significant CERN contribution

J-PARC beam Upgrade
- Continuous improvement to achieve 1.3 MW beam

ND280 Upgrade
- Out: P0D detector
- In: High Angle TPC (HATPC)
- In: SuperFGD

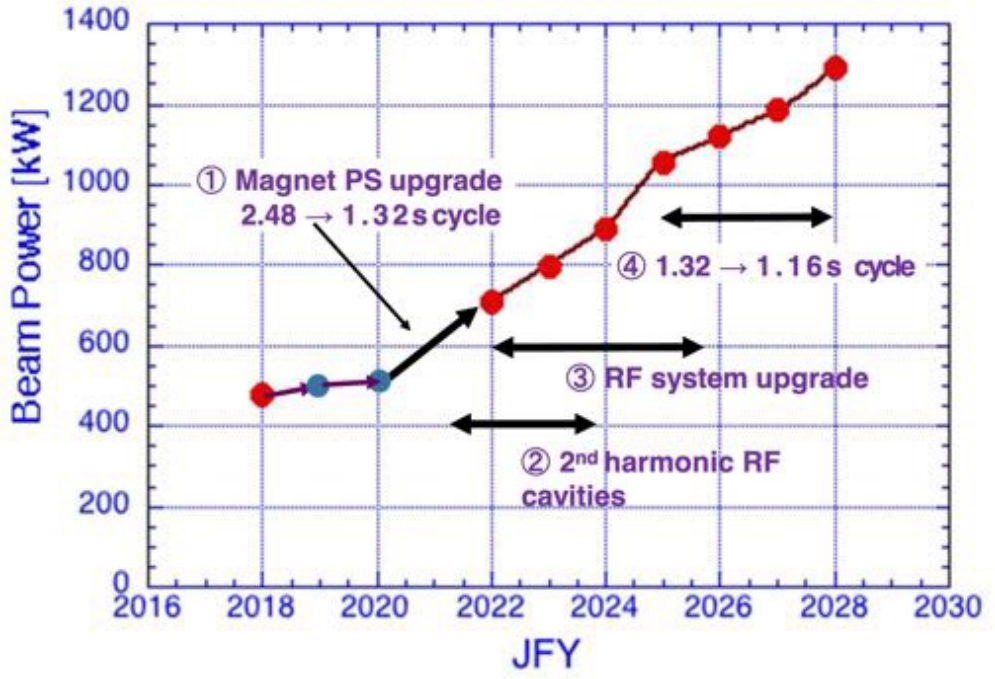


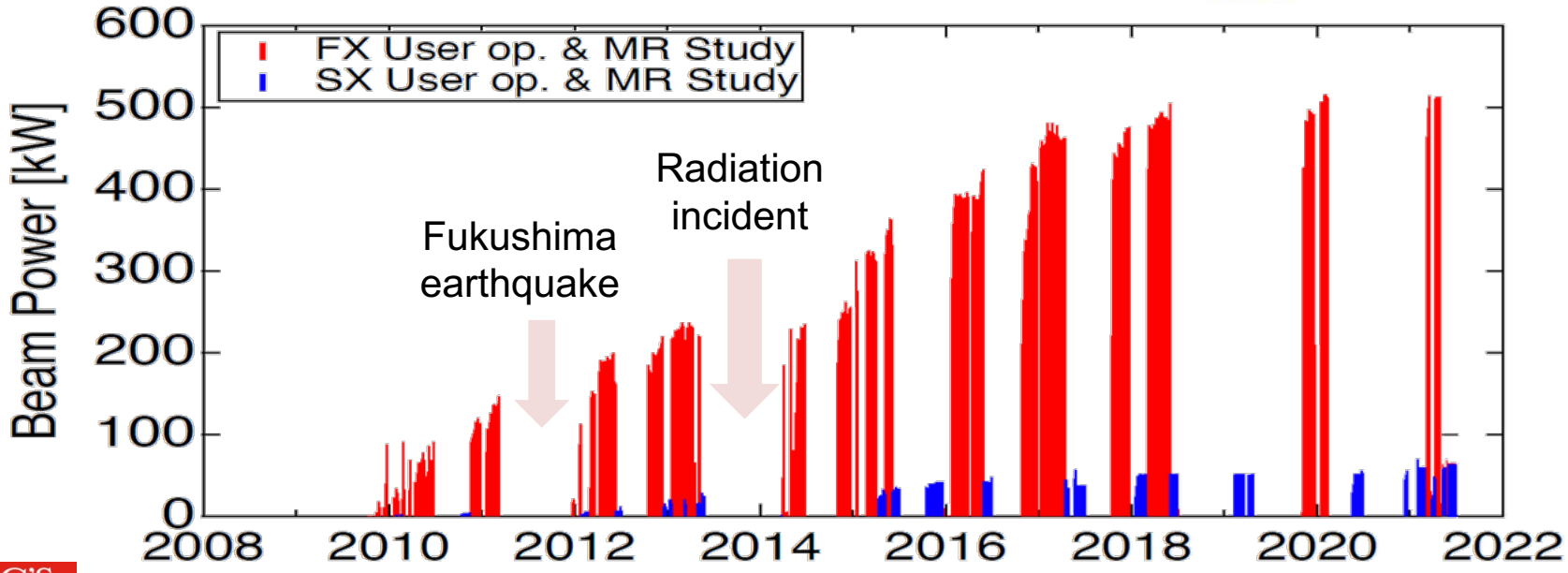




4. J-PARC Beam Upgrade

Key improvements
- Cycle 2.48s → 1.32s → 1.16s
- Proton per pulse 2.7E14ppp → 3.3E14ppp
- Power 515kW → 1.3MW



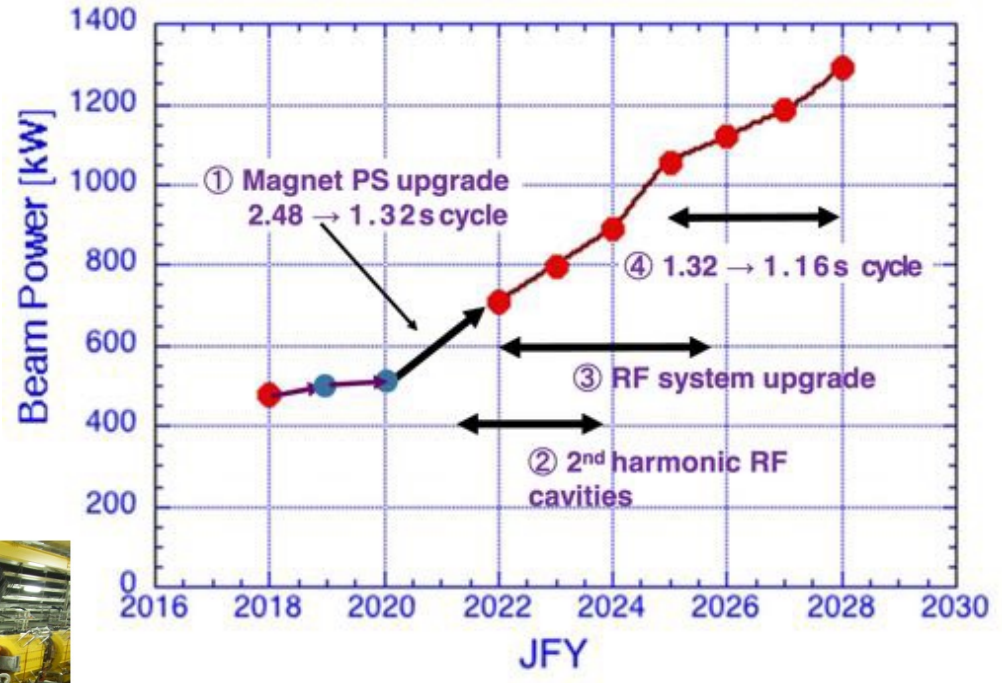


4. J-PARC Beam Upgrade

Key improvements

- Cycle 2.48s → 1.32s → 1.16s
- Proton per pulse 2.7E14ppp → 3.3E14ppp
- Power 515kW → 1.3MW

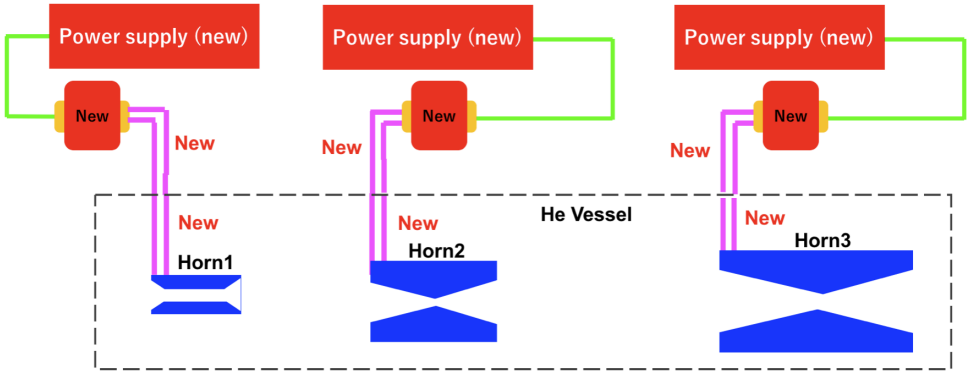
Horn current 250kA → 320kA
New power supplies
New RF cavities
New beam monitors
etc



capacitor bank

New RF cavity

New Wire Secondary Emission Monitor (WSEM)



1. Detector construction

2. Inner detector system

3. Outer detector system

4. J-PARC beam upgrade

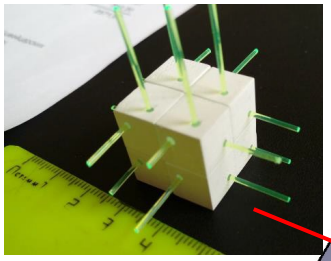
5. Near detectors

6. Conclusions

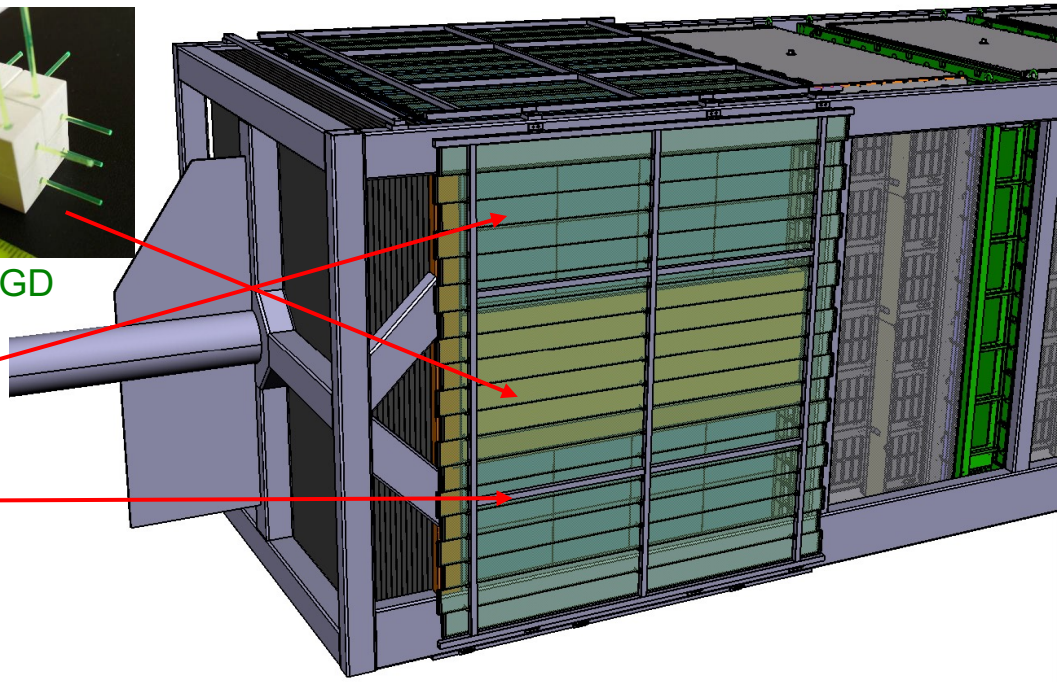
5. ND280 Upgrade

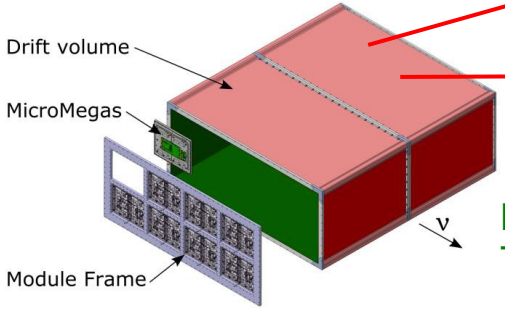
ND280 Upgrade

- Out: P0D detector
- In: High Angle TPC (HATPC)
- In: SuperFGD

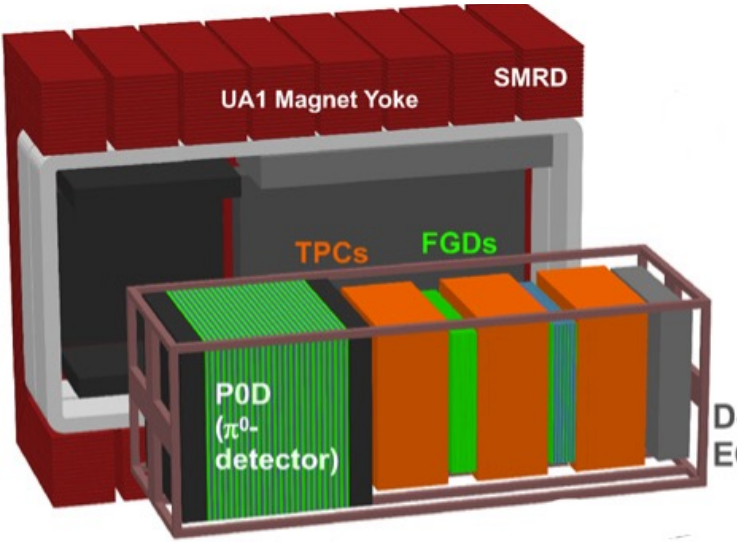


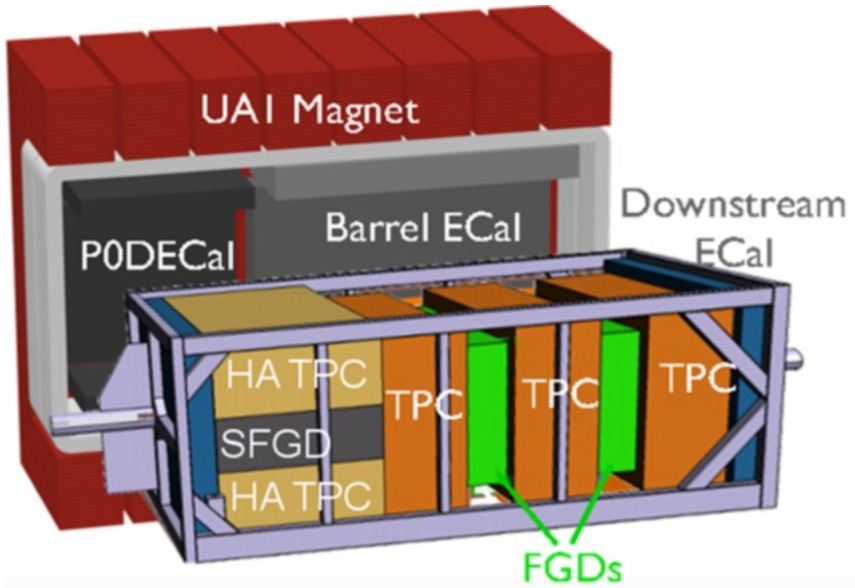
SuperFGD





High Angle TPC



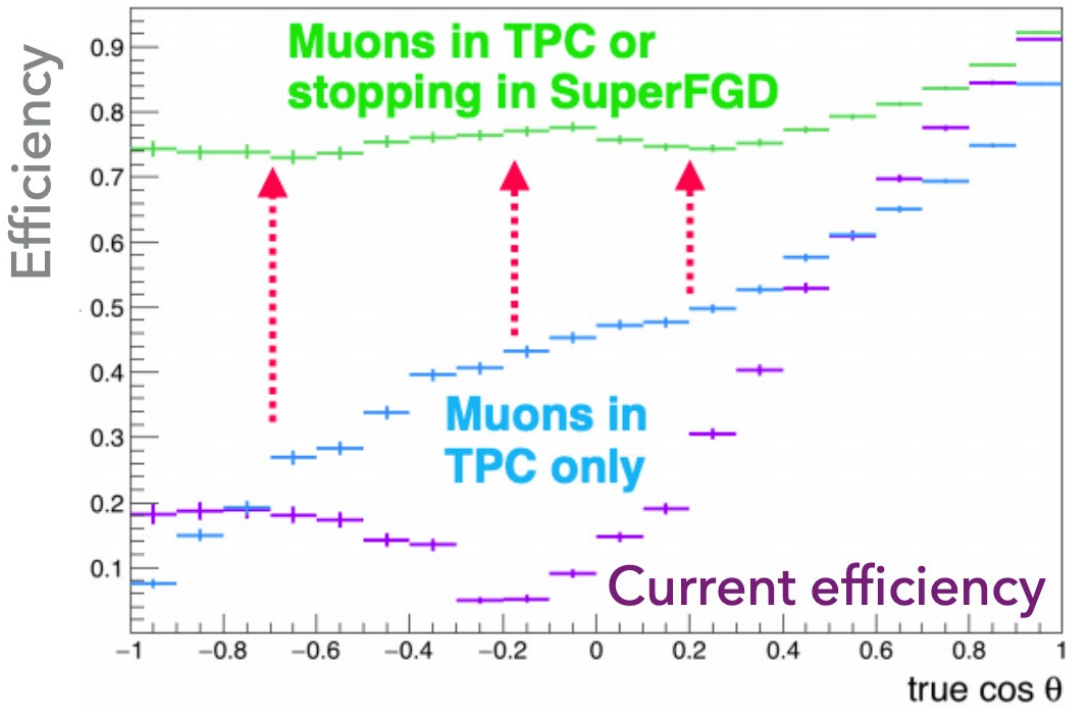


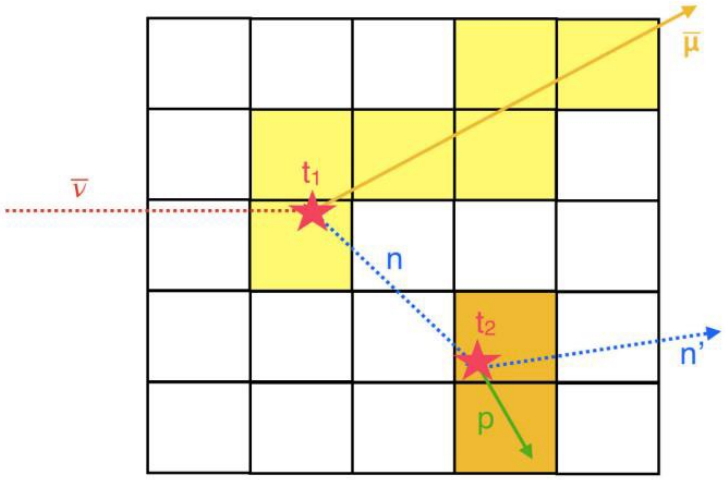
5. ND280 Upgrade

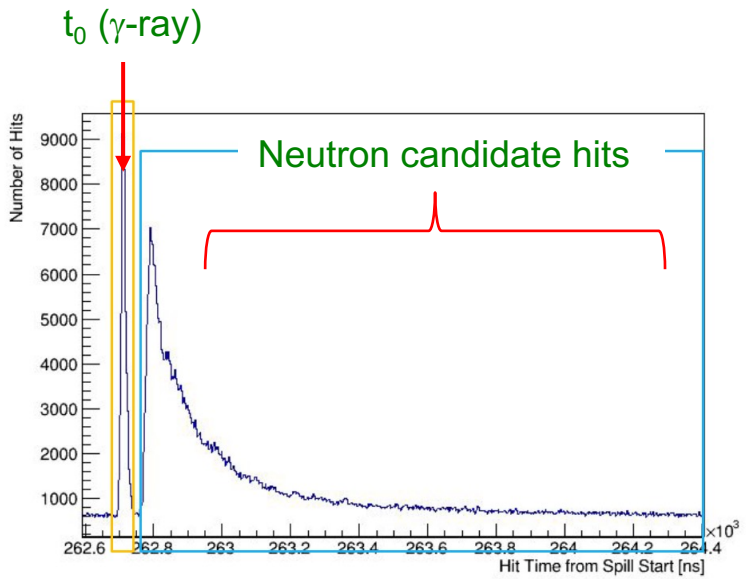
ND280 Upgrade
- Out: P0D detector
- In: High angle TPC (HATPC)
- In: SuperFGD

4π coverage
- It matches with Hyper-K phase space

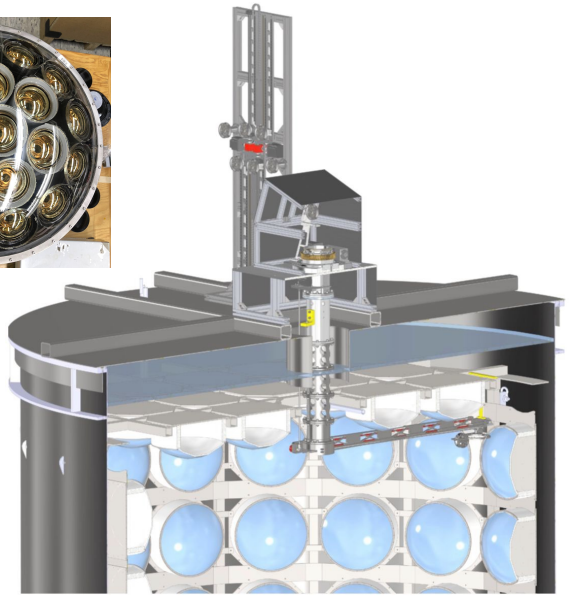
Neutron tagging
- SuperFGD beam test at LANL
- ToF to measure energy





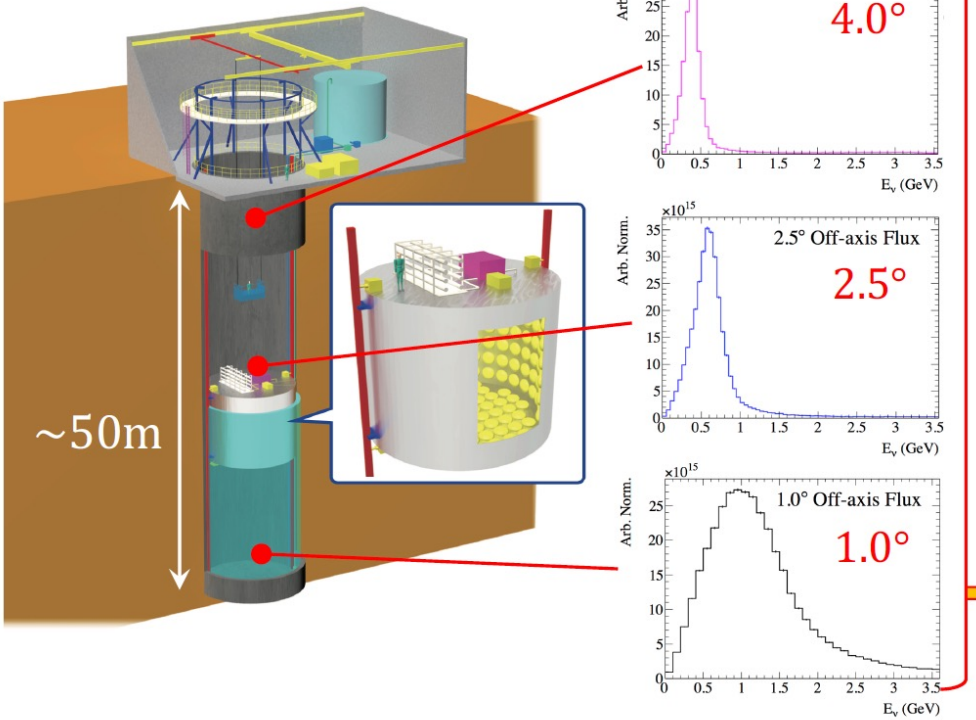


5. IWCD



Intermediate Water Cherenkov Detector

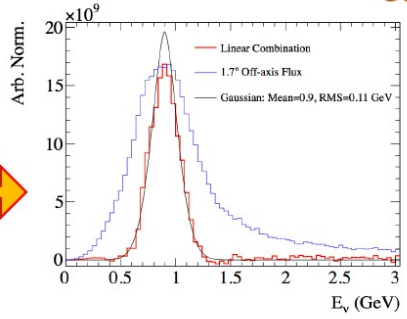
- nuPRISM concept, ~1km from the target
- mPMT units, driving force of HyperK machine learning effort
- Planned test beam at CERN



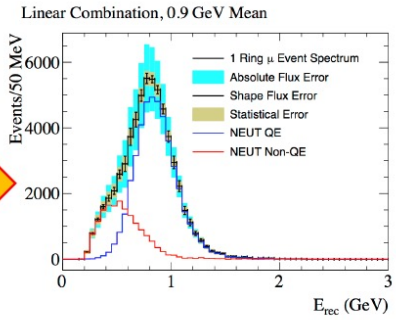
Physics target

- ν-int. measurement by off-axis scanning
- ν_e cross section (3-5% for $\sigma(\nu_e)/\sigma(\nu_\mu), \sigma(\overline{\nu}_e)/\sigma(\overline{\nu}_\mu)$
- NC and intrinsic ν_e BG measurement (3-4%)
- Neutron multiplicity with Gd loading

Linear sum to make monochromatic energy



Reconstruction



1. Detector construction

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HyperK sensitivities

... but the most exciting topic are “unknown unknowns”!

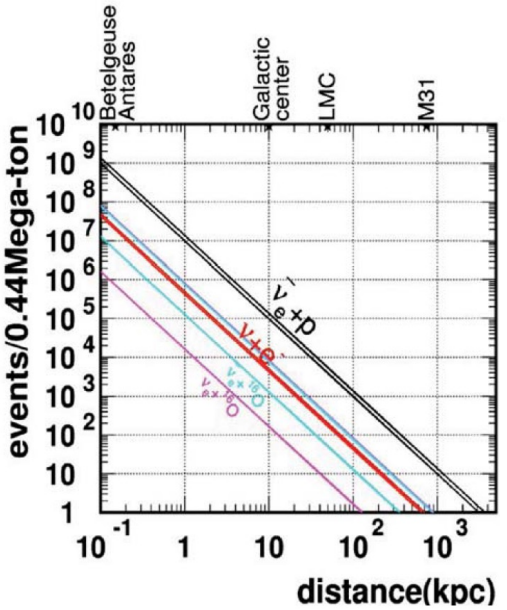
Core collapse supernova neutrinos
- Many events, potentially extra-galactic events

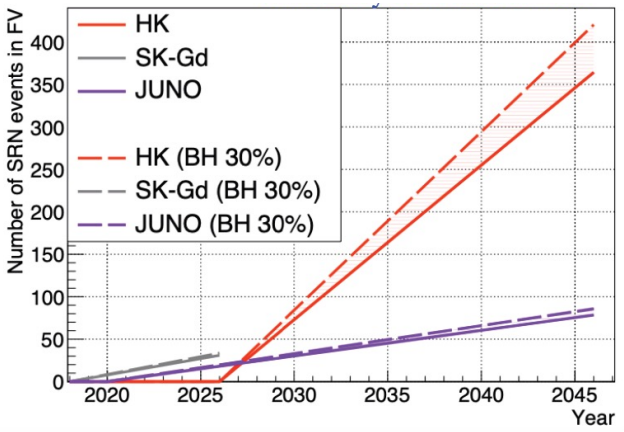
Diffused supernova neutrinos
- Many events

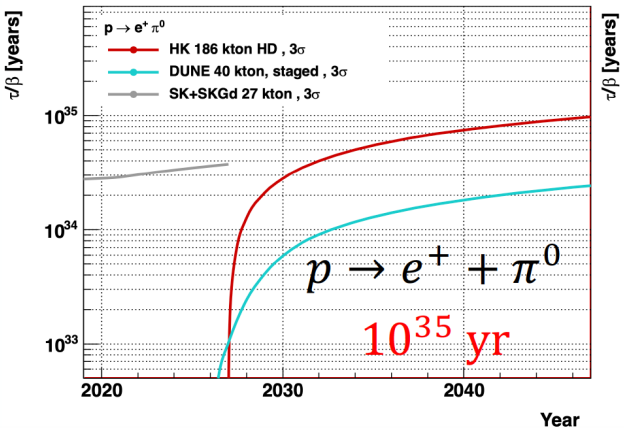
Proton decay
- Best sensitivity for main channels

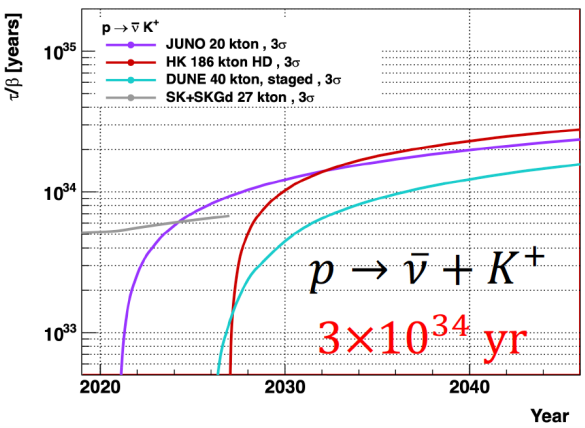
Oscillation physics
- CP violation
- Mass hierarchy
- Octant

2 example ideas for path forward to find physics of “unknown unknowns”









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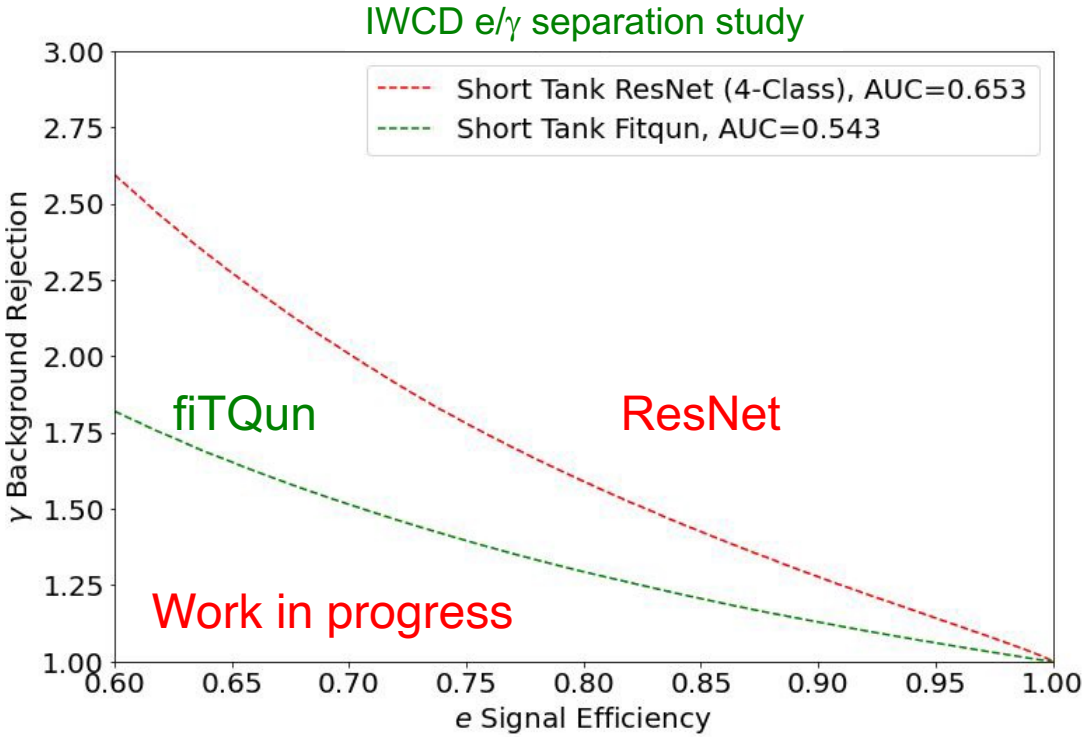
Path forward to unknown unknowns 1 - Machine Learning

WatChMaL
- International working group to develop Machine learning for water Cherenkov detector
- Kinematic reconstruction, particle identification
- Faster, higher background rejection, better resolution
- Suitable for mPMT reconstruction

fiTQun
- Likelihood based (LSND→MiniBooNE→SuperK)
- T2K analysis main tool
- ~1 event/few min (CPU)

ResNet
- ~100,000 events reconstruction/min (GPU)



PointNet, ArXiv:1612.00593

WatChMaL.org

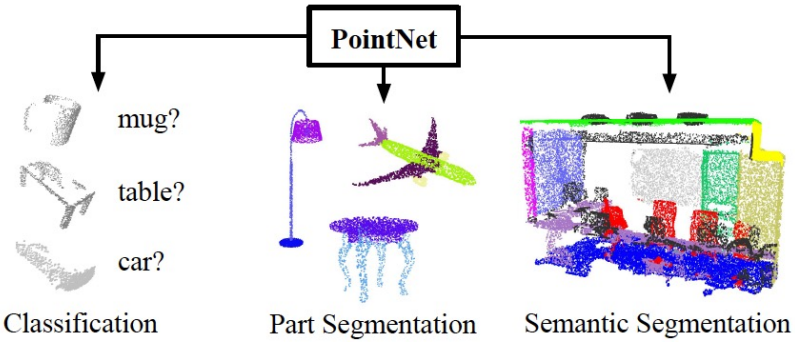
Path forward to unknown unknowns 1 - Machine Learning

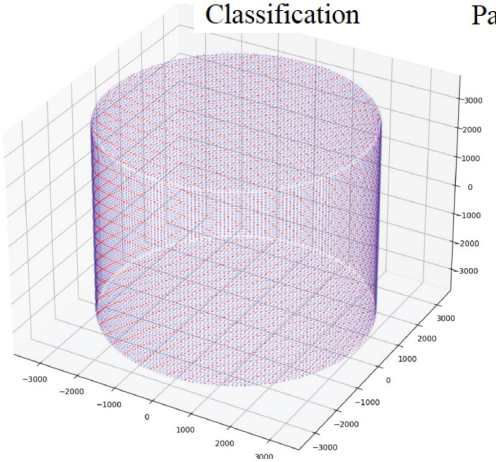
PointNet
- 3D point cloud (PMT charge, time, location)
- Suitable for water Cherenkov detector

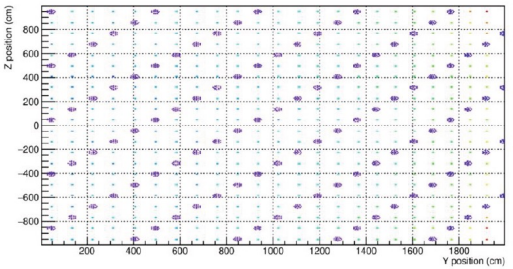
Simple geometry to prove performance
- e/μ separation
- e/π^o separation
- e/γ separation

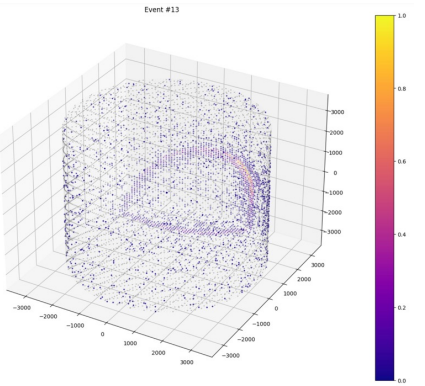
e, μ, π^o, γ simulation
- Uniform, isotropic
- [0,1GeV] above Cherenkov threshold

PointNet outperform fiTQun
- B&L PMTs only, need mPMTs info
- Need to use a realistic geometry
- Kinematic reconstruction

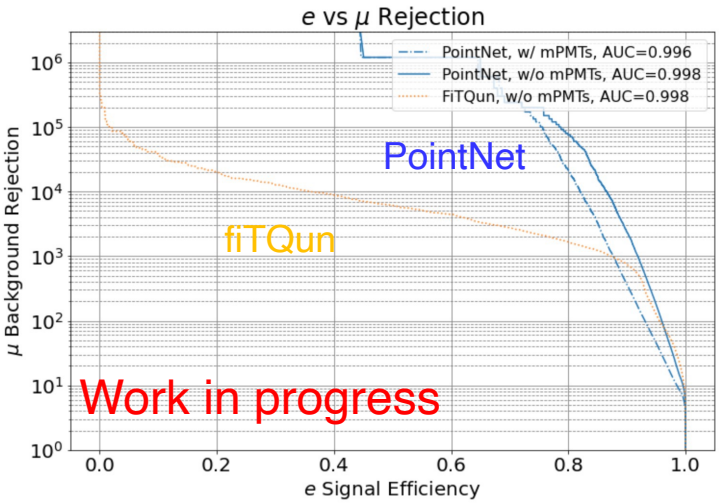








Teppei Katori



Joanna Gao

KING'S College LONDON

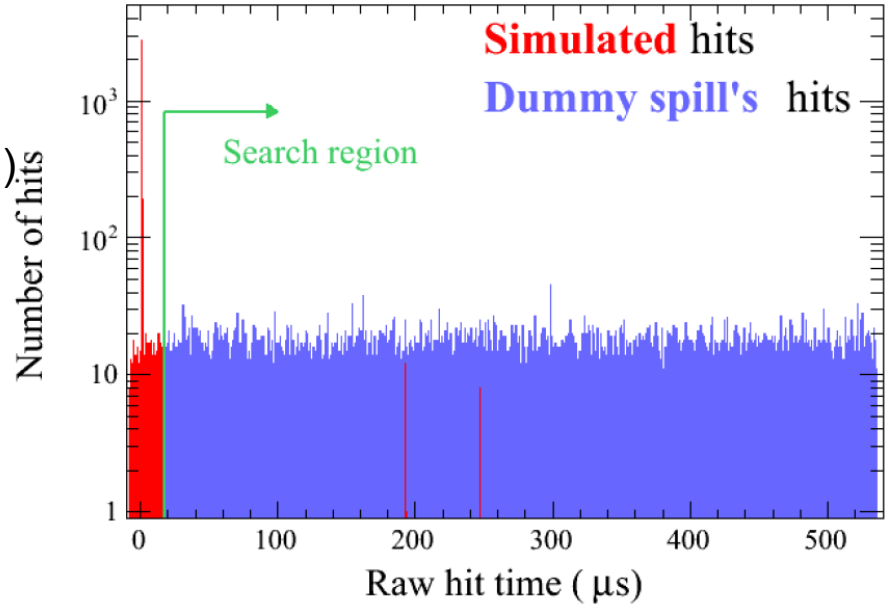
Akutsu, PhD thesis, U. Tokyo (2019)

Path forward to unknown unknowns 2 - Neutron tagging

Neutron tagging

- Supernova neutrinos, reactor neutrinos
- SK-Gd has ~50% tagging efficiency now (0.01%)
- 17% tagging efficiency in water fiducial volume

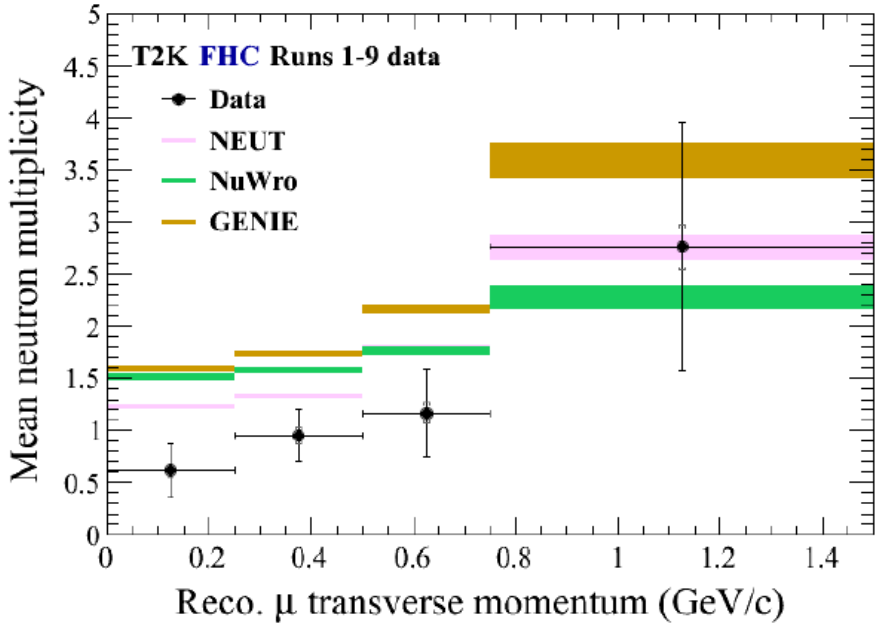
$n+p \rightarrow d+\gamma$ (2.2 MeV)

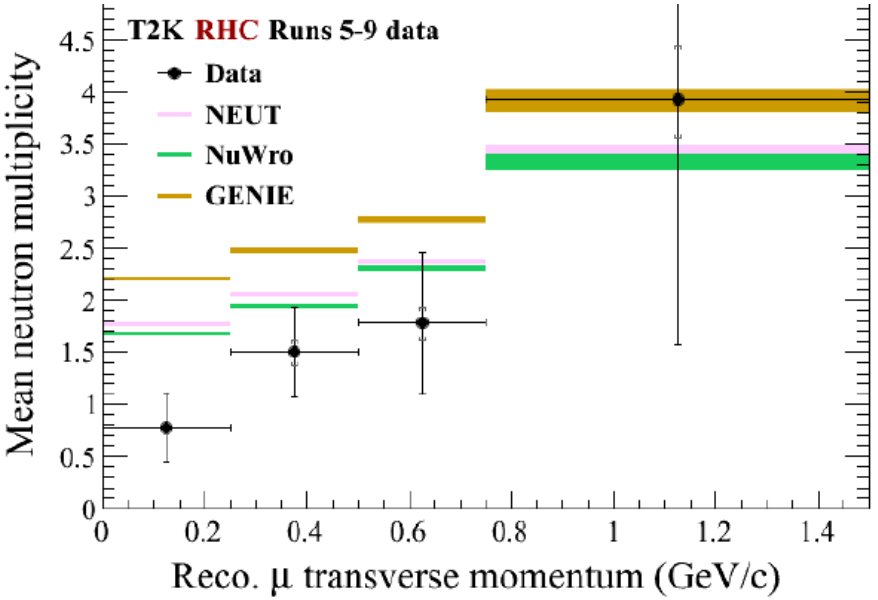


Multiplicity is not understood

- Primary interaction, FSI, Neutron propagation

CC beam-neutrino-induced neutron multiplicity





Path forward to unknown unknowns 2 - Neutron tagging

Neutron tagging for everything!

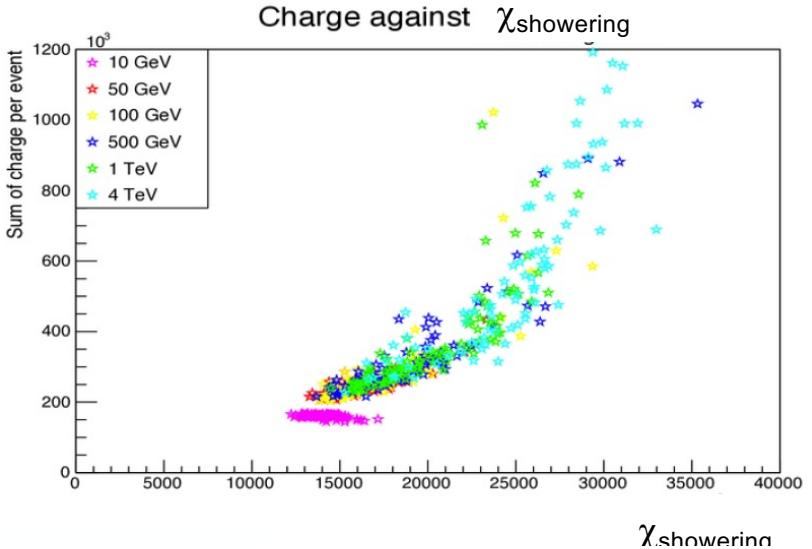
- PID, channel separation, kinematic reconstruction
- Input parameter for machine learning

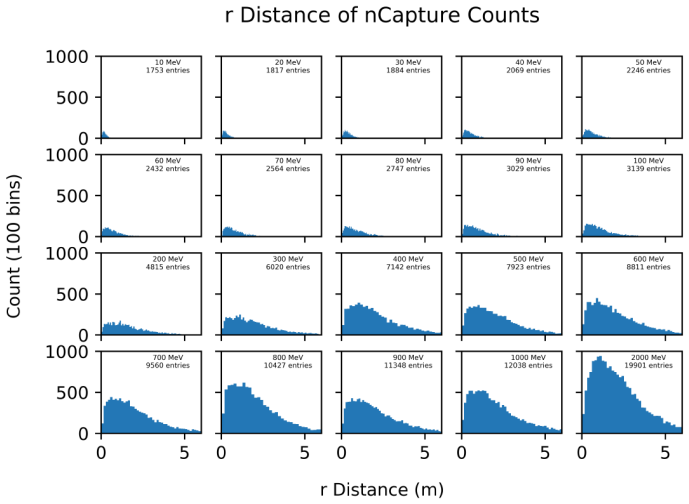
TeV neutrino factory

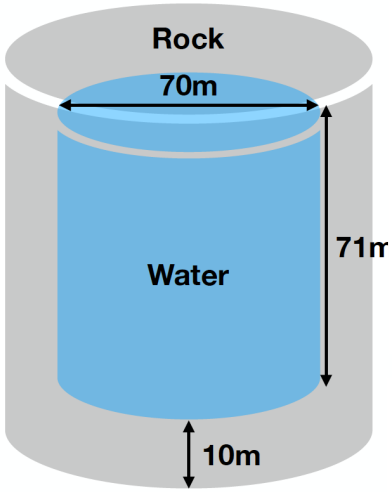
- SuperK observed ~1000 upmu from TeV neutrinos
- TeV neutrino kinematic reconstruction with neutrons

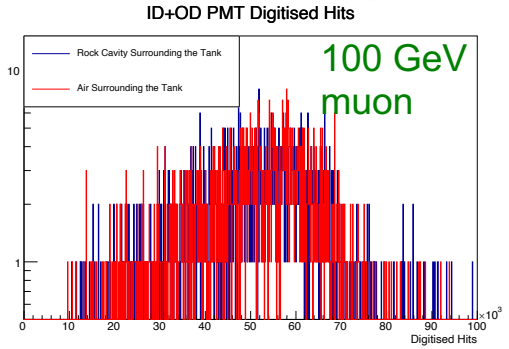
Boosted Dark Matter, proton decay, etc

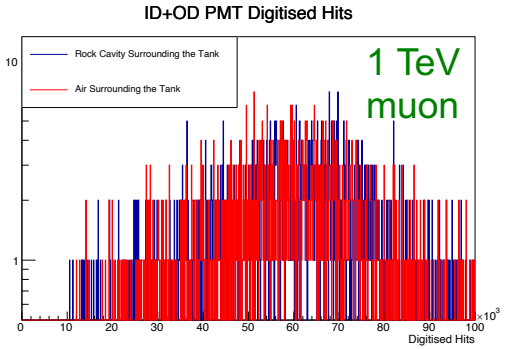
- So many unexplored new channels











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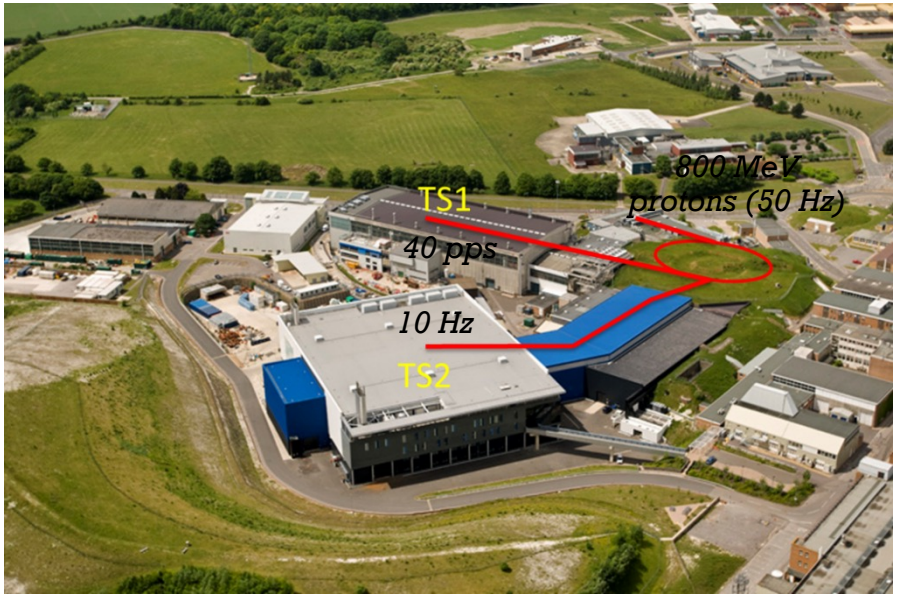
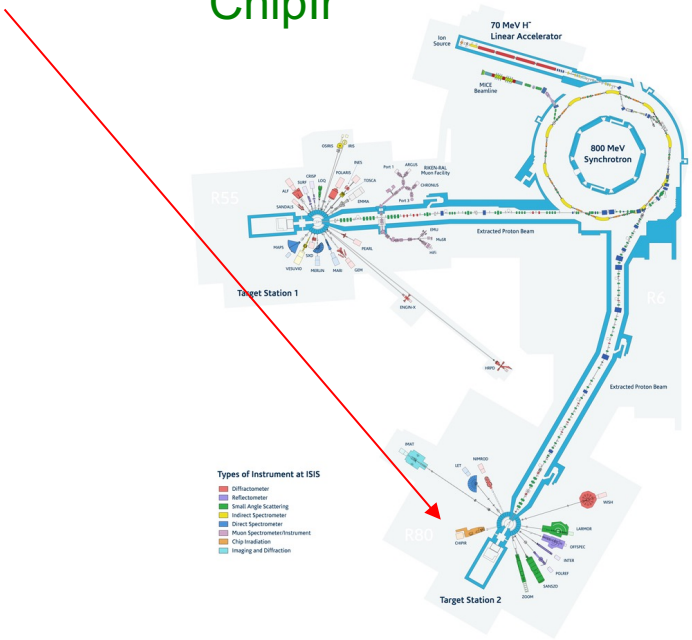
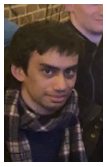
Neutron cross-section measurements

ISIS neutron source at Rutherford Appleton Laboratory
- Target station 2, ChipIr (Carlo Cazzaniga)
- up to several hundreds MeV



ChipIr





Nahid

Meurisse et al, Radiation Measurements 132 (2020) 106247
Chiesa et al., NIMA 902 (2018) 14–24

Neutron cross-section measurements

ISIS neutron source at Rutherford Appleton Laboratory
- Target station 2, ChipIr (Carlo Cazzaniga)
- up to several hundreds MeV

We started experiment set up. Beam test will be in 2024 to measure neutron-water cross-sections above 10 MeV. (including exclusive inelastic channels)

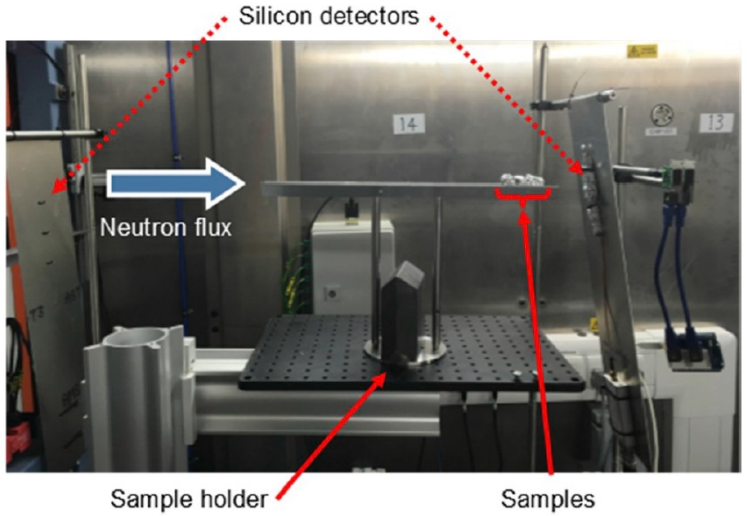
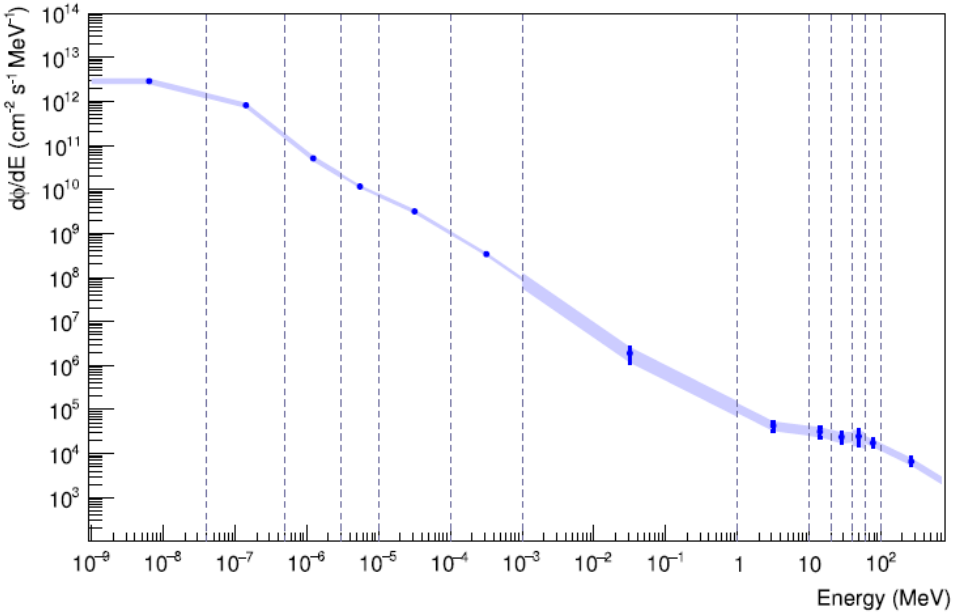
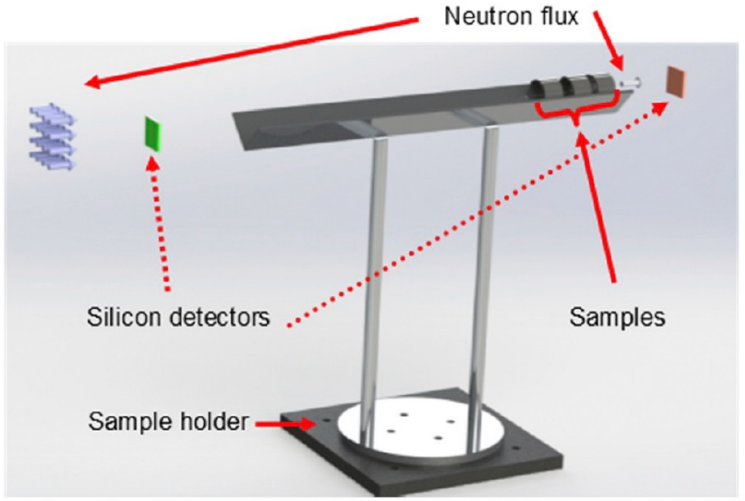
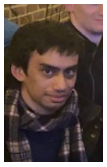


Fig. 2. Experimental setup inside the CHIP-IR facility.







Nahid

King's College London
Experimental Particle and Astroparticle Physics group (Est. 2019)

Hyper-Kamiokande/Super-Kamiokande/T2K
- 3 faculties, 1 fellow, 3 postdocs, 6 students

SNO+
- 2 faculties, 2 students

IceCube
- 1 faculty, 1 student

LZ (new!)

Francesca Di Lodovico
HyperK co-spokespersons

Jeanne Wilson
HyperK OD leader

We work on many aspects of HyperK detector
- OD design (hardware, software)
- DAQ
- Testing,
- Core software

etc

"We" work on many aspects, not you, Teppei

Conclusion

HyperK construction is on the right track

Growing collaborations (~500 people, ~100 institutions, ~20 countries)

There is no “red carpet”, the project include risks and challenges, but we try to solve one by one

There are many guaranteed physics, but most exciting topics are “unknown unknowns”

Hyper-Kamiokande collaboration (Feb. 2020)

Thank you for your attention!
Join us!

Backup

Reference

Overview
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Beam
“The J-PARC Neutrino Beam and Upgrades”, Megan Friend (NuFact2021)
https://indico.cern.ch/event/855372/contributions/4366134/
“New Proton Beam Monitors for the J-PARC Neutrino Beamline”, Megan Friend (NuFact2021)
https://indico.cern.ch/event/855372/contributions/4449132/

Near detector
“Intermediate water Cherenkov detector for the Hyper-Kamiokande experiment”, Ryosuke Akutsu (NuFact2021)
https://indico.cern.ch/event/855372/contributions/4441604/
“The T2K Near Detector Upgrade”, Martin Tzanov (NuFact2021)
https://indico.cern.ch/event/855372/contributions/4448809/

SuperK, ArXiv:2112.00092

Neutron tagging

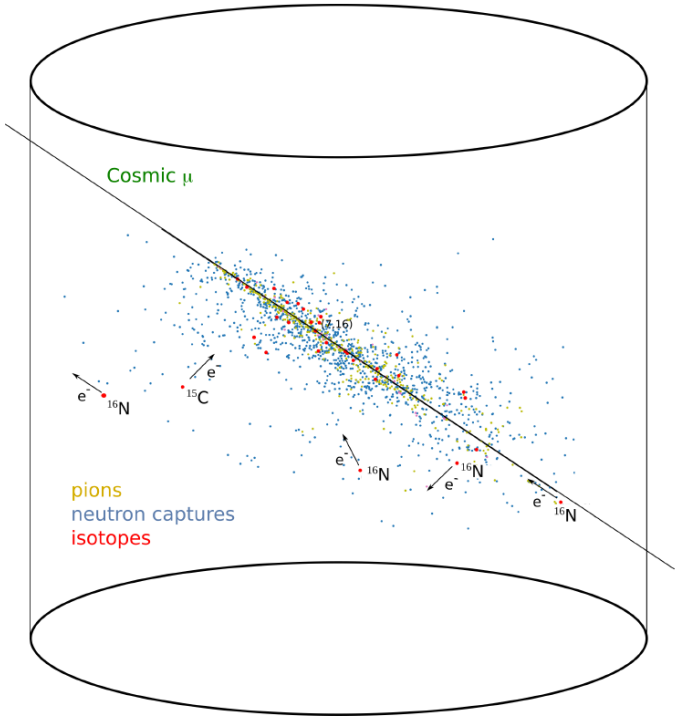
Neutron tagging

- Supernova neutrinos, reactor neutrinos
- Reasonable efficiency with water (10-20%)

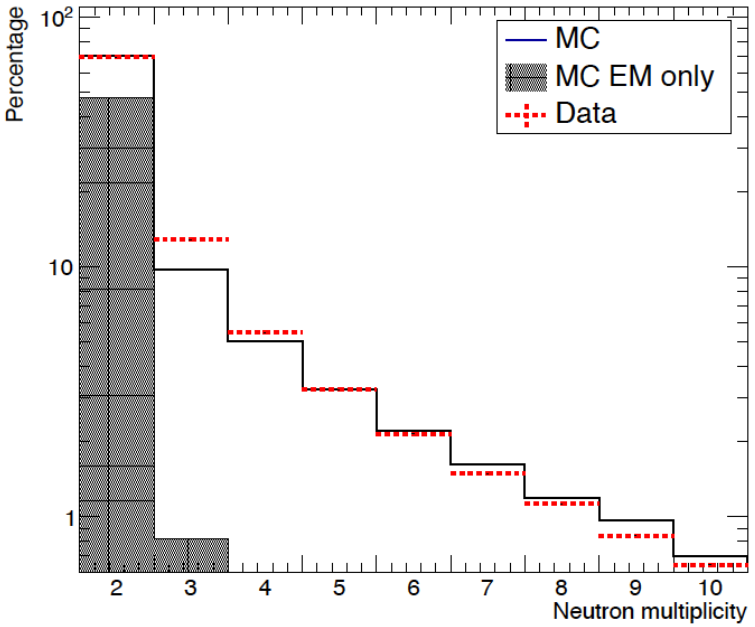
$n+p \rightarrow d+\gamma$ (2.2 MeV)

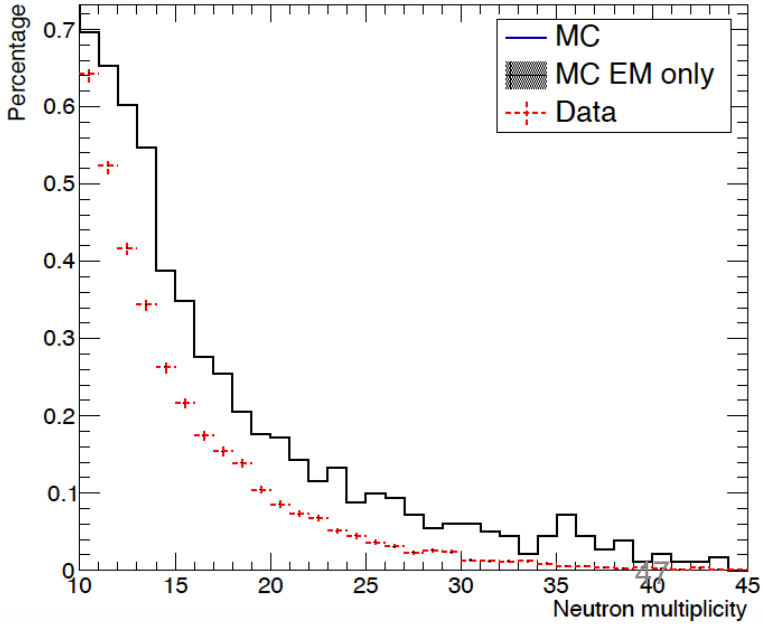
Spallation neutron multiplicity is not understood

- low multiplicity: low efficiency, fake signal
- high multiplicity: FLUKA problem



Spallation neutron multiplicity





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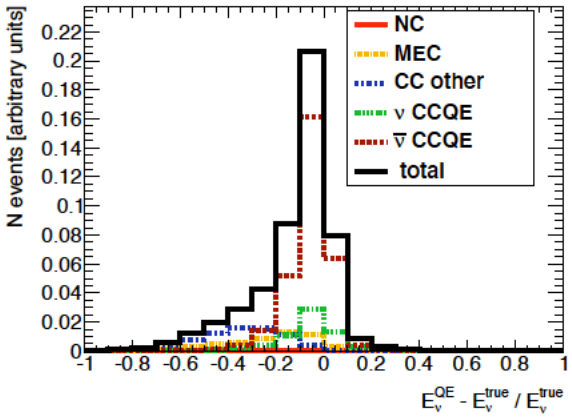
Neutron tagging

Neutron tagging

- Statistically separate signal and background
- Channel identification

nubarCCQE



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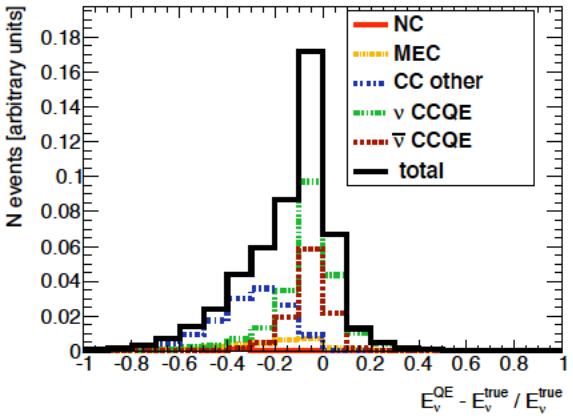

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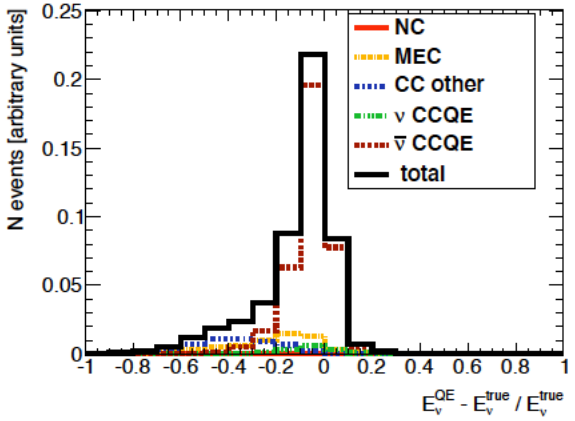
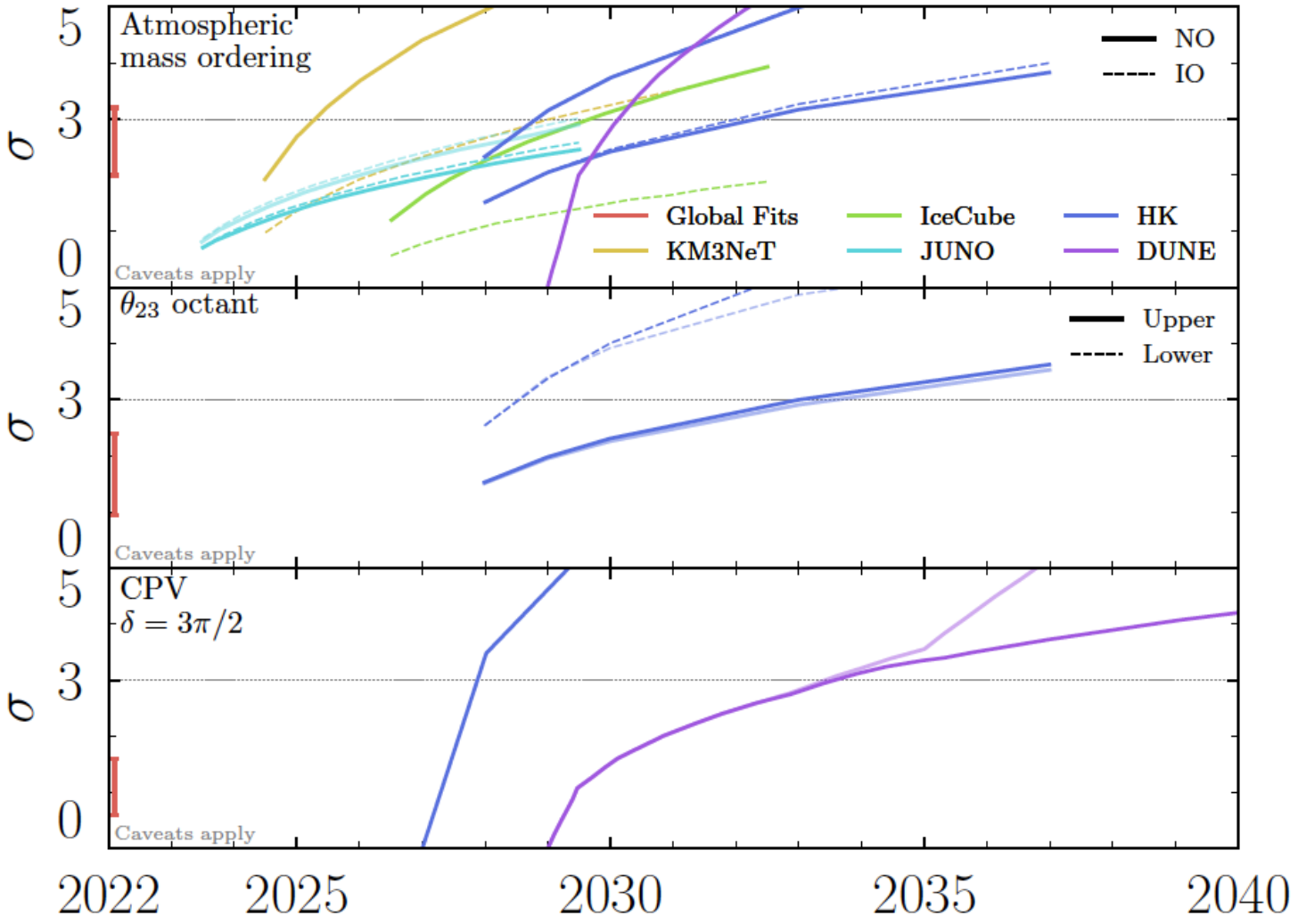


HyperK sensitivities

Oscillation physics
- CP violation
- Mass hierarchy
- Octant