Underground Laboratories in Asia

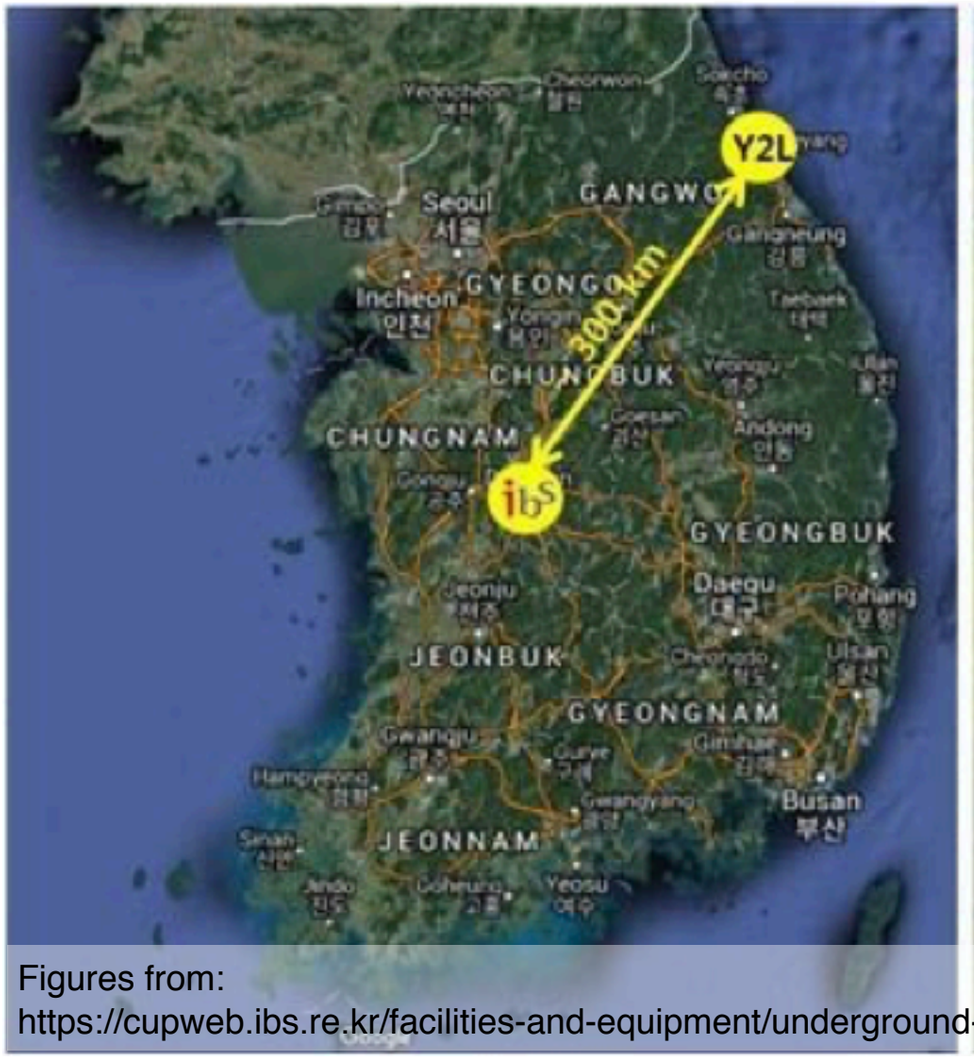
Hide-Kazu TANAKA
(ICRR, University of Tokyo)

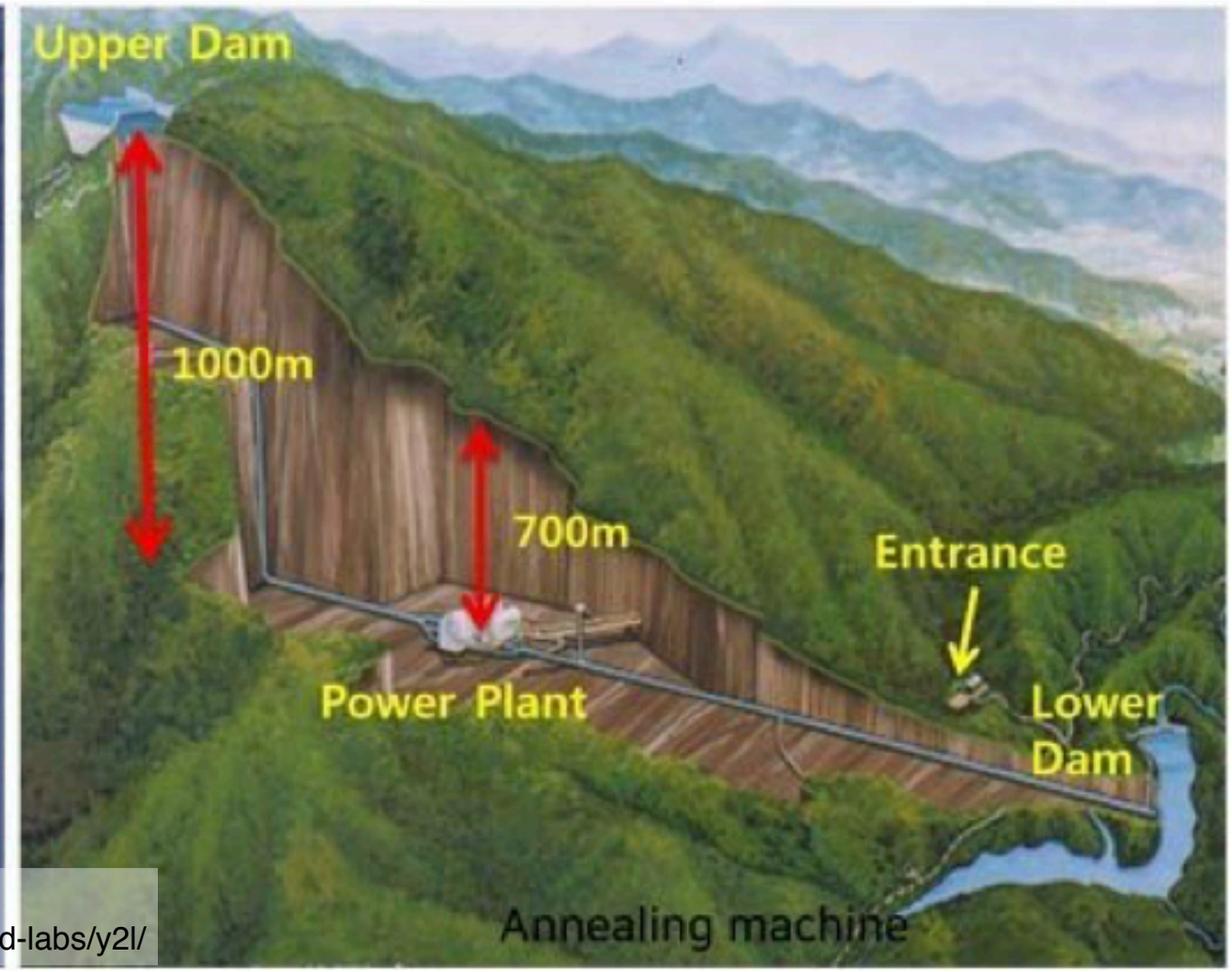
NNN2019 at Medellin, November 9, 2019

Underground labs in Asia

- Yangyang (Korea), Jinping (China), INO (India), Kamioka (Japan)
- Sorry, Daya Bay, RENO, JUNO and some others are not covered in this talk

Yangyang Underground Laboratory (Y2L)



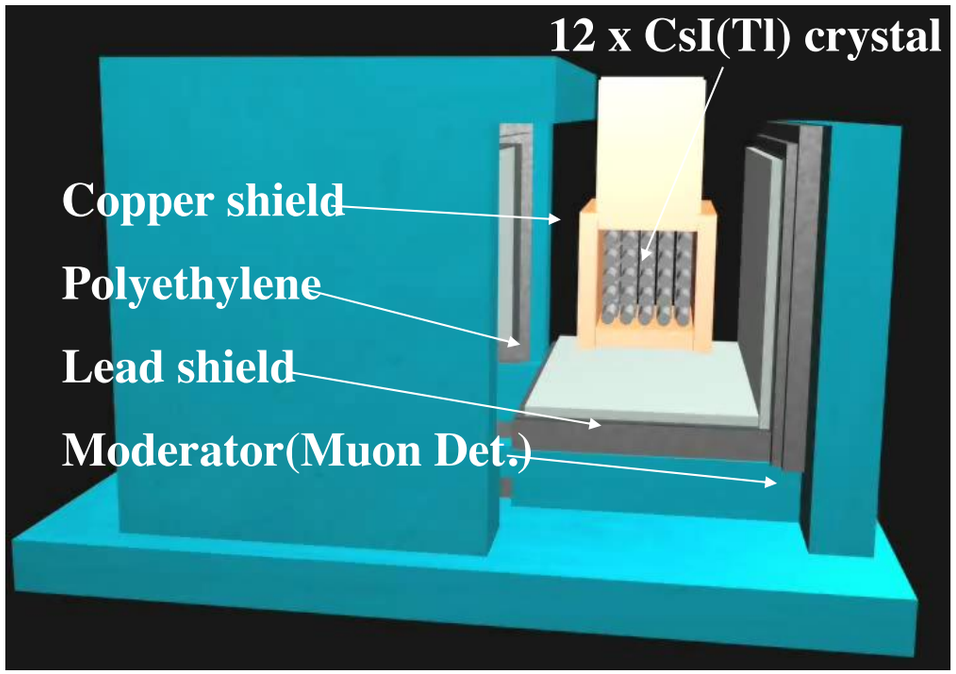


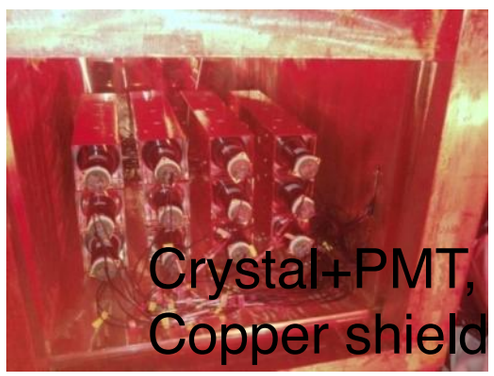
Figures from:
https://cupweb.ibs.re.kr/facilities-and-equipment/underground-labs/y2l/

- Y2L locates in a tunnel of Yangyang Pumped Storage Power Plant
- Minimum vertical depth: 700m
- Access to the lab by car via ~2km long horizontal tunnel
- Experiments:
  - KIMS: Dark matter search with CsI(Tl) crystals
  - AMoRE: 0νββ decay search with CaMoO4 crystals
  - COSINE: Dark matter search with NaI(Tl) crystals

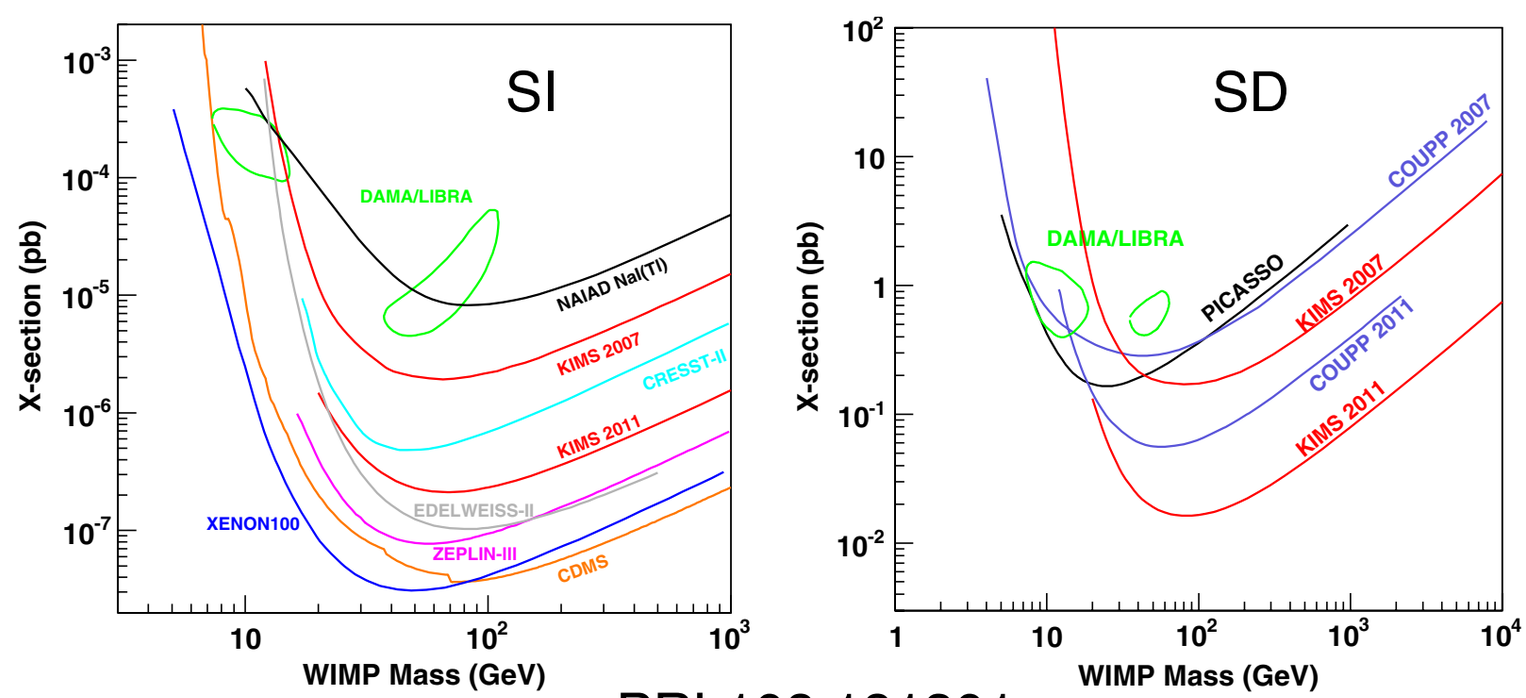
KIMS

(KIMS: Korean Invisible Mass Search)



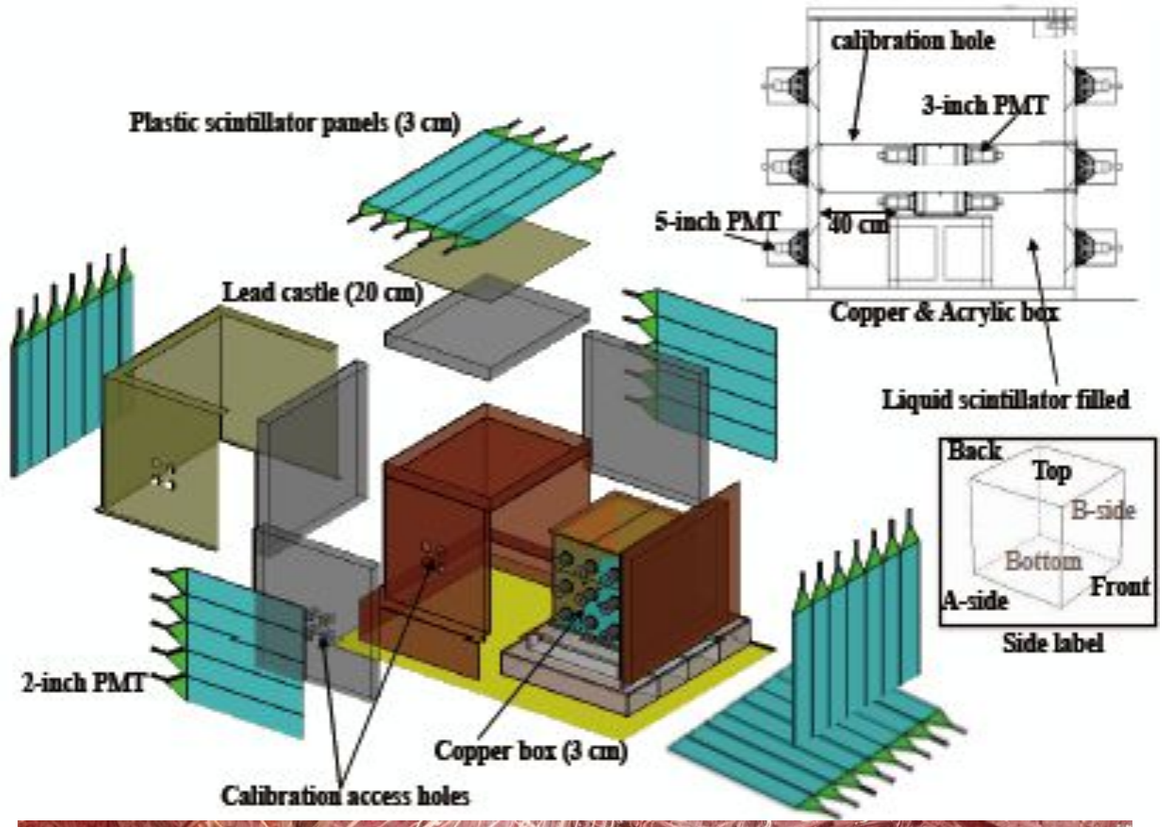


- Dark matter search with CsI(Tl) crystal
  - 12 crystals (104.4kg)
    - 8×8×30cm^3 (8.7kg) crystal w/ 3” PMTs
- Updated results: PRL 108 181301 (2012)
  - 2.5 years data (2009 - 2012)

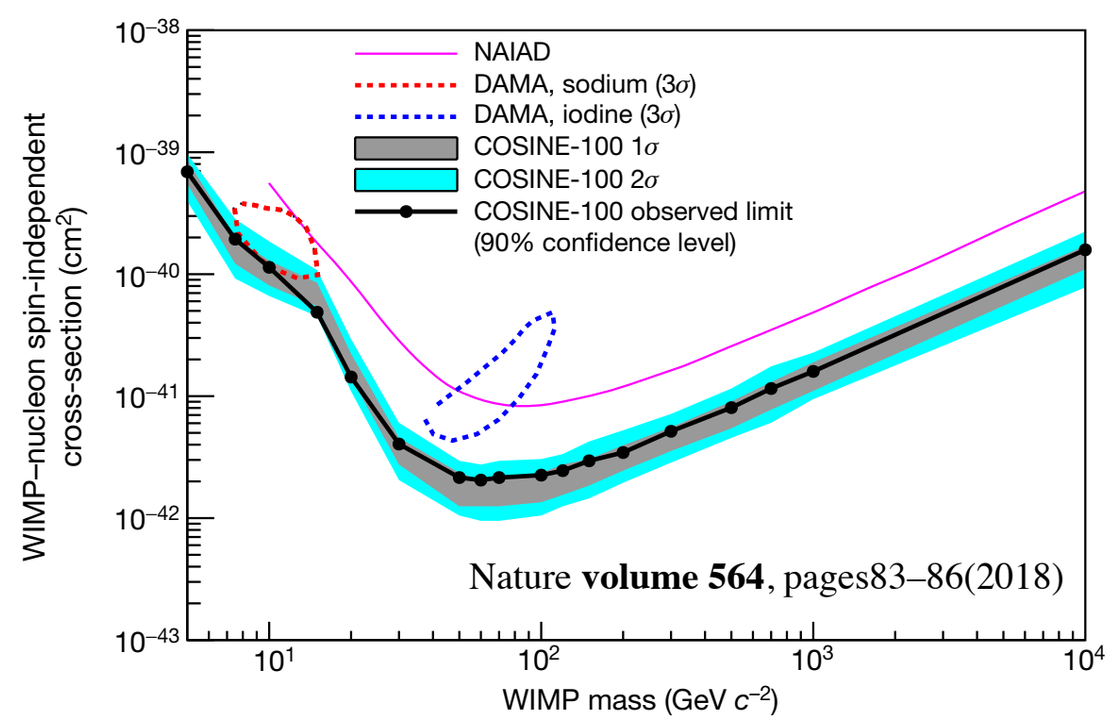


PRL108,181301

COSINE



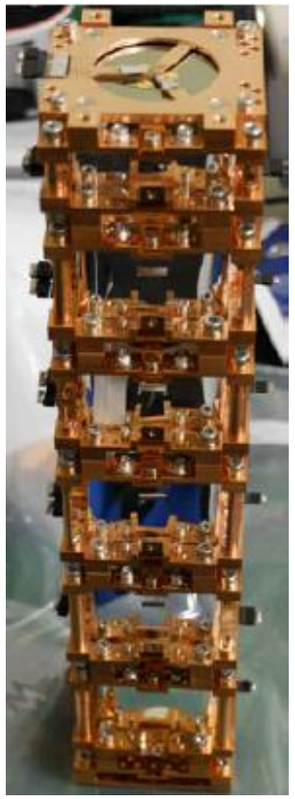
- Dark matter search with NaI(Tl) crystals
  - Aim to verify DAMA/LIBRA results
  - Annual modulation
- COSINE-100
  - NaI crystal 4×2 array with total mass 106kg
  - Operation 2016~
  - Nature 564, 83-86 (2018)
- COSINE-200 (200kg) prep. on-going

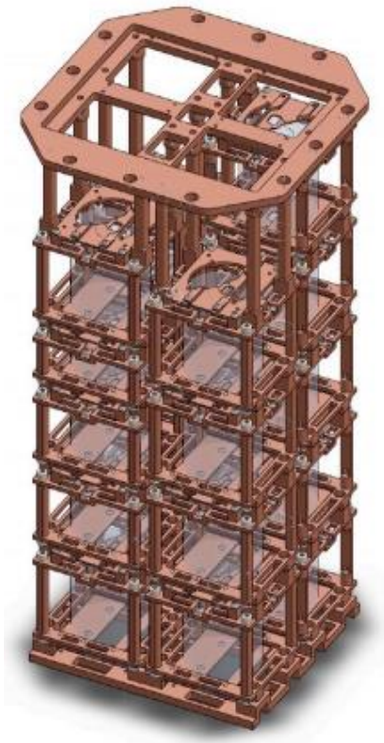


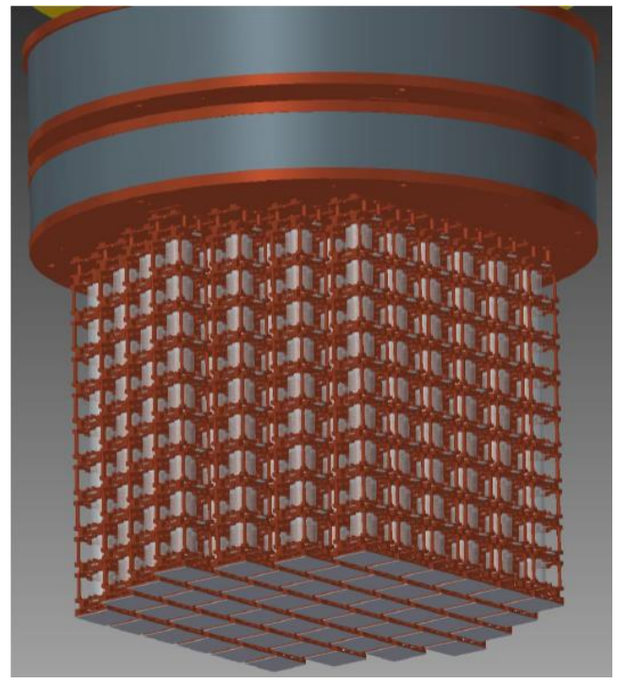
Figure/photo from Hyun Su Lee @DBD2018

AMoRE

(AMoRE: Advanced Mo-based Rare process Experiment)







- ββ experiment with CaMoO4 crystal (Mo enriched)
- AMoRE-pilot experiment (1.9kg) is running
  - EPJ C(2019) 79:791
  - $T^{0\nu}_{1/2} > 9.5\times10^{22}$ y (90%CL)
  - $m_{\beta\beta} < 1.2 - 2.1$eV
- AMoRE-I prep. on-going

	AMoRE-Pilot	AMoRE-I	AMoRE-II
Mass [kg]	1.9	~6.1	~200
Channels	12	36	~1000
BKG goal [ckky]	0.01	0.001	0.0001
Sensitivity [year]	$\sim10^{24}$	$\sim10^{25}$	$\sim5\times10^{26}$
Sensitivity [meV]	380 to 640	120 to 200	17 to 29
Location	Y2L	Y2L	Yemilab
schedule	2017 to 2018	2019~	2021~

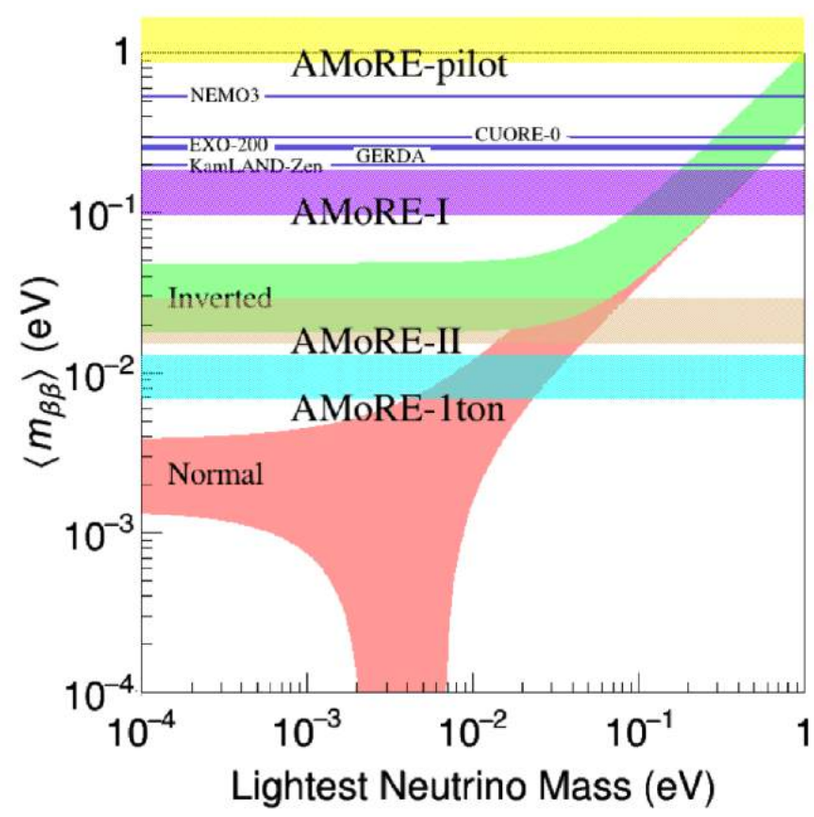
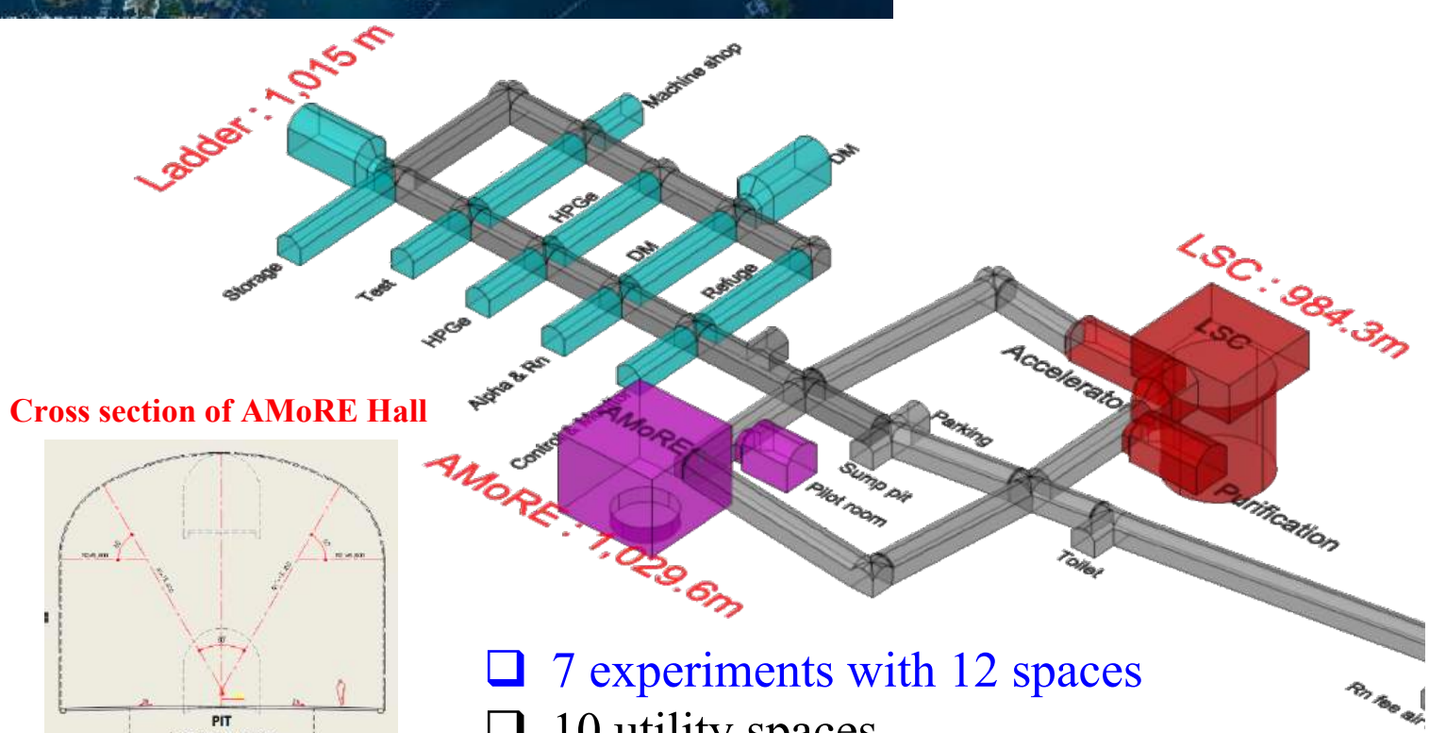


Figure and table from Kyungmin Seo at TAUP2019

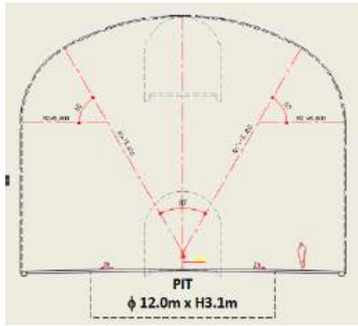
Yemilab: A new underground lab in Korea

Figures from Moo-Hyun Lee at TAUP2019

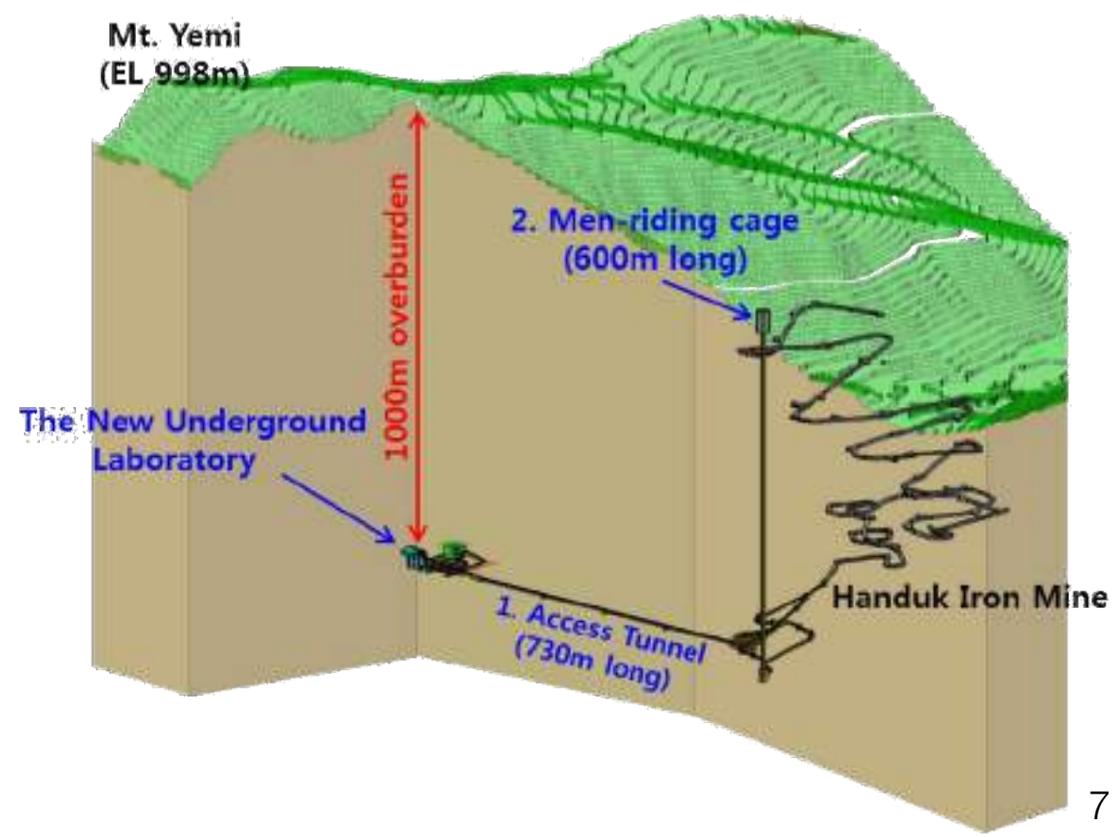
- Yemilab in Handeok mine (iron mine)
- Started tunnel excavation for the lab and completed in middle of 2020
- ~1000m overburden at the lab
- AMoRE-II will be located in Yemilab



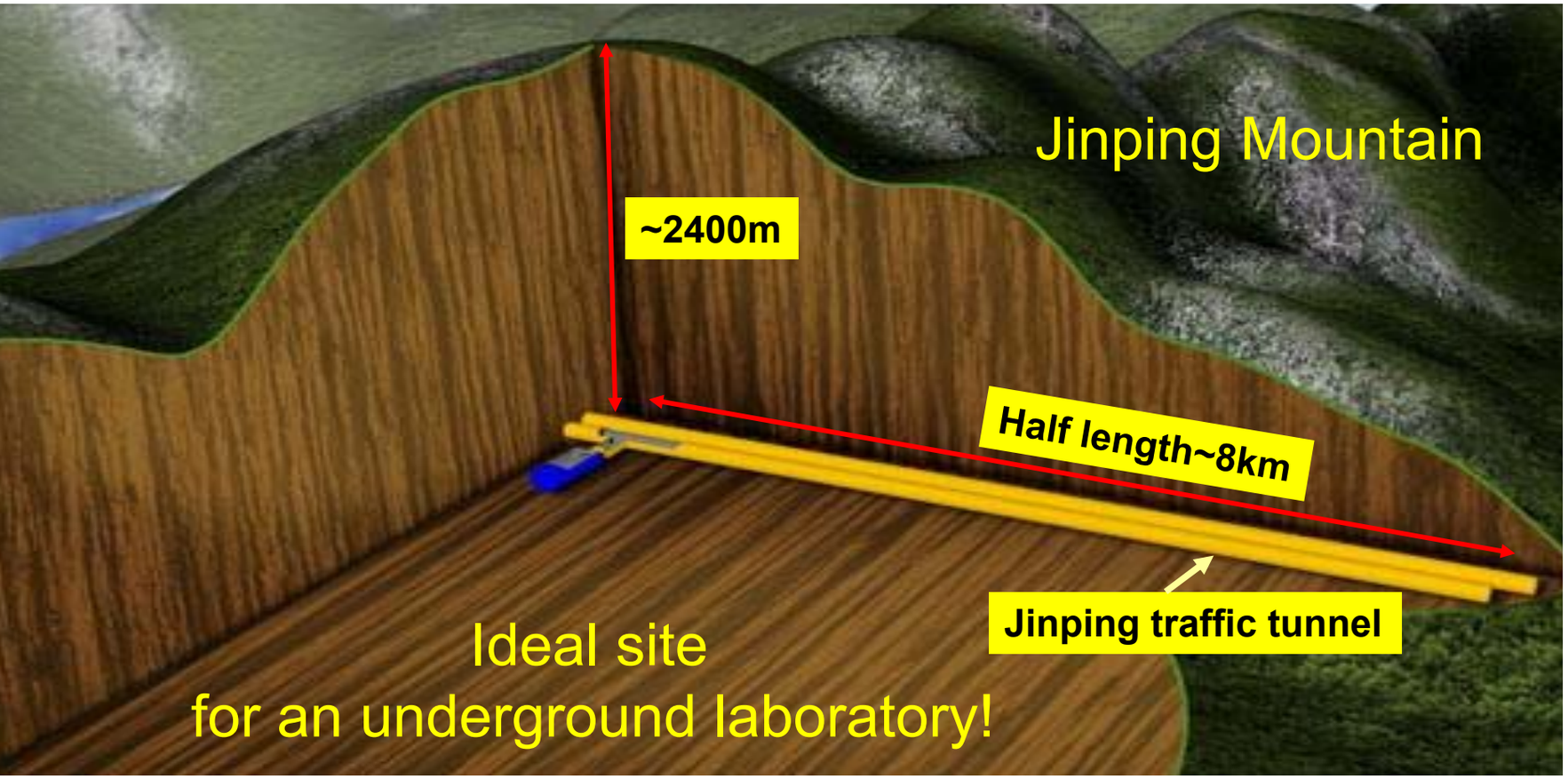
Cross section of AMoRE Hall

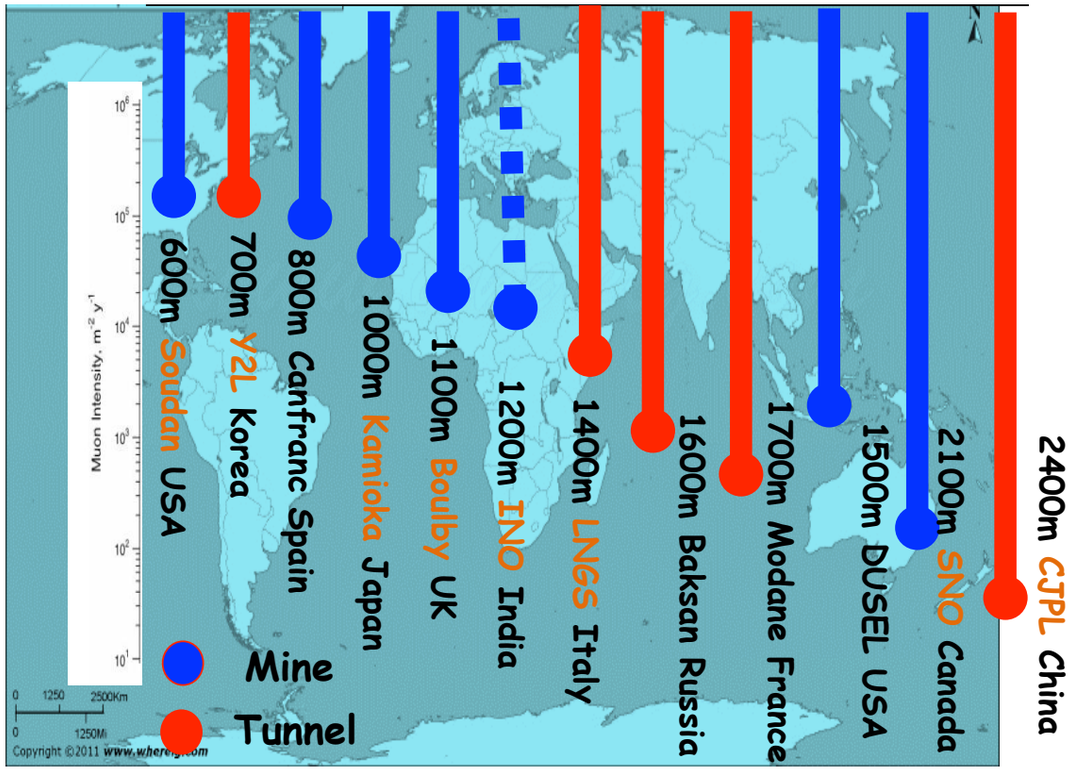


- ❑ 7 experiments with 12 spaces
- ❑ 10 utility spaces



China Jinping Underground Laboratory (CJPL)





- Jinping Hydropower Station
- Mountain peak: 4193m
- Maximum rock overburden: ~2400m (6720 m.w.e)
- Drive-in road tunnel access (tunnel length 17.5km)
- Experiments: **CDEX** (low-mass WIMP 1-5GeV), **PandaX** (high-mass WIMP >5GeV)

CDEX

(CDEX: China Dark matter Experiment)

Dark matter search with germanium detector

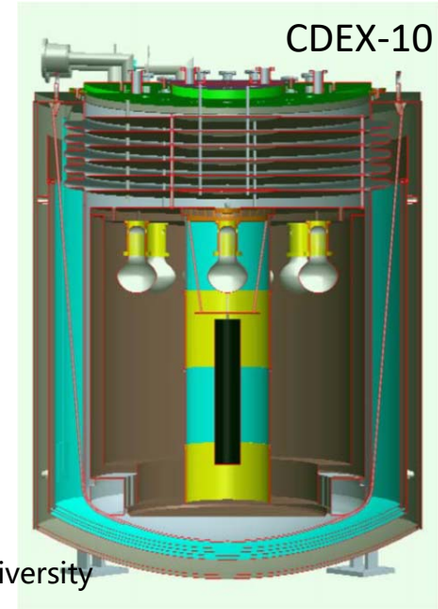
Slide/figure from Hao Ma (May 2017)

- CDEX-1: Development of HPGe detector, its background understanding and the studies of its performances based on 1kg-scale-mass HPGe detector.

Energy threshold：

CDEX-1: 400eV → CDEX-10: <300eV;

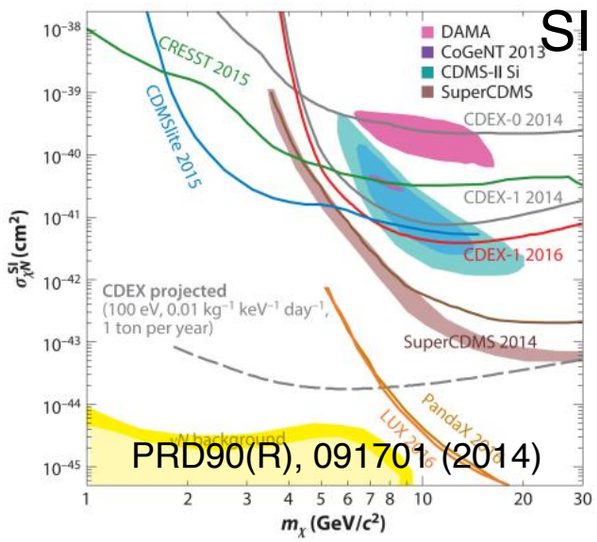
- CDEX-10: Performances of HPGe array detector system and its passive/active shielding systems.
- CDEX-10X: Fabrication of HPGe detector and Germanium crystal growth by CDEX.



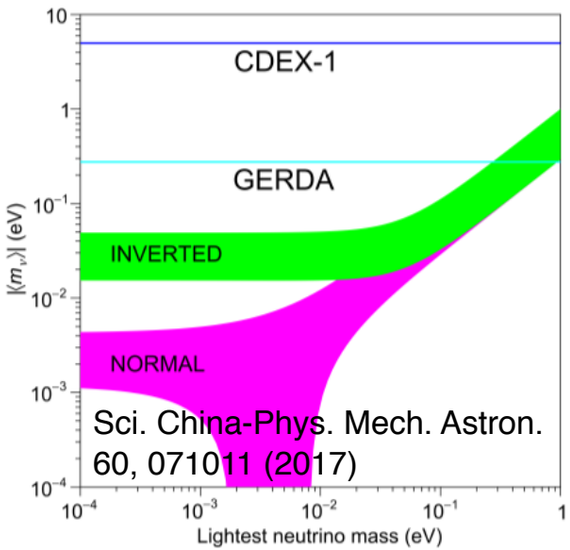
CJPL

LRT 2017 @ Ewha Woman's University

- CDEX-1 currently running:
  - Physics results on WIMP DM, Axion DM, 0νββ (^{76}Ge)
- CDEX-10: a prototype toward CDEX-1T at CJPL-II (see later slides)



PRD90(R), 091701 (2014)

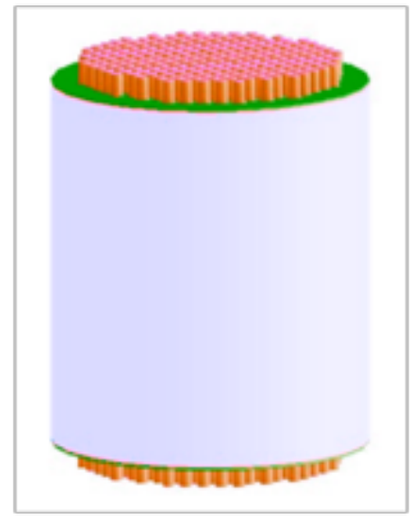


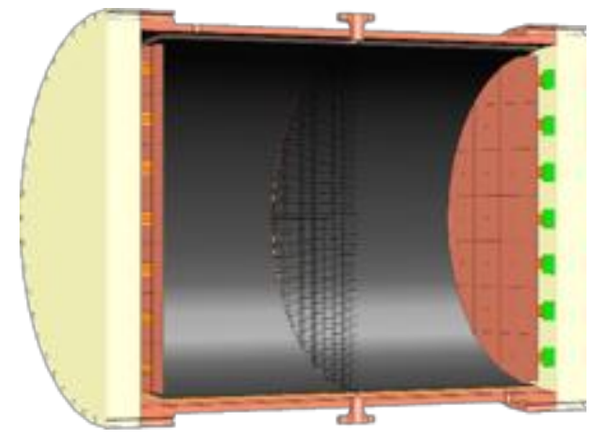
Sci. China-Phys. Mech. Astron. 60, 071011 (2017)

PandaX

Slides from Yong Yang (July 2019)

- Dark matter search with dual-phase Xe TPC
- 0νββ decay search with high pressure ^{136}Xe TPC (PandaX-III)





PandaX-I: 120 kg DM experiment 2009-2014

PandaX-II: 500 kg DM experiment 2014-2018

PandaX-xT: Next stage: 4-ton DM experiment Future

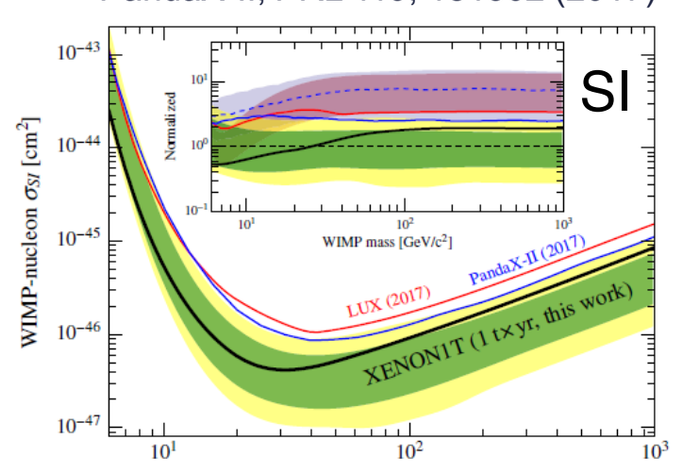
PandaX-III: 200 kg to 1 ton HP gas ^{136}Xe 0vDBD experiment Future

CJPL-II (→See next slide)

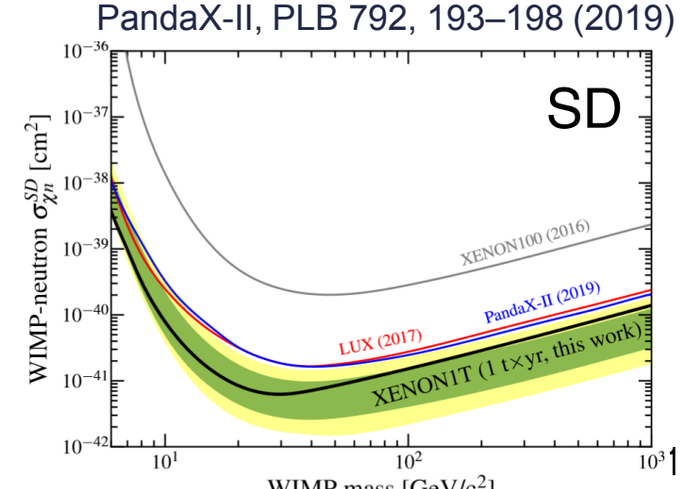
PandaX-II physics results

Dark matter models	Exposure (Ton-day)	Publications
WIMP-nucleon Spin-Independent	33	PRL 117, 121303 (2016)
WIMP-nucleon Spin-dependent	33	PRL 118, 071301 (2017)
Inelastic scattering	27	PRD 96, 102007 (2017)
Axion and ALP	27	PRL 119, 181806 (2017)
WIMP-nucleon SI	**54**	**PRL 119, 181302 (2017)**
DM models with a light mediator, self-interacting DM (*)	**54**	**PRL 121, 021304 (2018)**
EFT models and SD (*)	**54**	**PLB 792, 193–198 (2019)**

PandaX-II, PRL 119, 181302 (2017)



PandaX-II, PLB 792, 193–198 (2019)

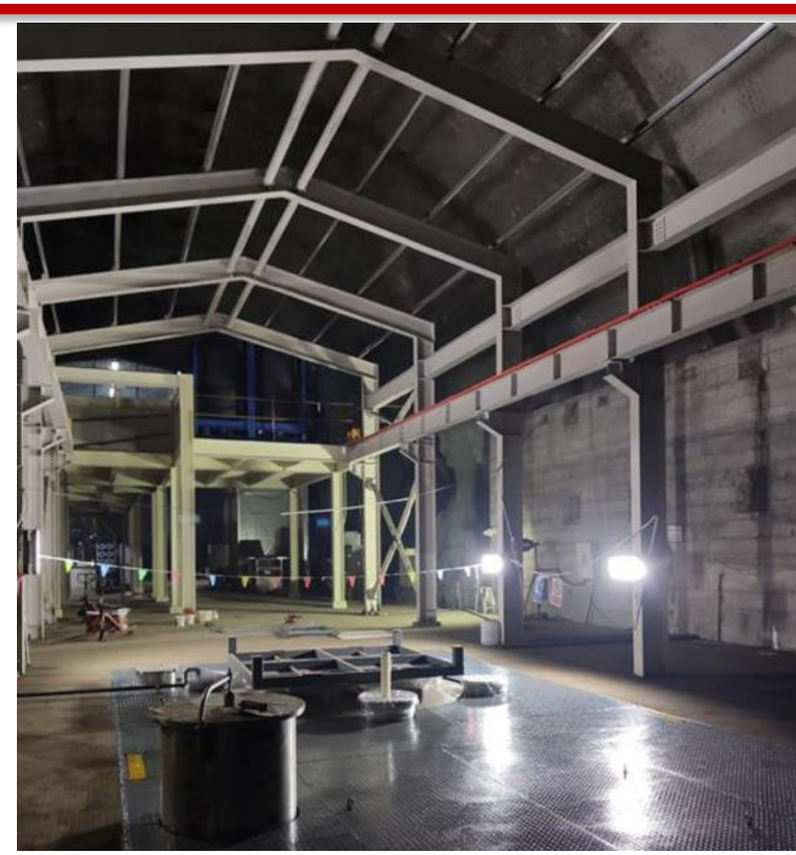


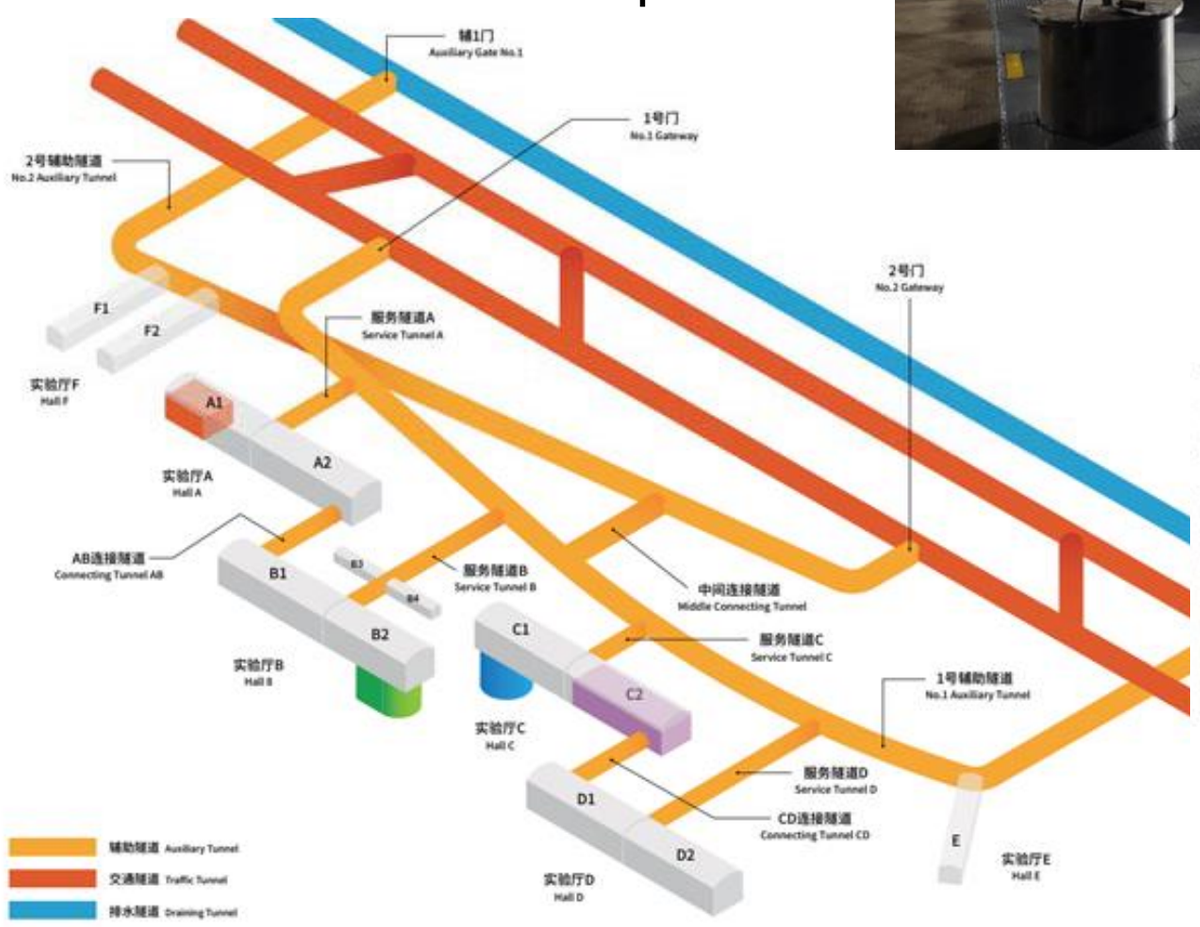
New experiment hall at CJPL-II

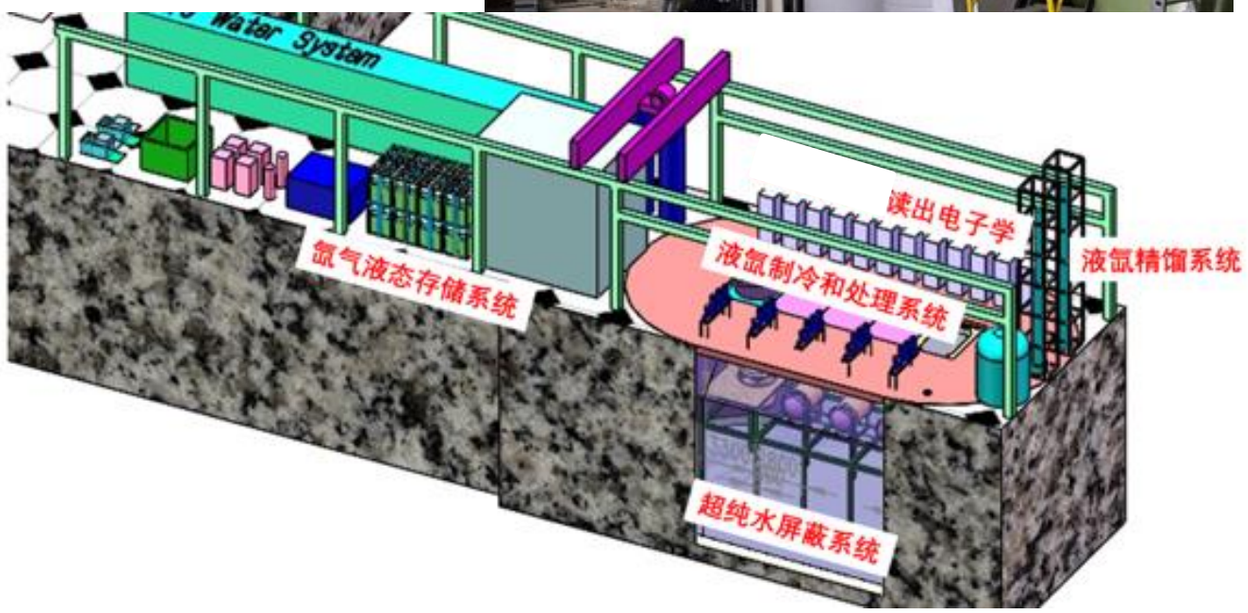
Slides from Yong Yang (July 2019)

Possible users:

- CDEX-1T (DM, 0νββ), PandaX-1T, LAr DM., CUPID-China. – Nuclear astroparticle physics
- Solar neutrino experiment
- Rock mechanics experiment



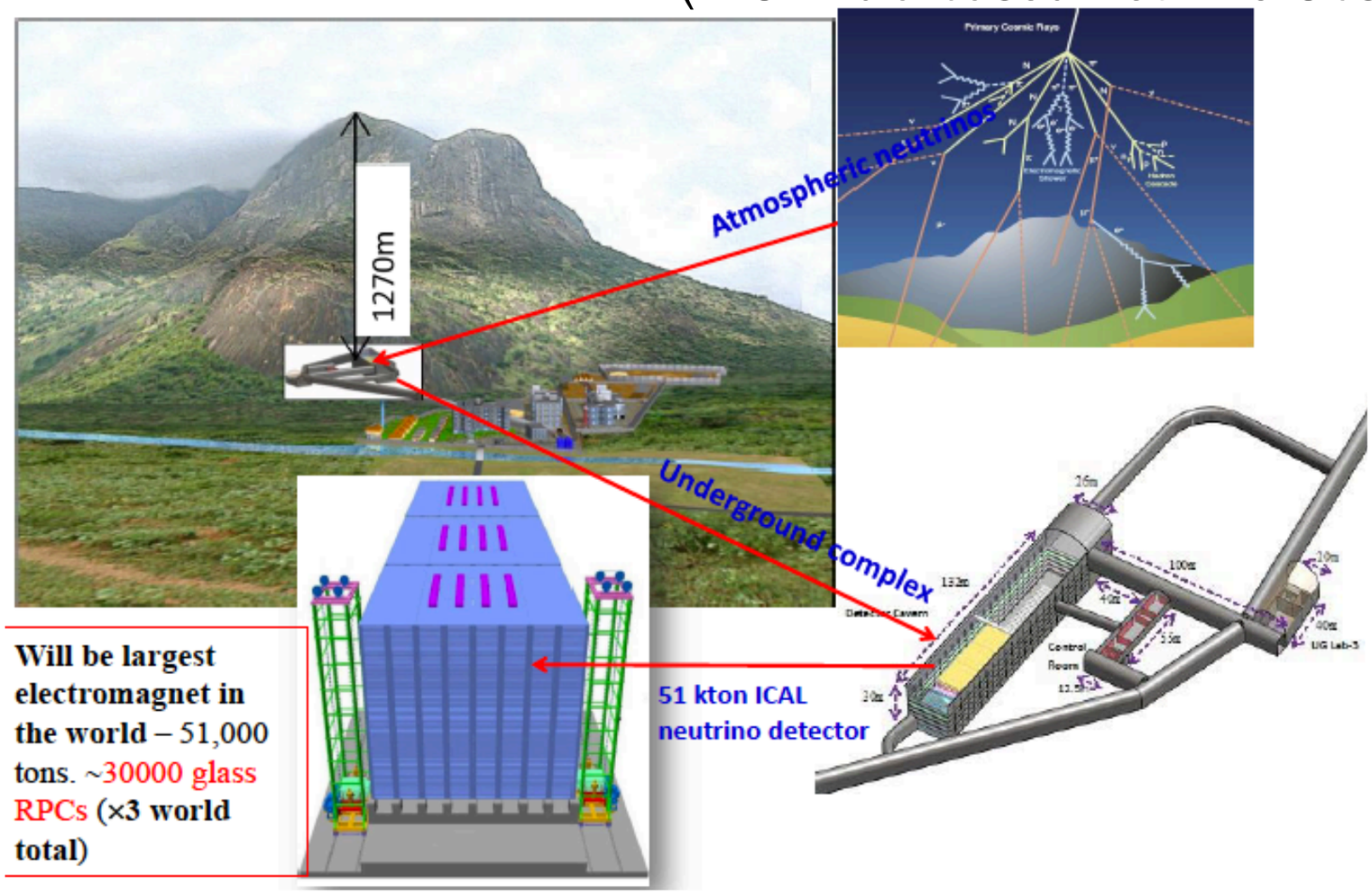




INO

(INO: India-based Neutrino Observatory)

Figures from Sanjib Kumar Agarwalla at Prospect of Neutrino Physics 2019

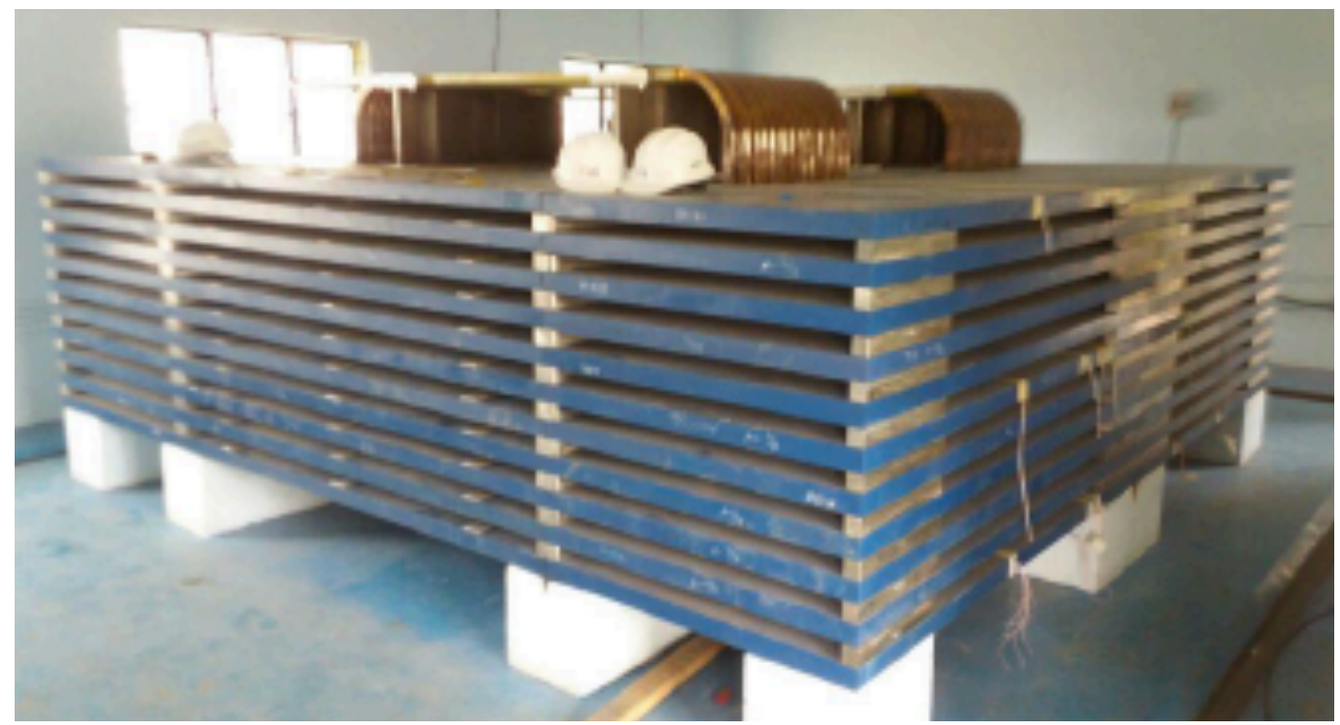


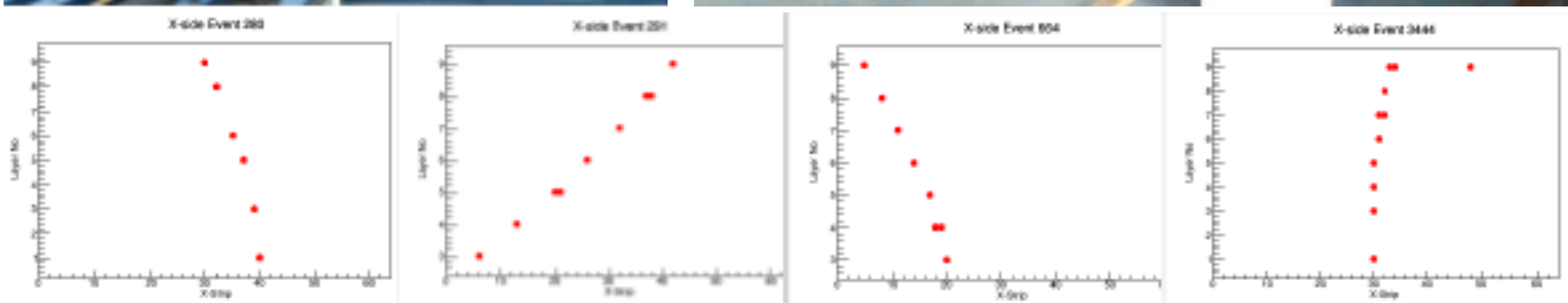
- 2km-long tunnel to below the peak at 1560m (overburden ~1200m)
- Neutrino mass hierarchy measurement with atmospheric neutrino using 50kton magnetize iron calorimeter (ICAL)
  - Separate ν and ν̄ in atm-ν over a wide range of neutrino energies, cf. mass hierarchy sensitive to 2~8GeV
  - Physics Whitepaper of ICAL at INO: arXiv:1505.07380

INO detector

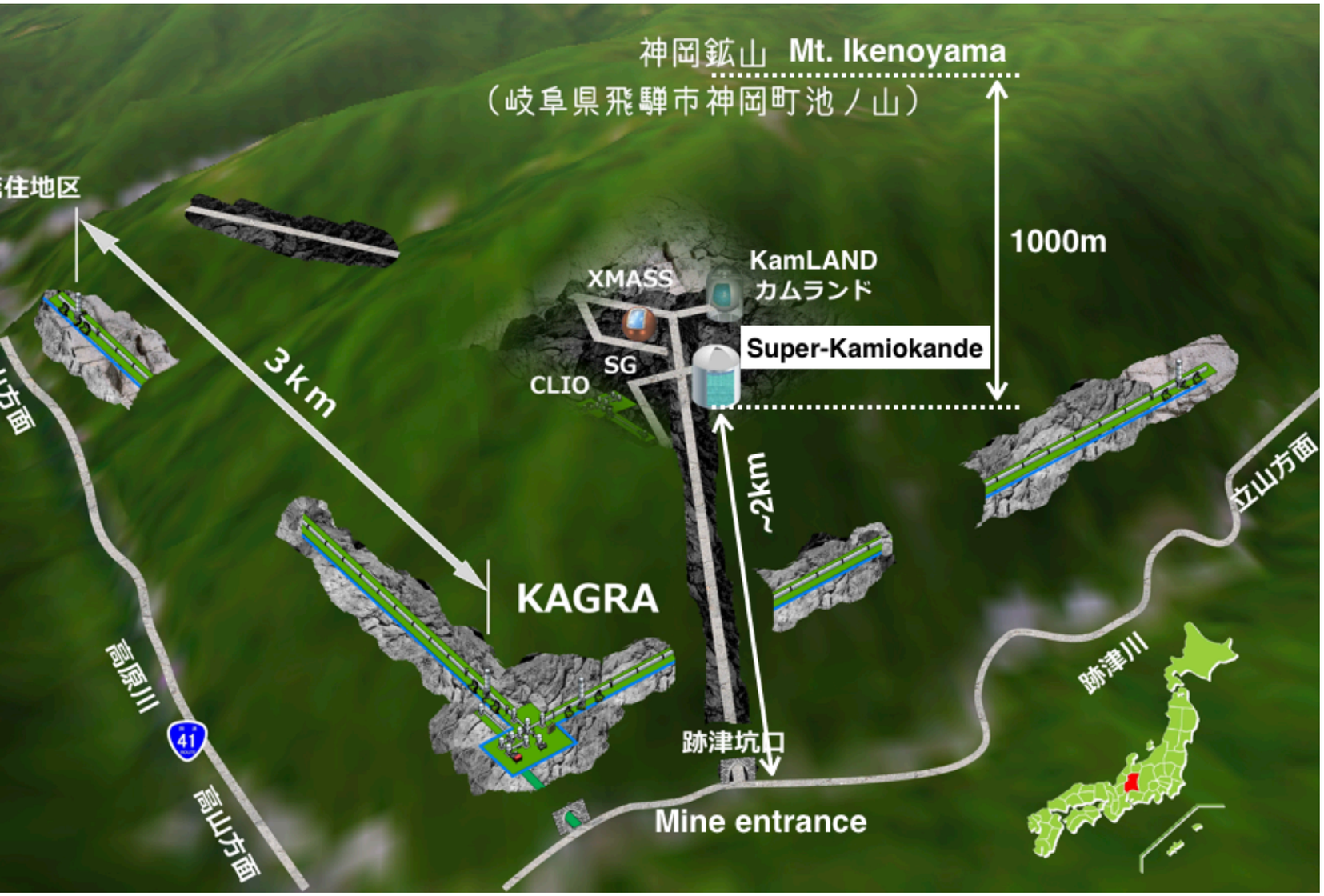
Figures from Sanjib Kumar Agarwalla at Prospect of Neutrino Physics 2019

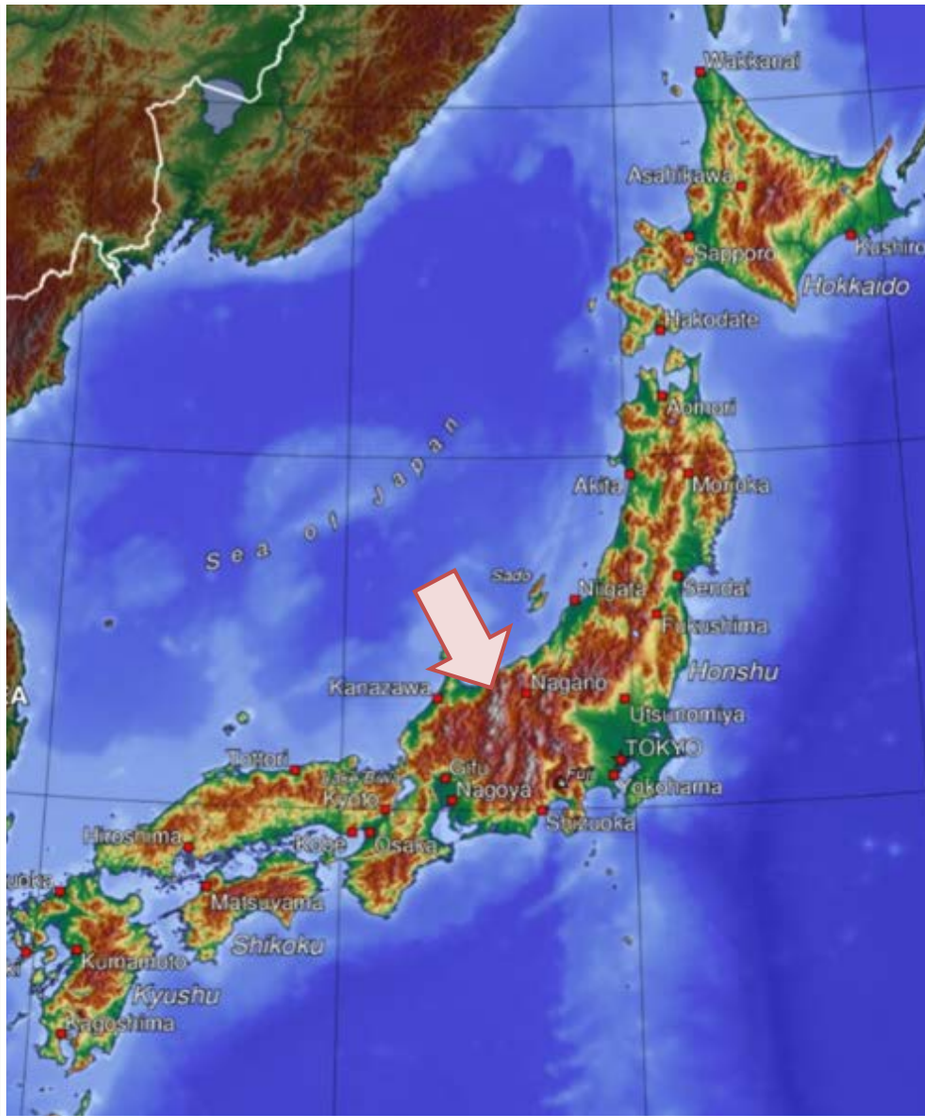
- ICAL: magnetized iron as target mass and RPC as active detector module — Target mass of 17kton × 3 modules
- mini-ICAL detector (8 RPCs) has been built and seeing cosmic-ray $\mu^{\pm}$





Kamioka

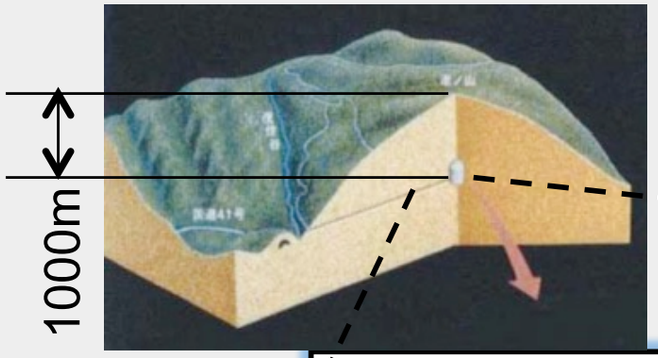




- 1000m underground (2700m.w.e)
- Horizontal access tunnel (~2km)
- ~10 minutes from ground facility by car
- 24hrs accessible

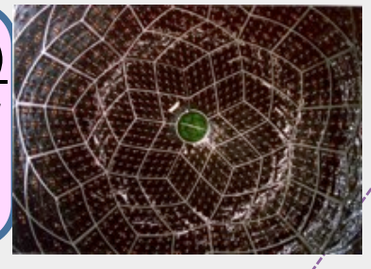
- Serves for many experiments
  - Super-Kamiokande, KamLAND, XMASS, KAGRA (and CLIO), CANDLES, NEWAGE, EGADS
  - Hyper-Kamiokande

Kamioka Underground Laboratories



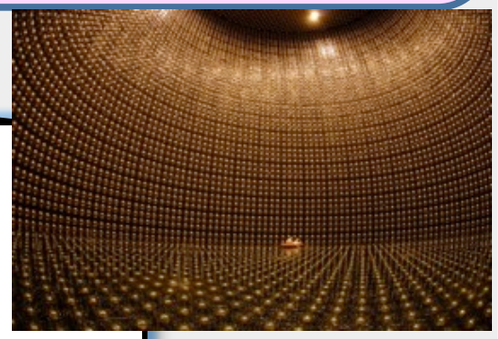
KamLAND (Tohoku Univ.)

1000ton liquid scintillator detector
Reactor, geo neutrinos
^{136}Xe double beta decay



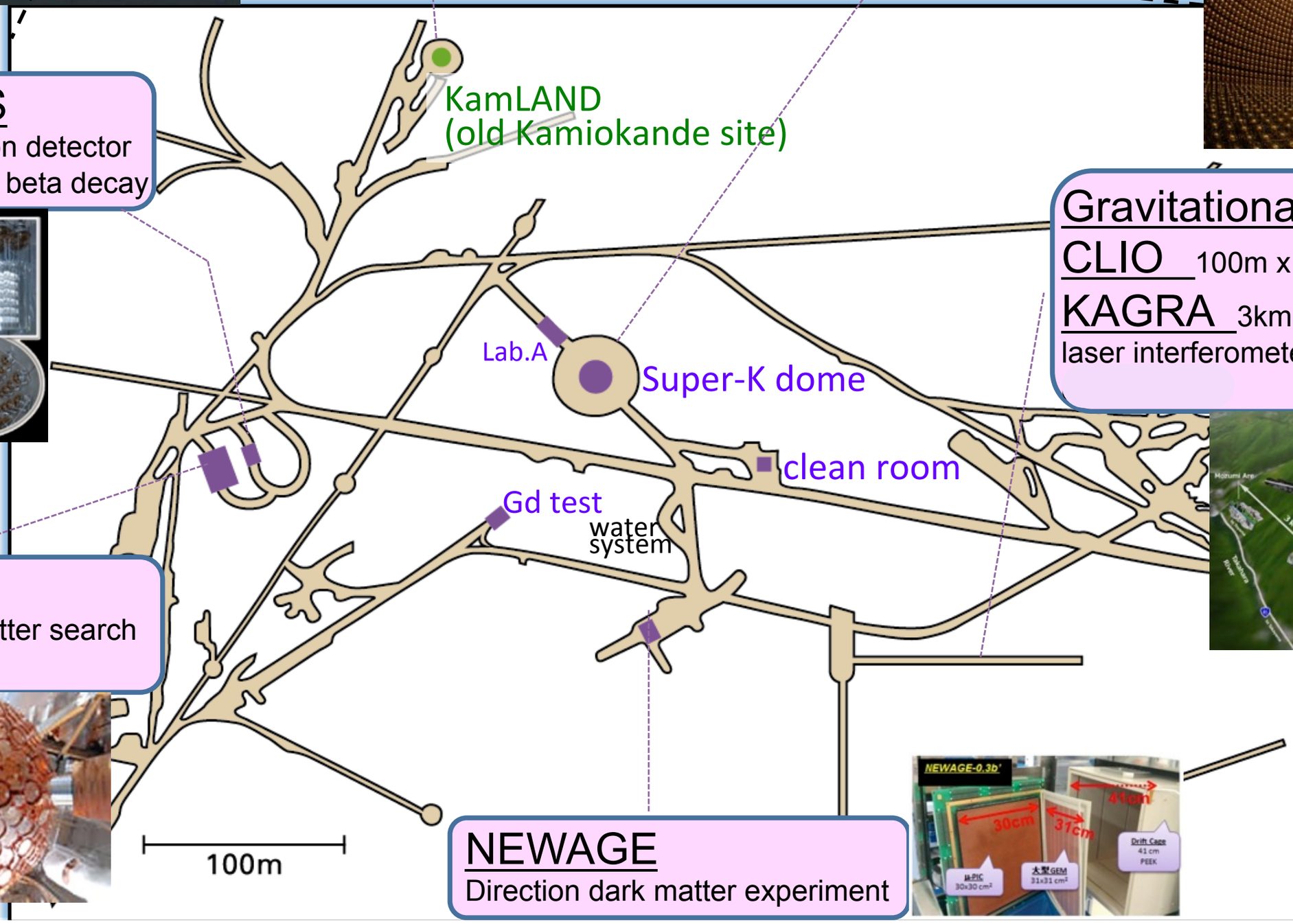
Super-Kamiokande

50,000 ton water Cherenkov detector
Atmospheric, solar, supernova neutrinos
Proton decay, indirect dark matter search
Far detector for T2K



CANDLES

CaF_2 scintillation detector
for ^{48}Ca double beta decay



Gravitational-wave

CLIO 100m x 100m prototype
KAGRA 3km x 3km cryogenic laser interferometer

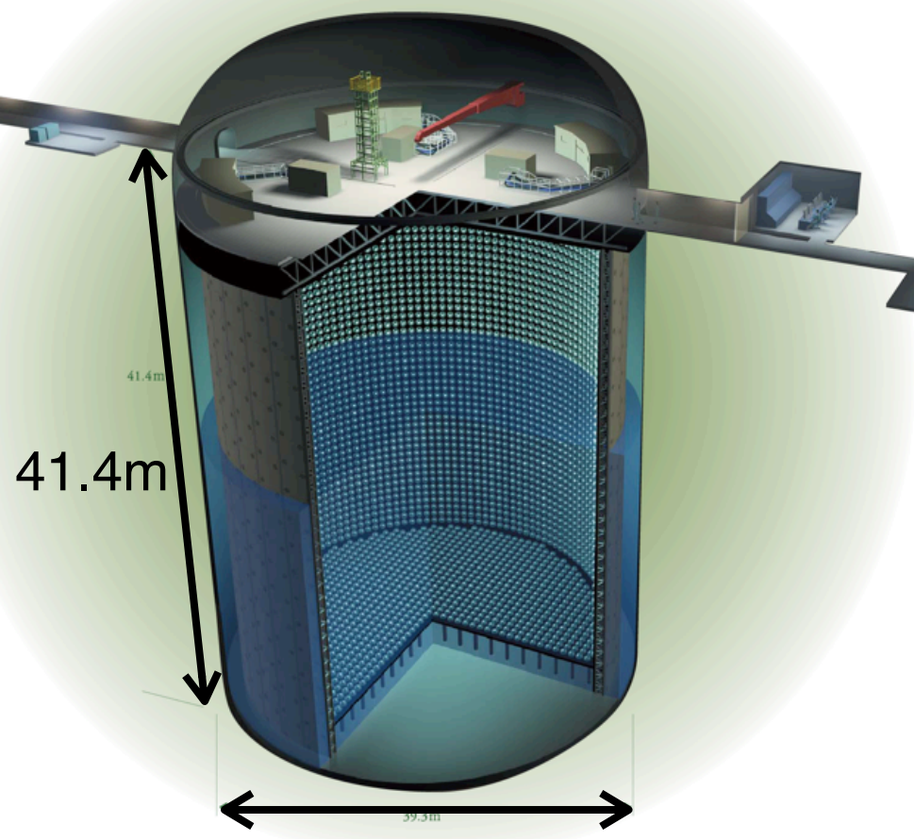
XMASS

Direct dark matter search experiment

NEWAGE

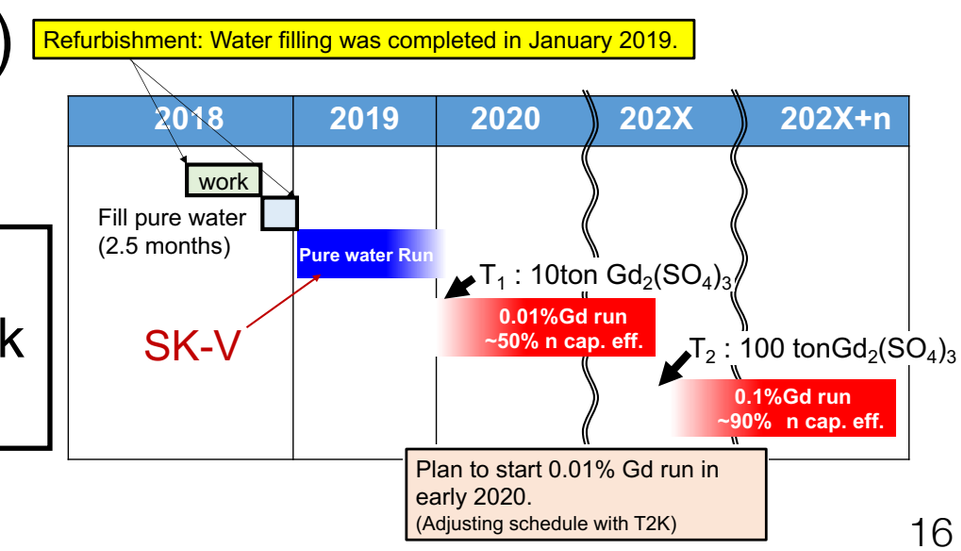
Direction dark matter experiment

Super-Kamiokande



- **The largest water Č ring imaging detector**
- Cover a wide E_ν range over a few MeV to TeV
  - Solar ν, SNν, T2K ν-beam, PDK, atm-ν, indirect WIMP search, etc
- **SK → SK-Gd**
  - Load Gd in the ultra pure water and aim to observe Supernova Relic ν
    - Inverse double beta decay
  - Beneficial for atm-ν (ν, ν̄ separation), PDK
  - Detector refurbishment complet in Jan 2019
    - Gd loading in early 2020 (currently pure water running)

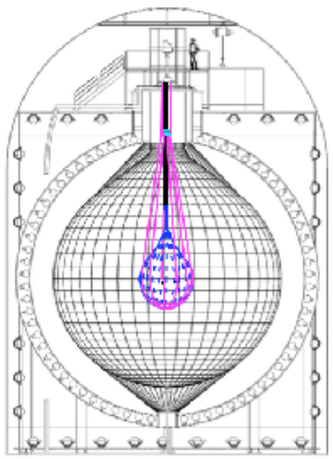
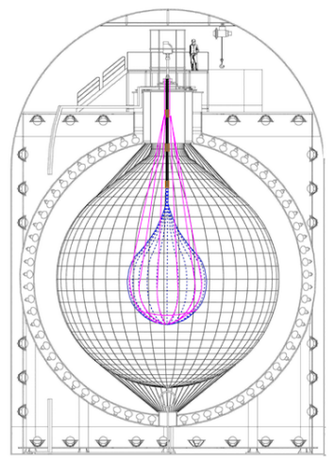
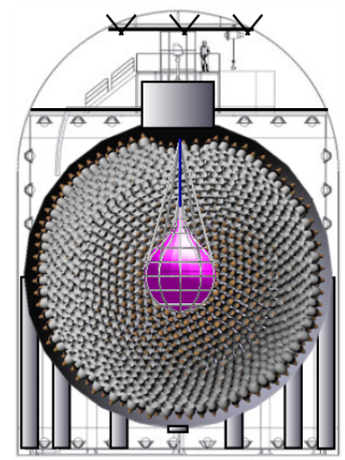
See Linyan WAN's talk & Yasuhiro NAKAJIMA's talk for further details



KamLAND-Zen

Figures from Yashihito Gando at TAUP2019

(KamLAND-Zen: Kamioka Liquid scintillator Anti-Neutrino Detector Zero neutrino double beta decay search)

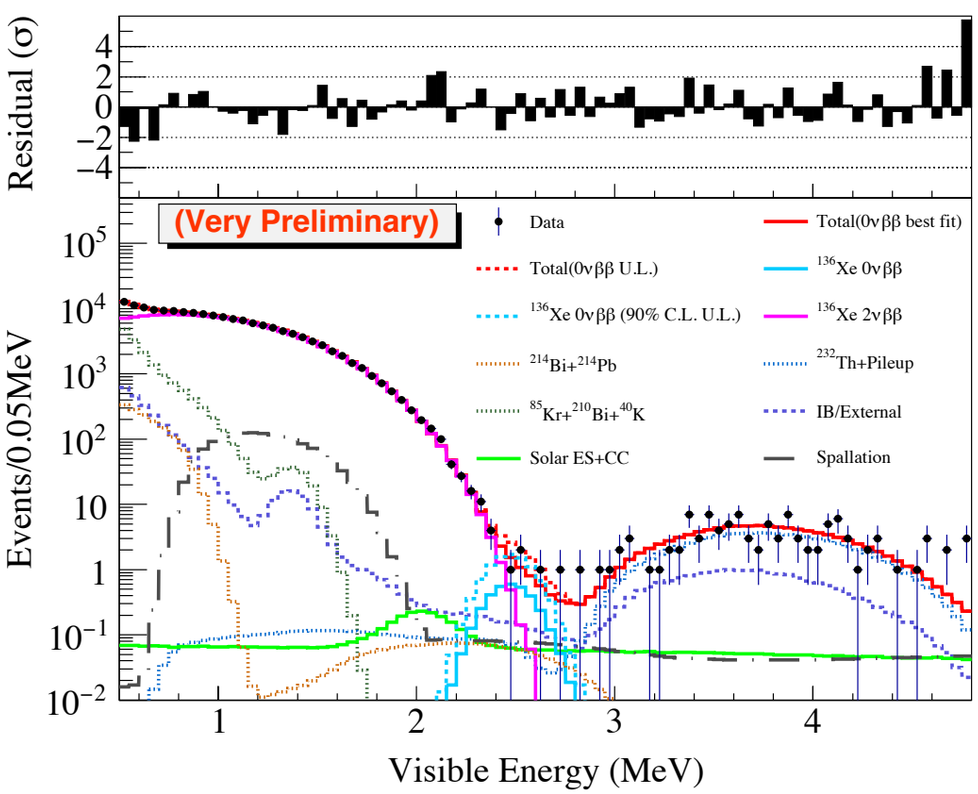
Past	Ongoing	Future
		
KamLAND-Zen 400	KamLAND-Zen 800	KamLAND2-Zen
R = 1.54m mini-balloon	R = 1.90m mini-balloon	
Xenon 320 ~ 380 kg	Xenon 745 kg	Xenon ~ 1 ton
2011 ~ 2015	Jan. 22, 2019 ~	

Xenon loaded LS in inner mini-balloon

- ~91% enriched ^{136}Xe
- Xe extraction and LS purification method established

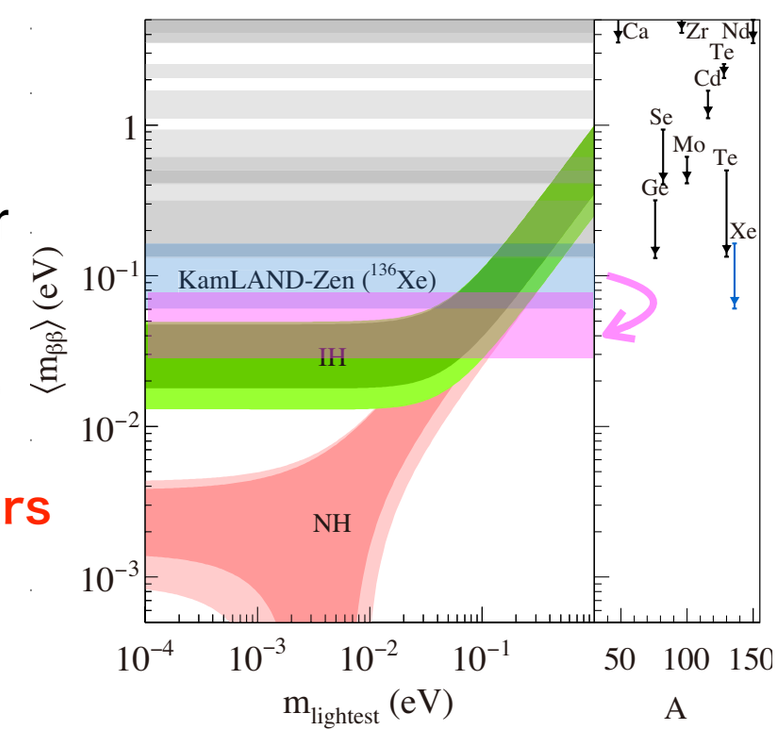
KamLAND-Zen 800 began operation in Jan. 2019 for 0νββ decay search

- Detector condition improved from KamLAND-Zen 400: Bkg from film (^{232}Th daughters) reduced to ~1/10



- No evidence of 0νββ so far
- → $T^{0\nu}_{1/2} > 4\times10^{25}$ years at 90% CL (very preliminary)

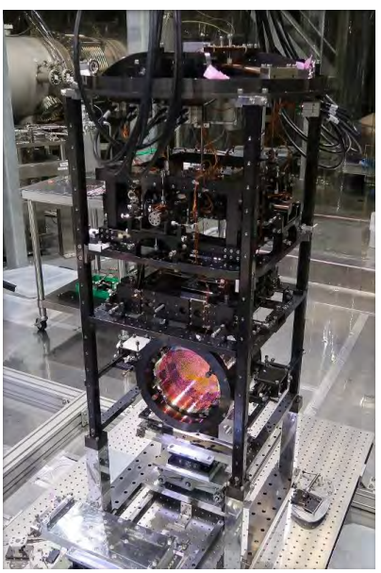
Toward 5 × 10^{26} yr in 5 years

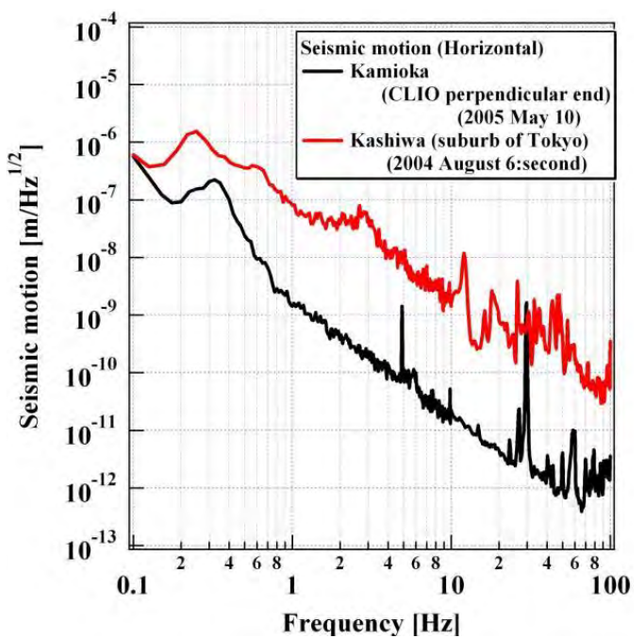


KAGRA

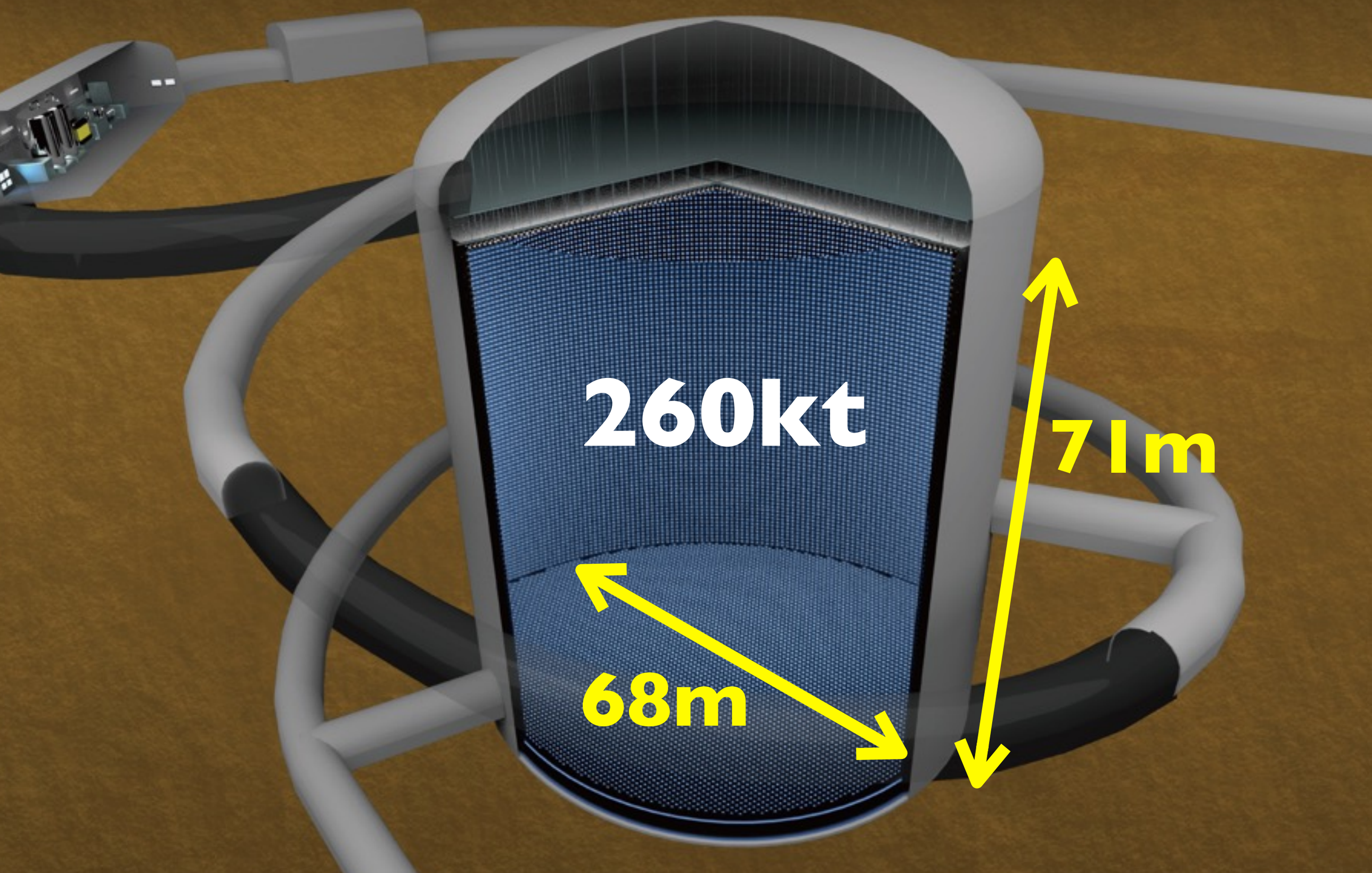
(KAGRA: Kamioka Gravitational Wave Detector)

- Large scale cryogenic gravitational wave telescope (20 K)
  - Two 3km-long arms which form a laser interferometric gravitational wave detector
- Seismic noise serious background for GW detection and underground site is order of magnitude “quite”
- Detector construction completed in 2019
  - → Commissioning & observation started
- MoA between KAGRA, LIGO and Virgo



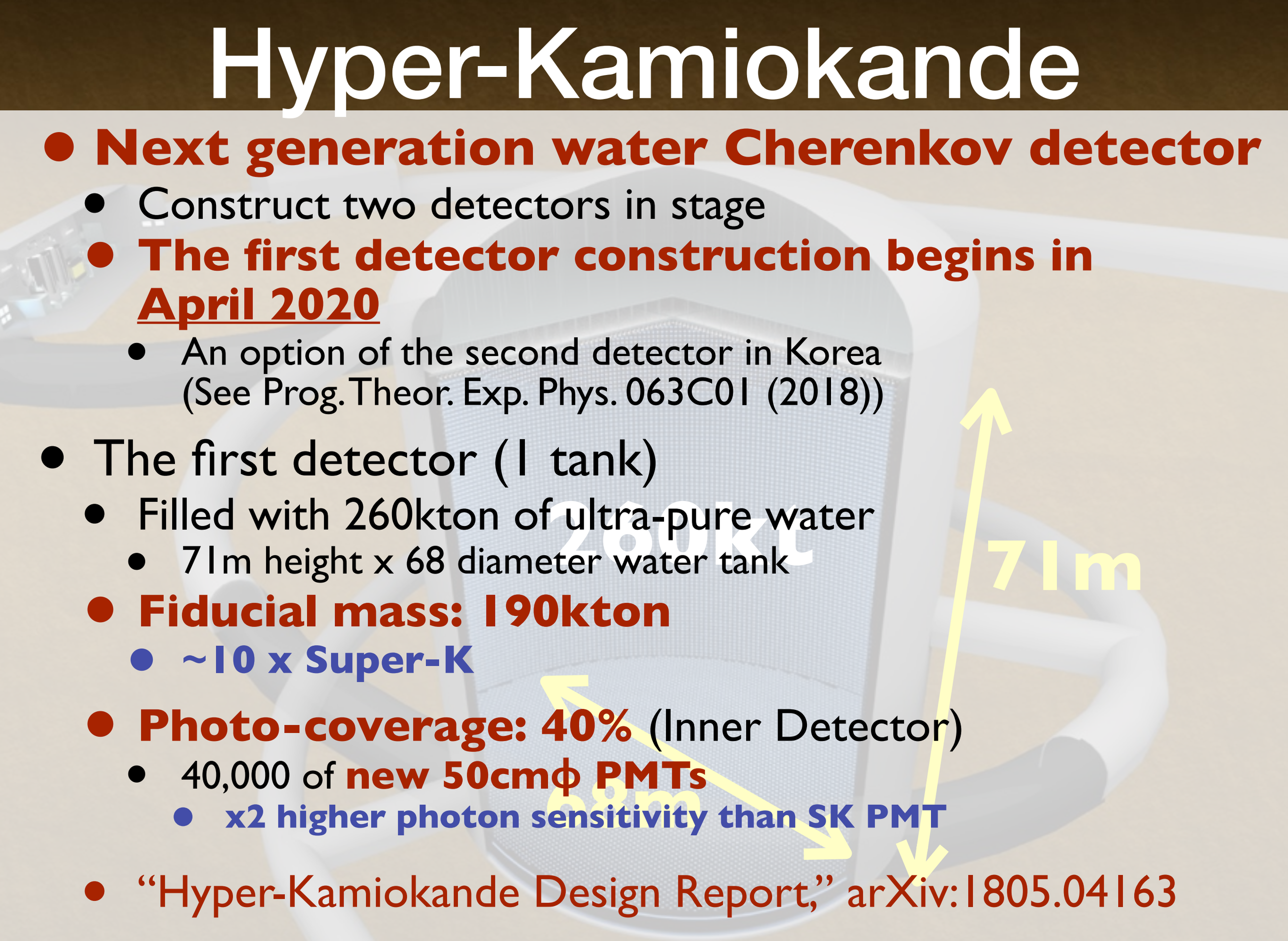


Hyper-Kamiokande



Hyper-Kamiokande

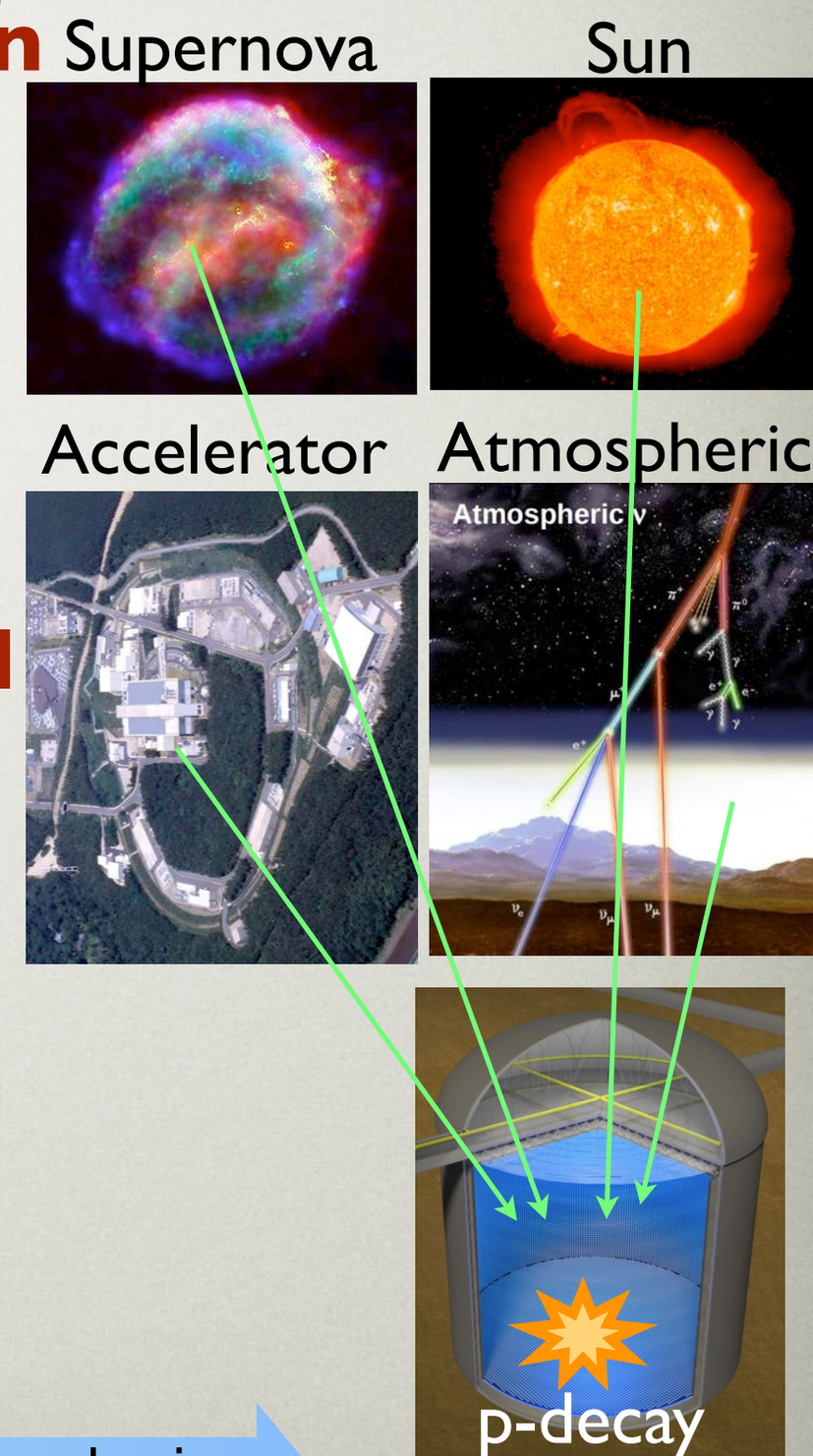
- **Next generation water Cherenkov detector**
  - Construct two detectors in stage
  - **The first detector construction begins in <u>April 2020</u>**
    - An option of the second detector in Korea (See Prog. Theor. Exp. Phys. 063C01 (2018))
- The first detector (1 tank)
  - Filled with 260kton of ultra-pure water
    - 71m height x 68 diameter water tank
  - **Fiducial mass: 190kton**
    - **~10 x Super-K**
  - **Photo-coverage: 40%** (Inner Detector)
    - 40,000 of **new 50cmϕ PMTs**
      - **x2 higher photon sensitivity than SK PMT**
- "Hyper-Kamiokande Design Report," arXiv:1805.04163

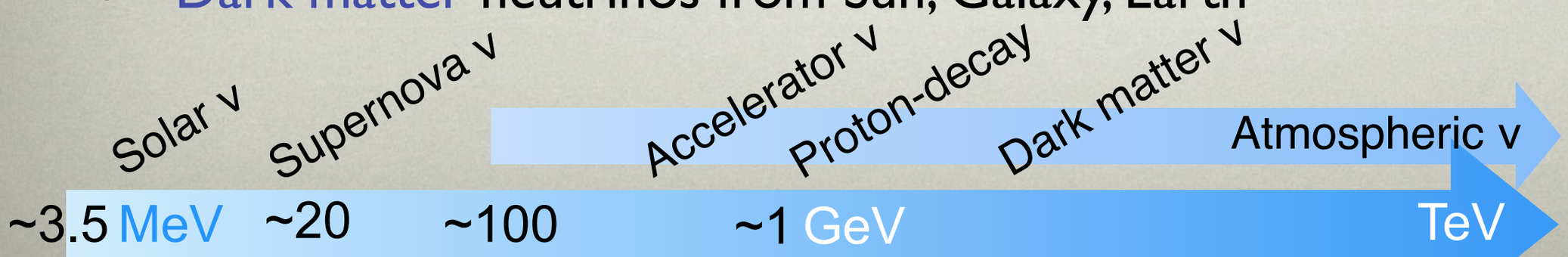


Hyper-K: multi-purpose detector

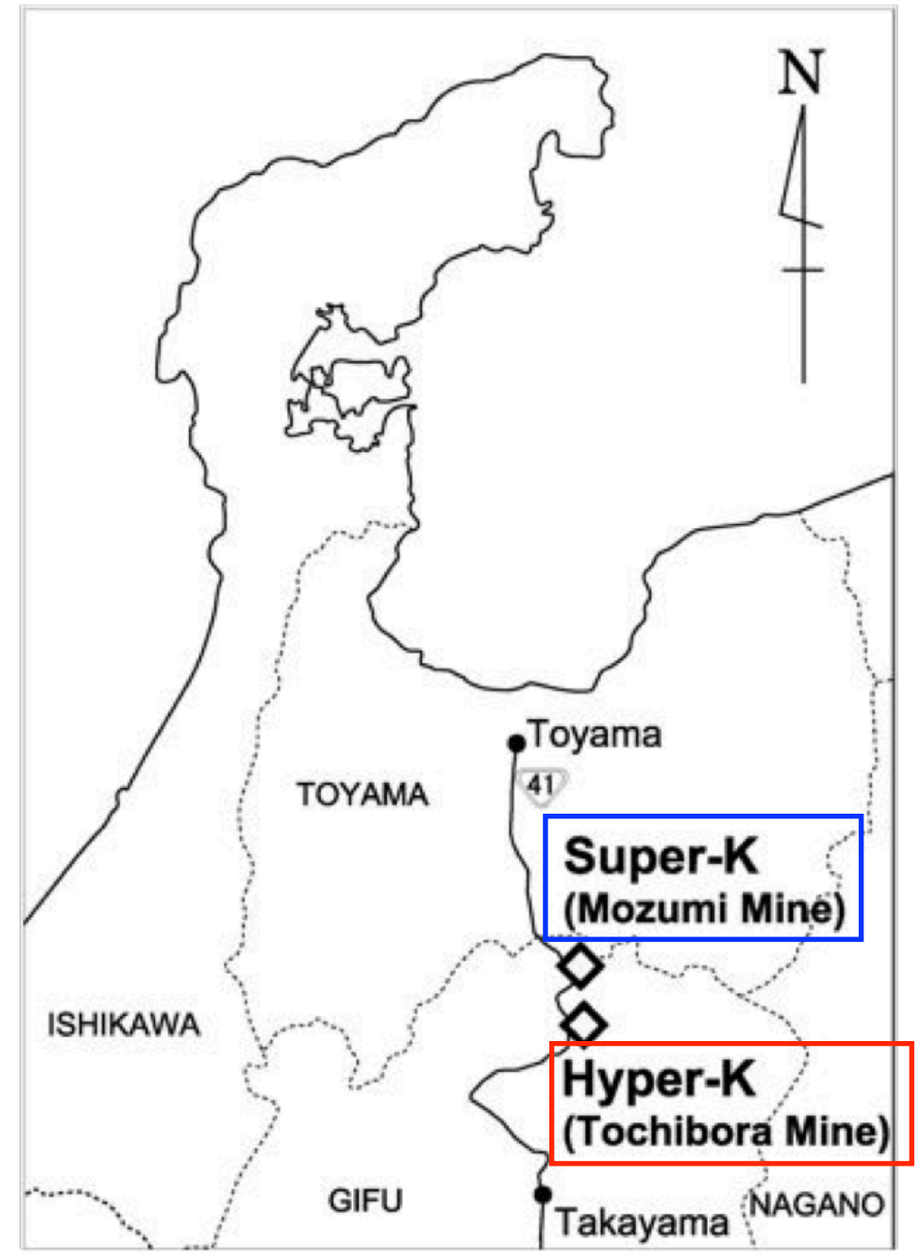
See Mahdi Taani's talk for details

- **Comprehensive study of ν oscillation**
  - CPV: 76% of δ space w/ 3σ, <22° precision
  - MH determination for all δ with J-PARC/Atm ν
  - θ_{23} octant determination at $|\theta_{23}-45°|>2°$
  - <1% precision of Δm^2_{32}
  - Test standard ν oscillation scenario w/ acc/atm ν
- **Proton decay 3σ discovery potential**
  - 1×10^{35} years for $p\rightarrow e^+\pi^0$
  - 3×10^{34} years for $p\rightarrow \nu K^+$
- **Astrophysical neutrino**
  - Solar ν: test standard matter effect (MSW) model
  - Supernova ν, supernova relic-ν
  - Dark matter neutrinos from Sun, Galaxy, Earth



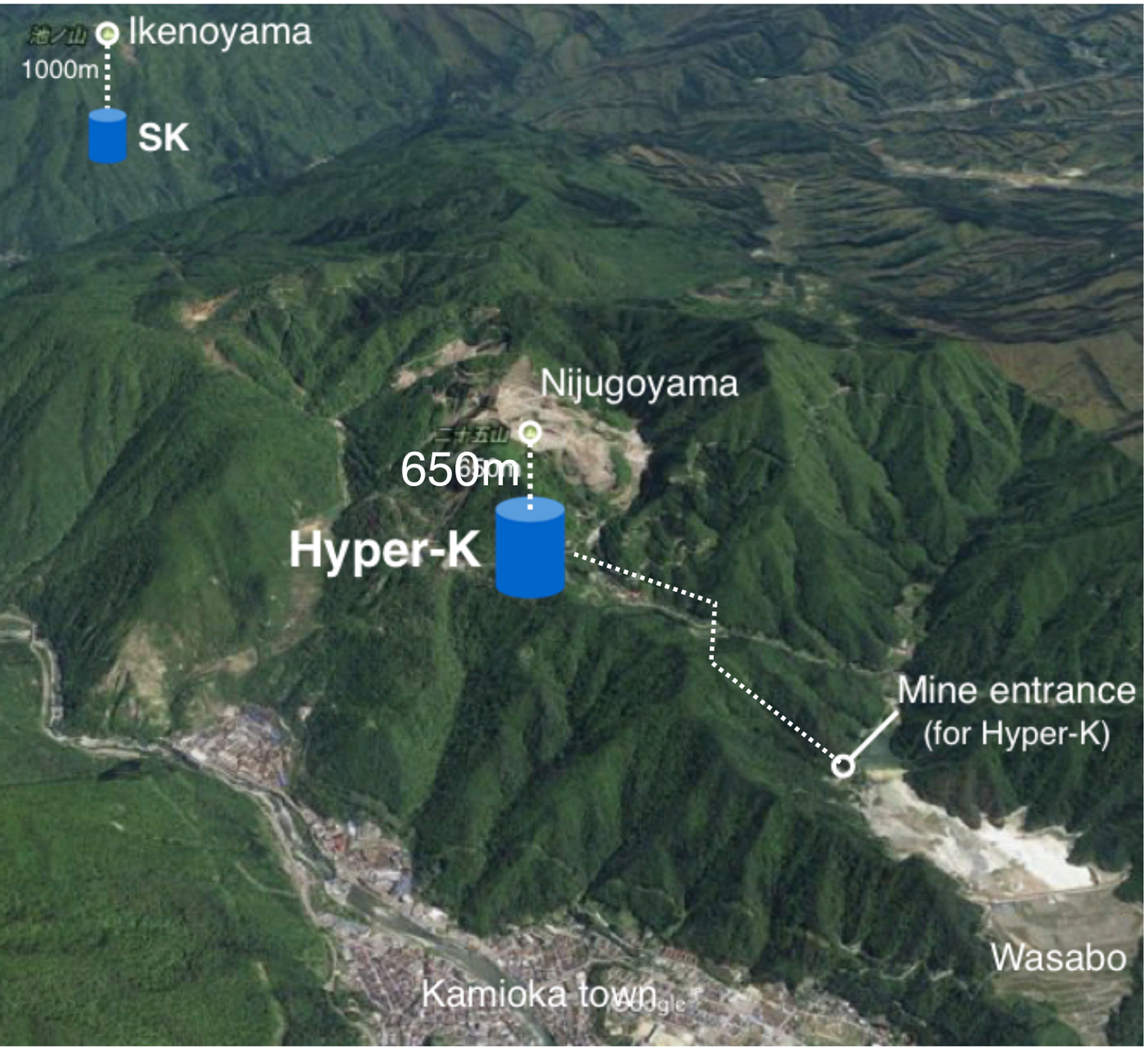


Hyper-K site

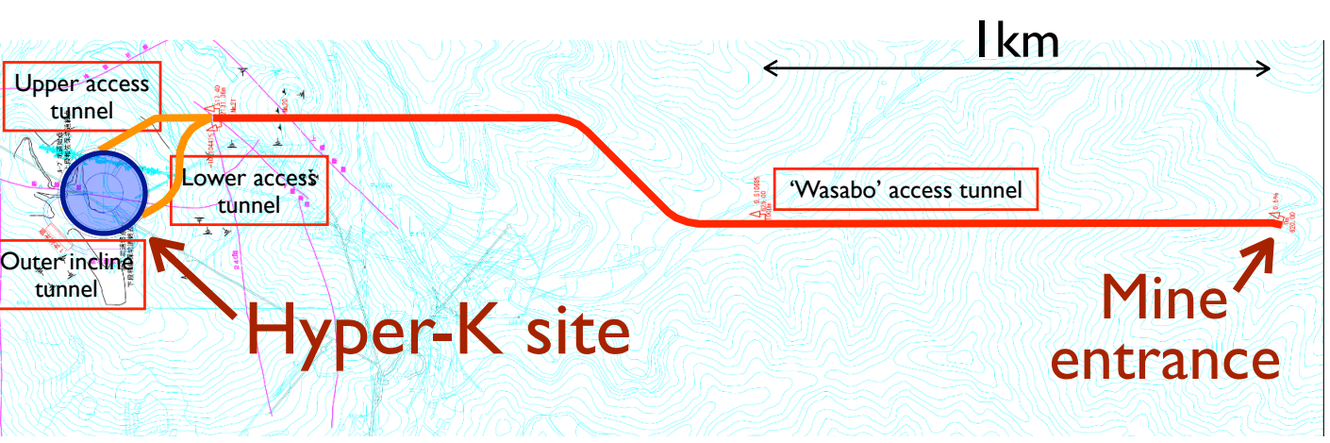


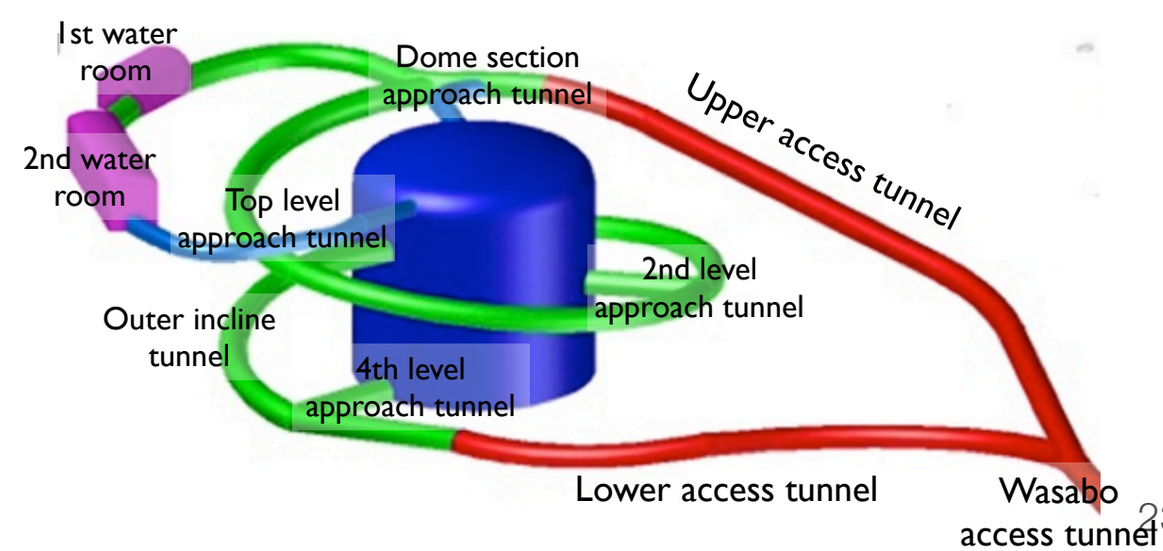
- Hyper-K site locates under Mt. Nijugoyama
- ~8km south from Super-Kamiokande (Mt. Ikenoyama)
- Identical baseline (295km) and off-axis angle (2.5deg) to T2K

Hyper-K site

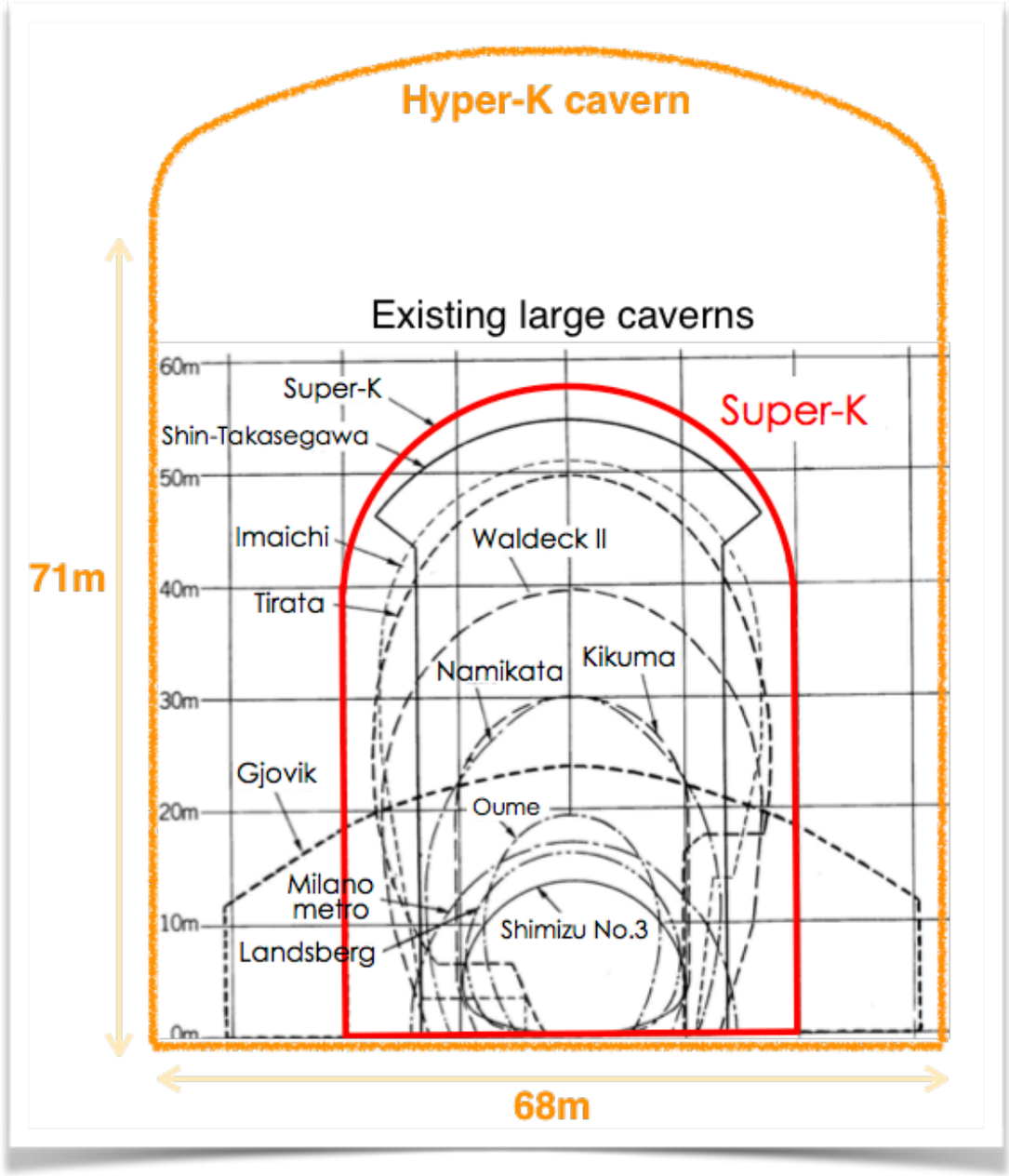


- Access to the Hyper-K site by car via ~2km-long tunnel from mine entrance
  - Excavate a new access tunnel to HK
- Overburden: 650m
- Ventilation ("Rn less" air), elec. power incoming unit, etc at the mine entrance
  - Electricity needs to be newly routed from Kamioka town to the mine entrance
  - Construction for electricity (electric pole, wiring, etc) started in 2019
- Water purification system, detector control room, … are underground
  - Similar to Super-K





Hyper-K cavern



- Hyper-K cavern will be the world largest underground (human-made) cavern
- **Hyper-K construction will begin in April 2020 and complete in ~FY2027**

Summary

- Several underground labs in Asia
- Serve for many experiments:
  - Dark matter, 0νββ, neutrino, proton decay, gravitational wave, low background facility (low bkg crystal production, screening), …
- Underground labs in Asia are growing:
  New underground labs under construction or begin construction soon
  - CJPL-II (China), Yemilab (Korea), Kamioka (Hyper-K; Japan)