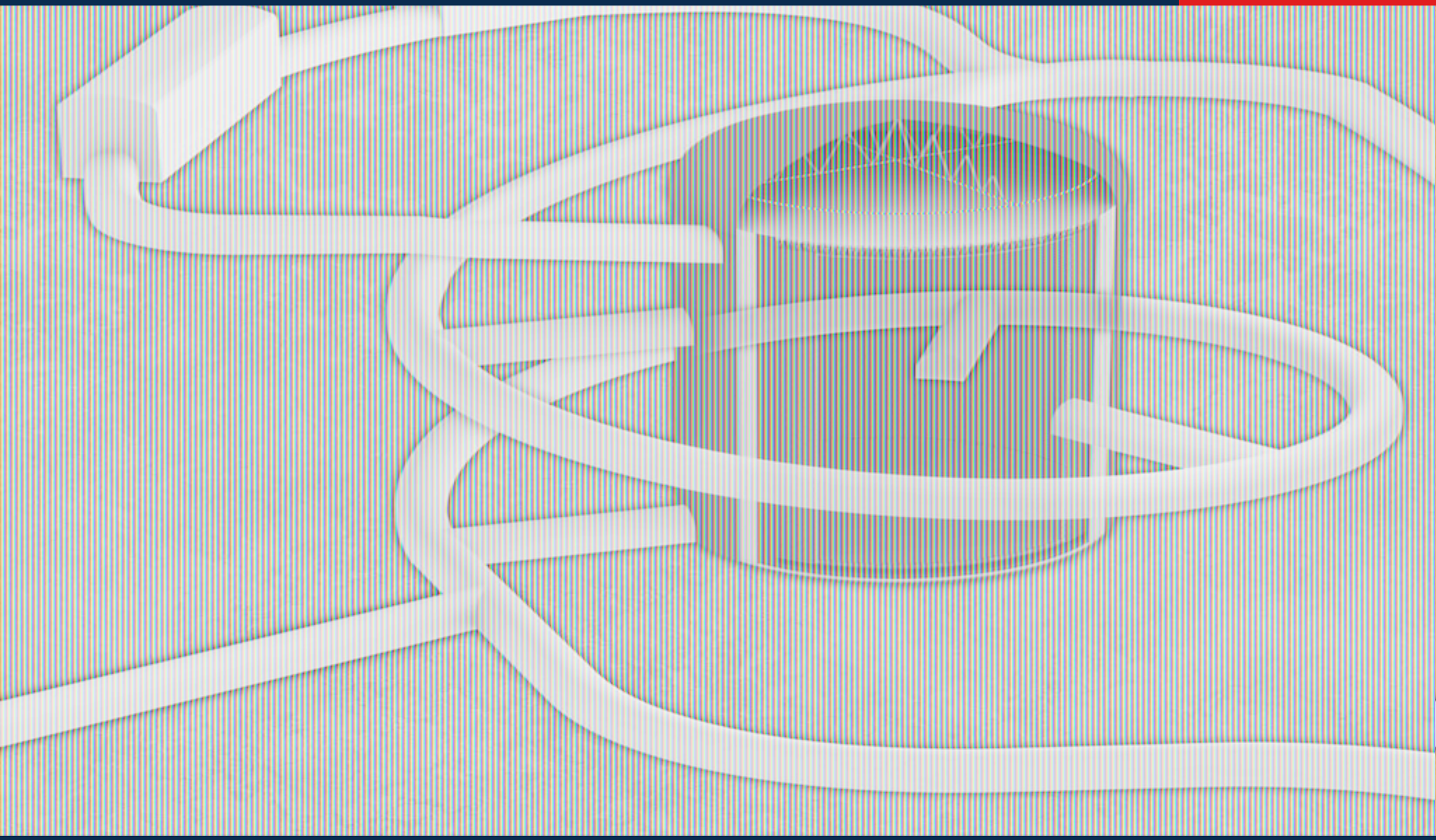
Neutrino Astronomy with Hyper-Kamiokande

Dr. Jost Migenda (they/them)
for the Hyper-Kamiokande collaboration

KING'S College LONDON

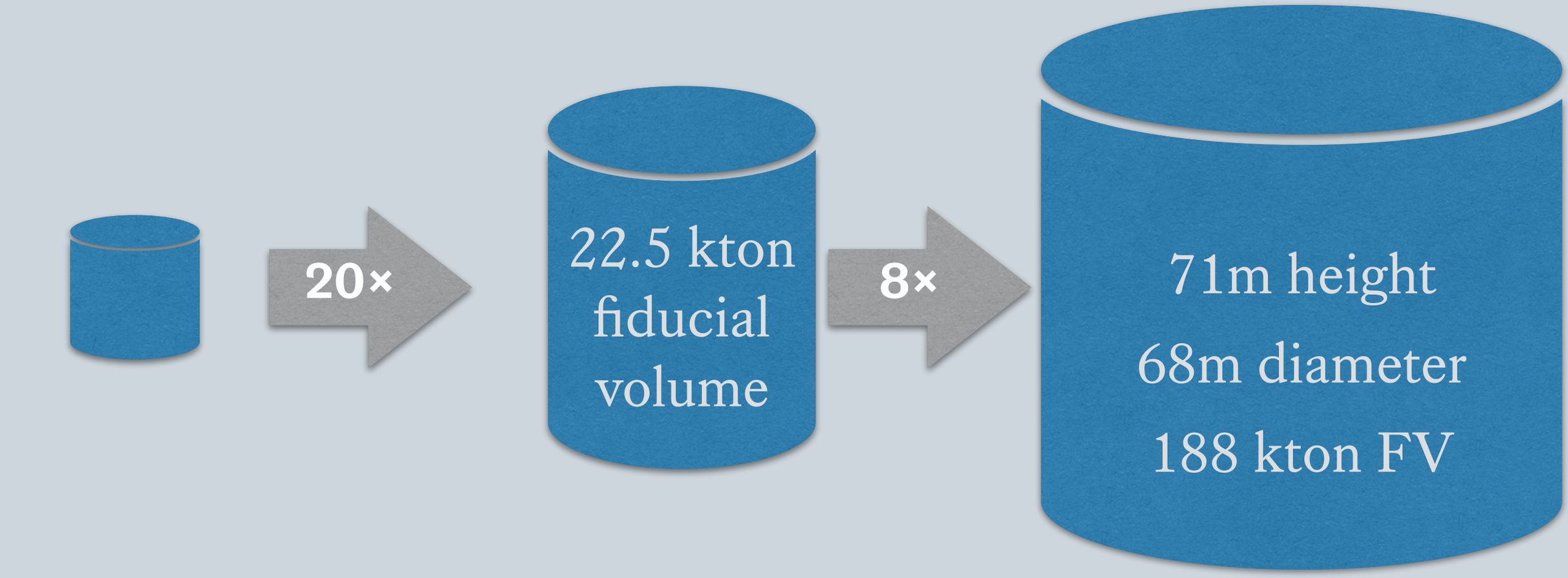


Hyper-Kamiokande

Kamiokande
1983–1996

Super-Kamiokande
1996–today (and beyond)

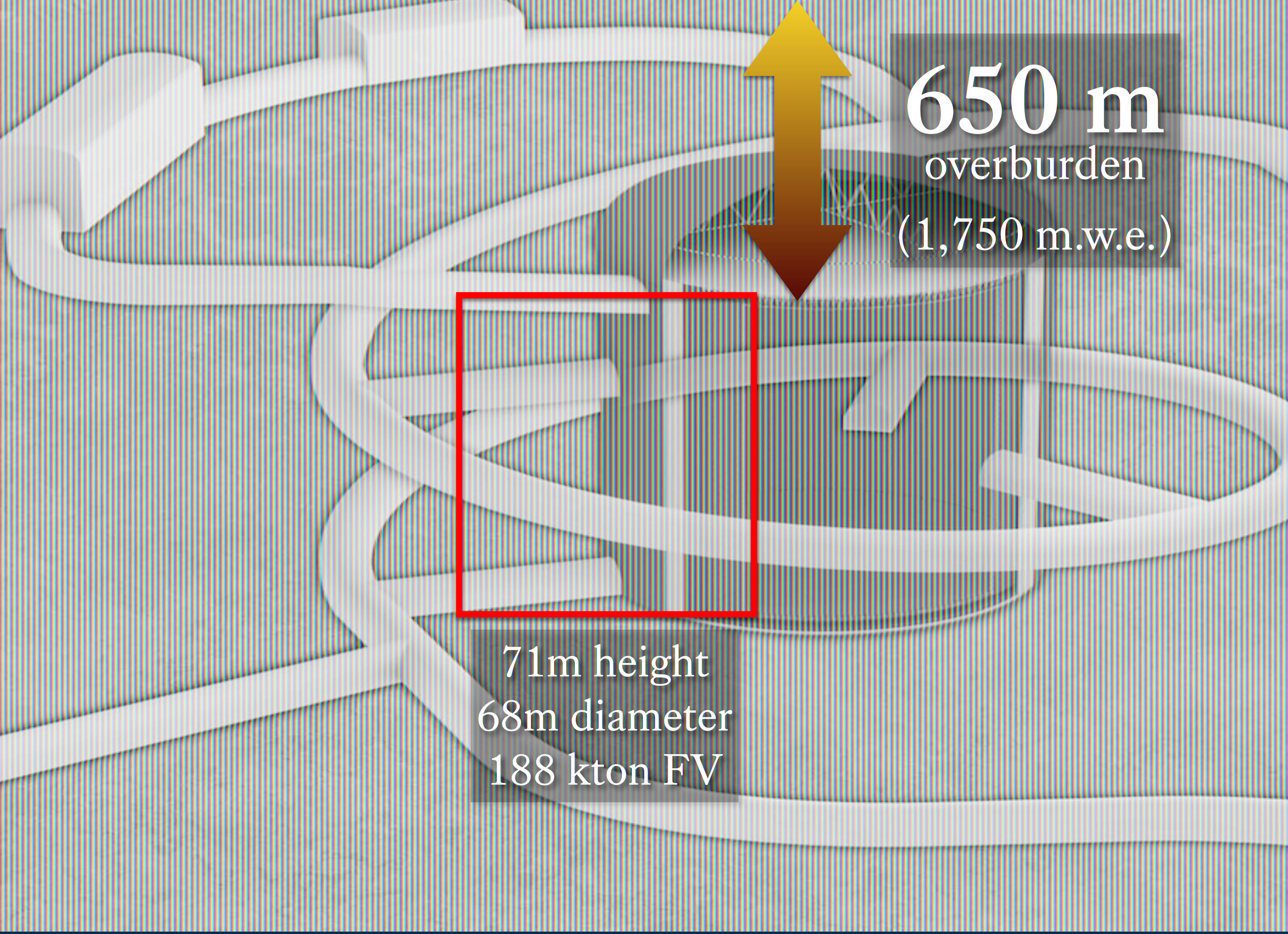
Hyper-Kamiokande
~2027–???

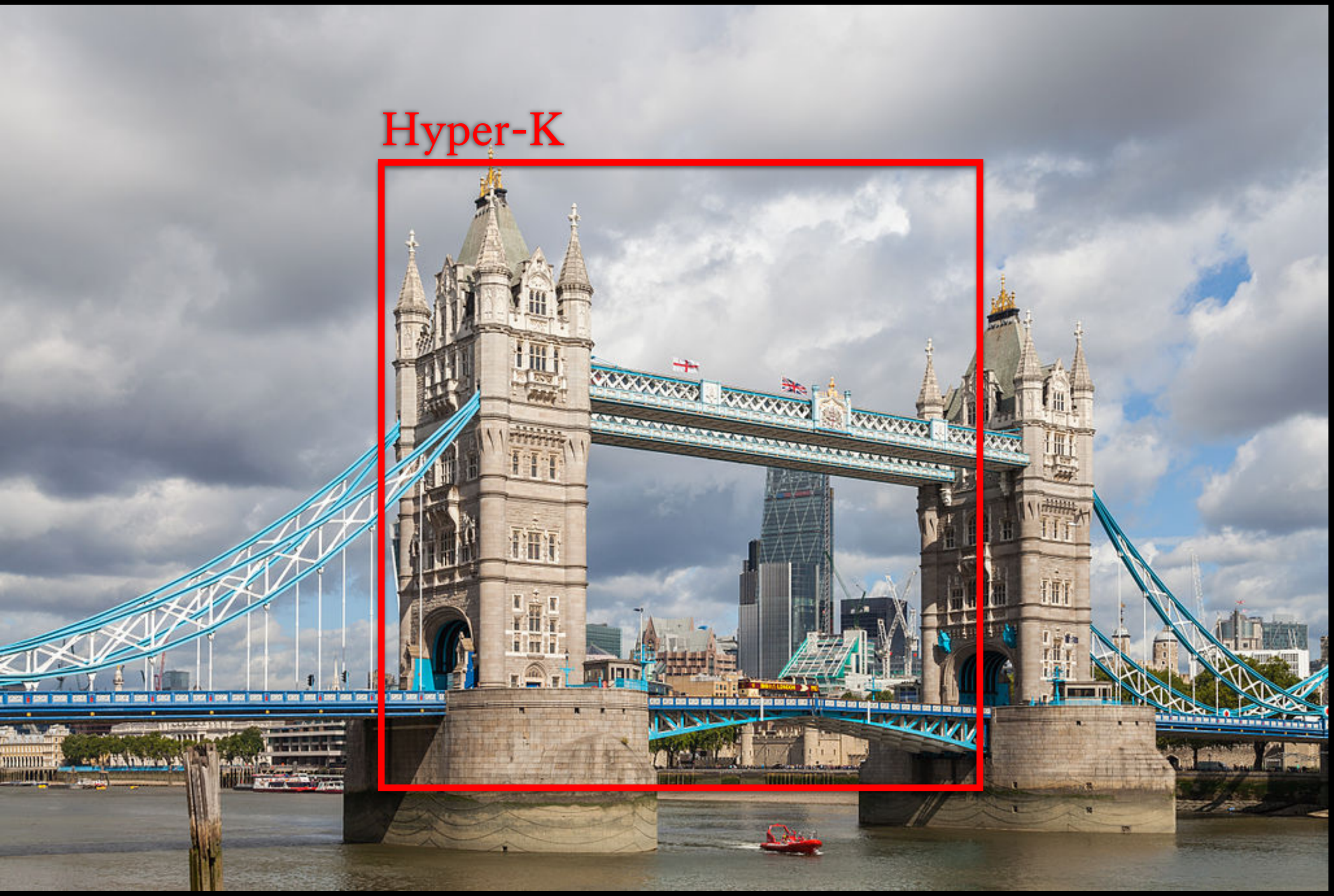


Koshiba, 2002

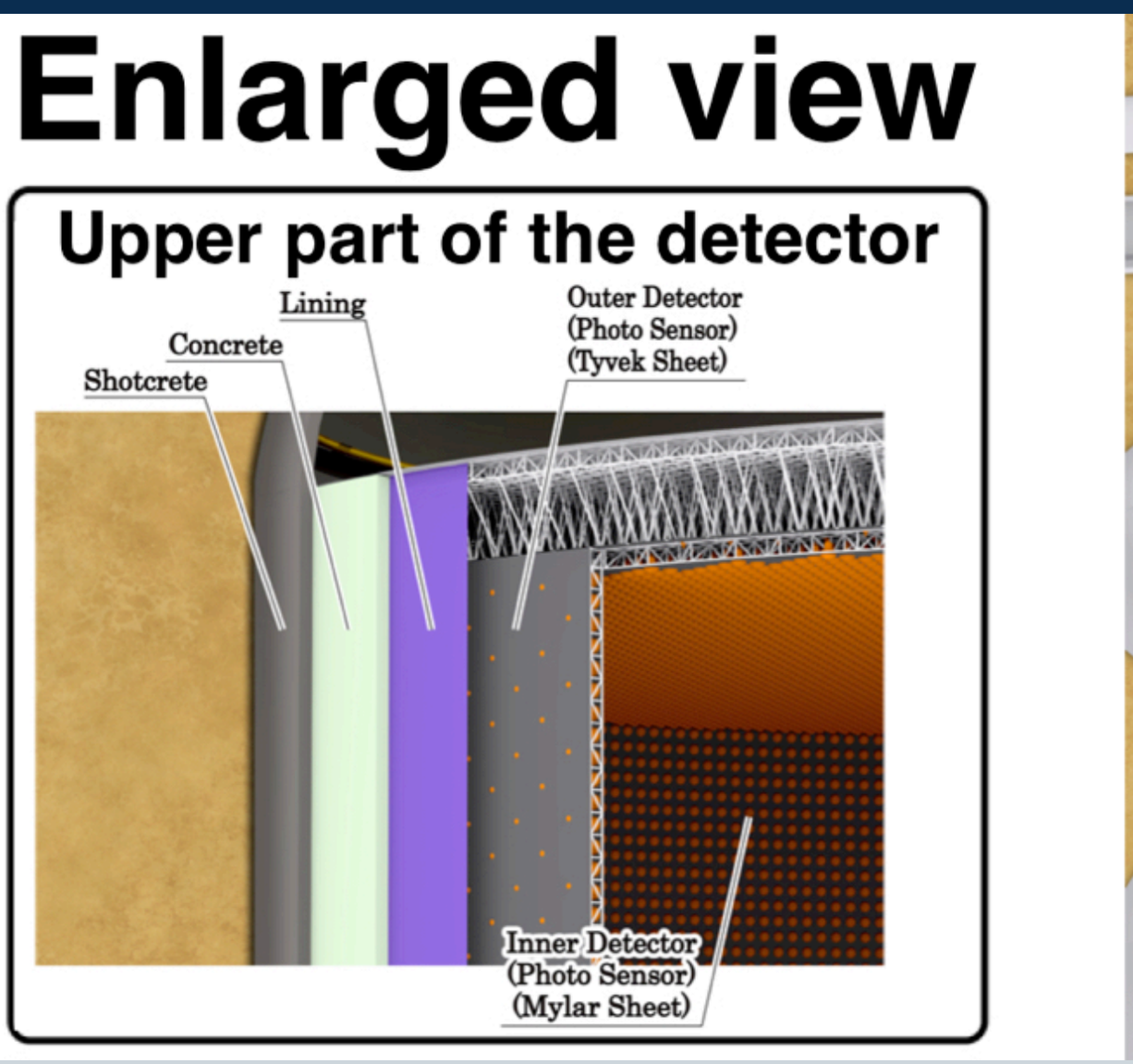
Kajita, 2015

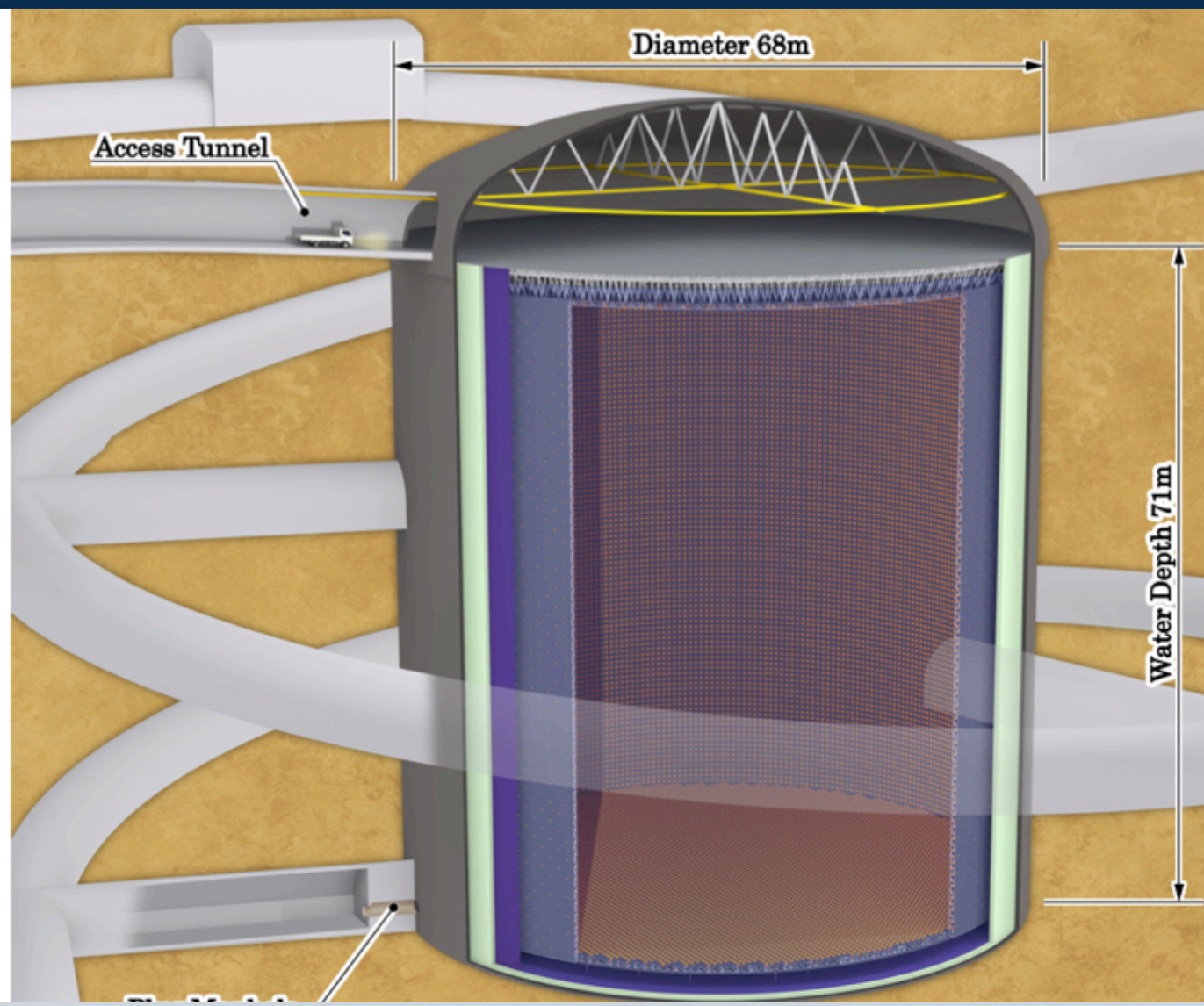
???, 20??


650 m
overburden
(1,750 m.w.e.)
71m height
68m diameter
188 kton FV



Outer Detector

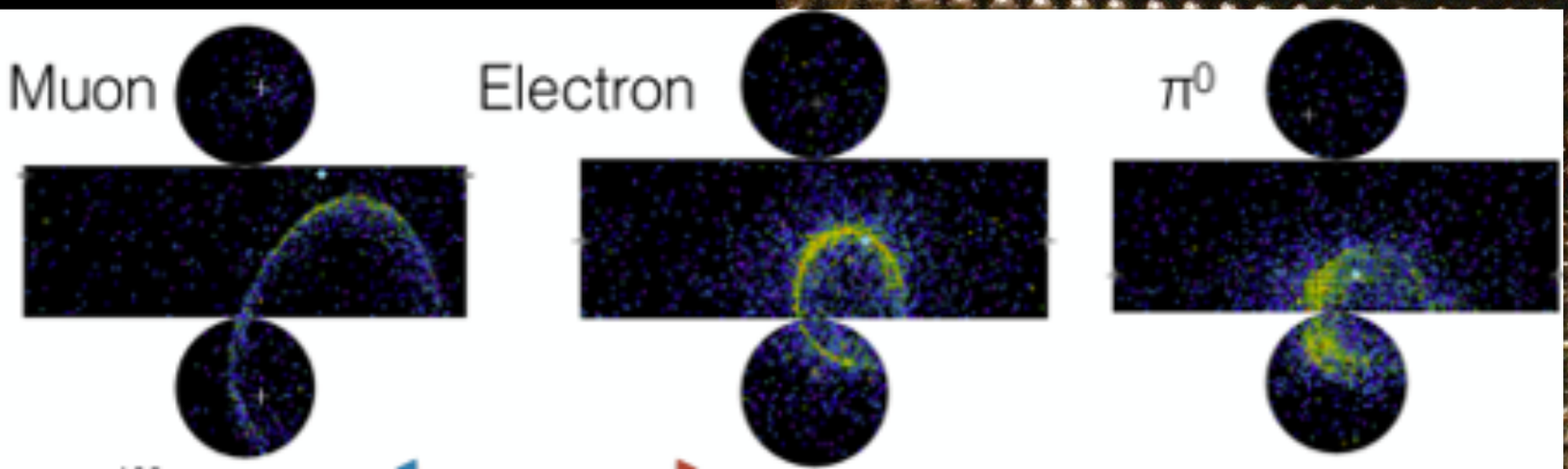




- 1–2 m wide
- Both active veto & passive shielding
- Investigating design with 8cm PMTs and wavelength-shifting plates
  (DOI:10.1088/1742-6596/1468/1/012240)

Photosensors detect Cherenkov light

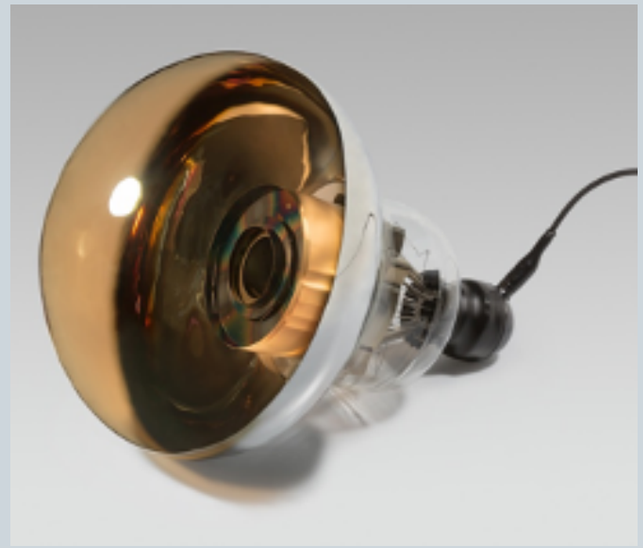
Image credit: Kamioka Observatory, ICRR (Institute for Cosmic Ray Research), The University of Tokyo



Inside Super-Kamiokande

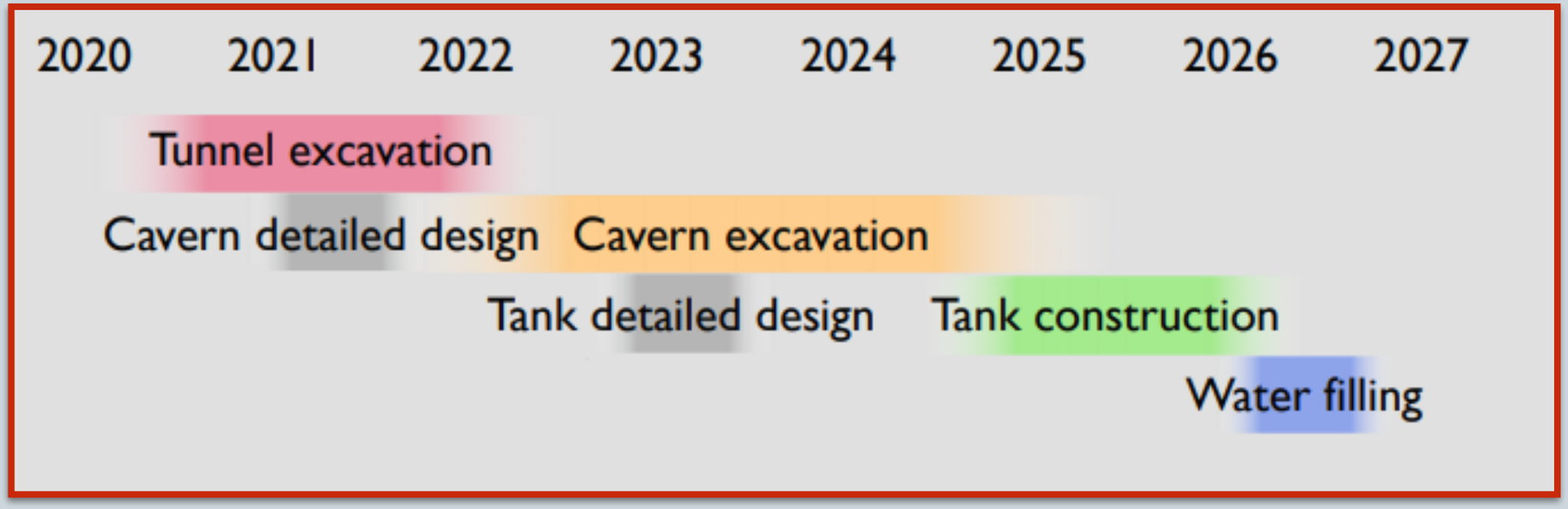
Photosensors

- 50 cm PMTs with box-and-line dynode
  - 2× timing resolution & 2× photon detection efficiency compared to Super-K PMTs
  - More pressure-resistant
  - Up to 40,000 in ID (40% photocoverage)
  - Mass production started in December 2020

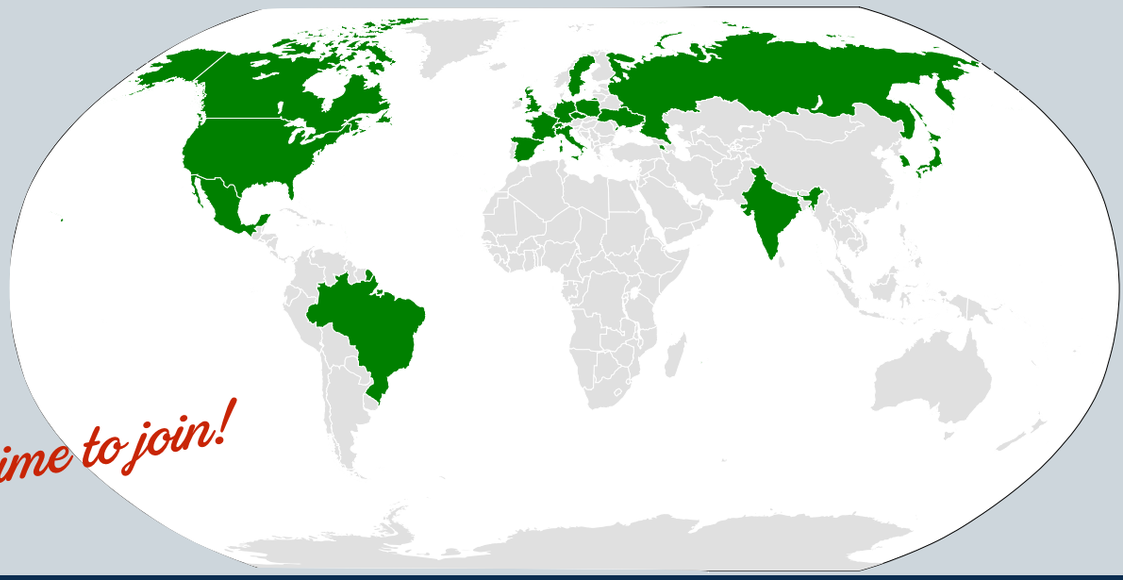


- Multi-PMT (mPMT) modules
  - 19× 8 cm PMTs in hemispherical pressure vessel
  - Directional information, improved timing & spatial resolution
  - Currently investigating hybrid design with 20,000 50 cm PMTs + several thousand mPMTs

Current Status

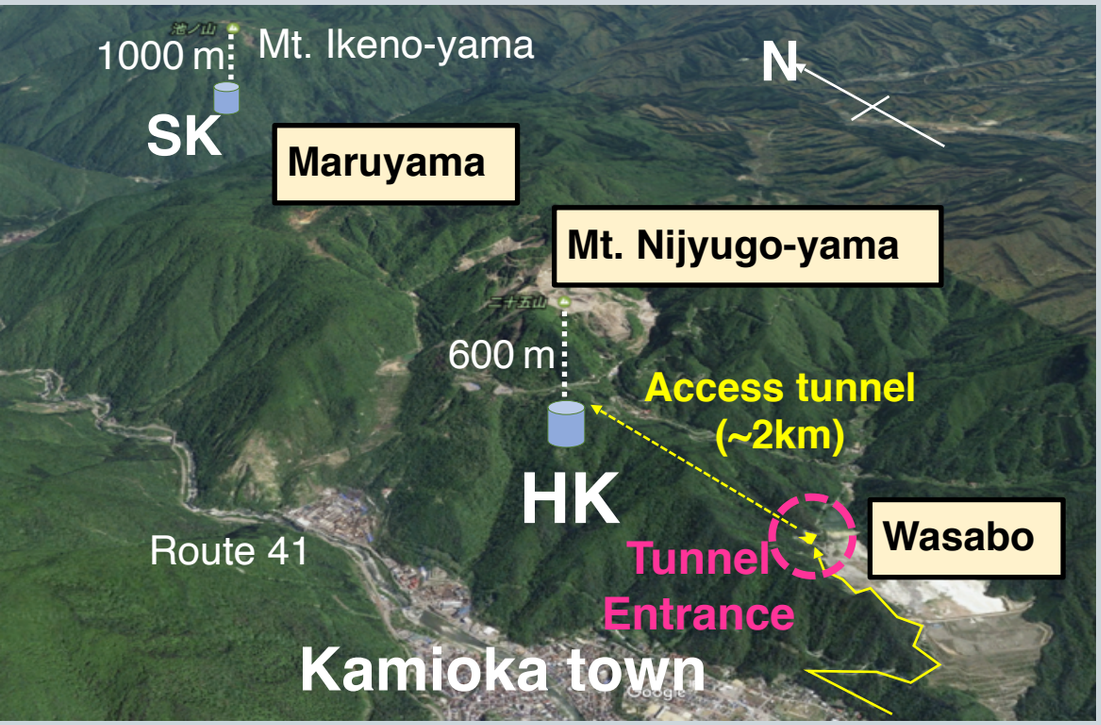


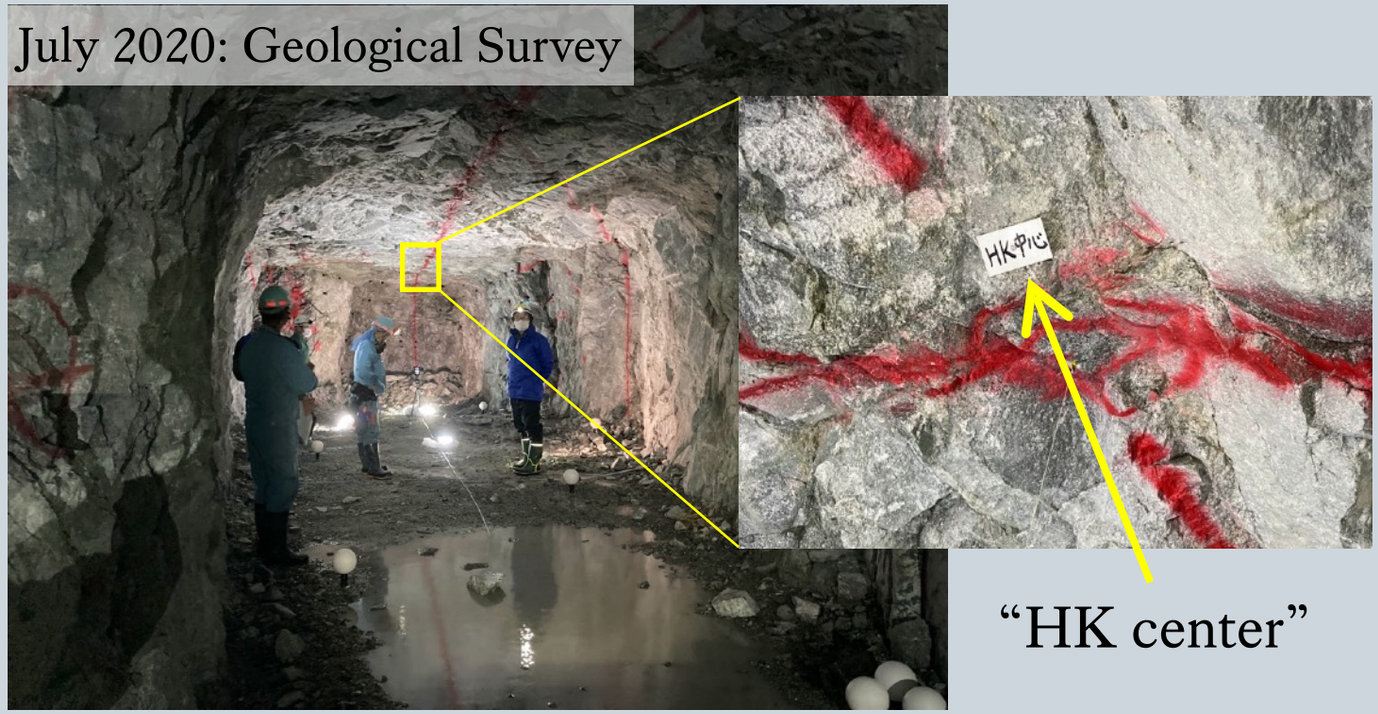
- Funding approved by Japanese government in 2020
- Geological survey in 2020, excavation has started
- Detector R&D still ongoing
- 400+ members from 19 countries:



Now is a great time to join!

Construction Progress





New Research Building at Kamioka

- It is under construction & will be completed later this year.
- It has 4 floors and 3,050 m^2 total floor area.

Dormitory rooms

Dining rooms

Many visiting researchers' rooms on 2nd and 3rd floor

Lab rooms to construct detector components

Big hall to accommodate about 150 people on the 1st floor.

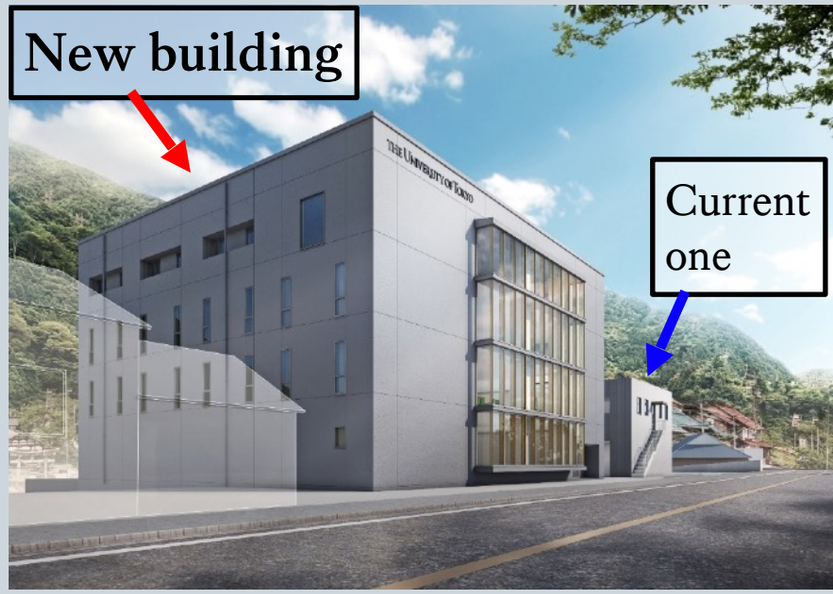
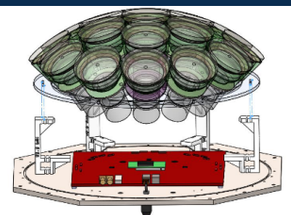
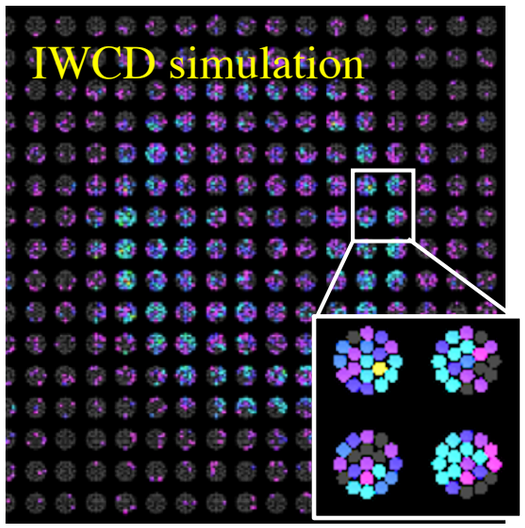


Image of new research building

Detector R&D for HK

Multi-PMT module:
(ref. KM3NeT)
High resolution Cherenkov ring imaging essential for IWCD
Consider to use for part of HK

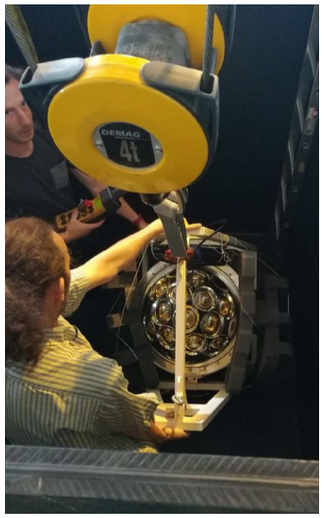




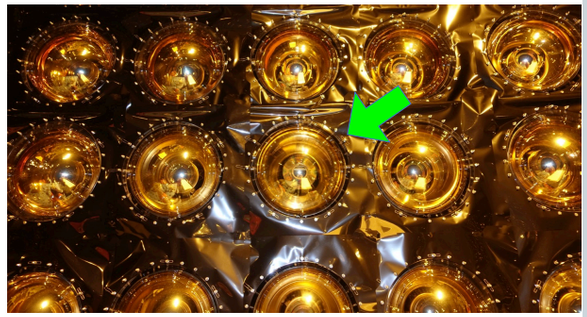
Prototype at TRIUMF

Electronics at INFN

20-inch MCP PMT:
Test in dark room

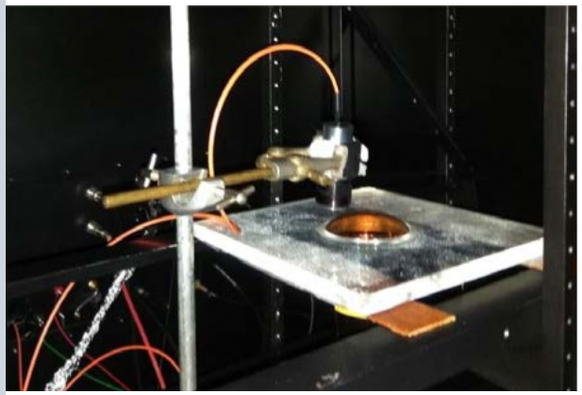


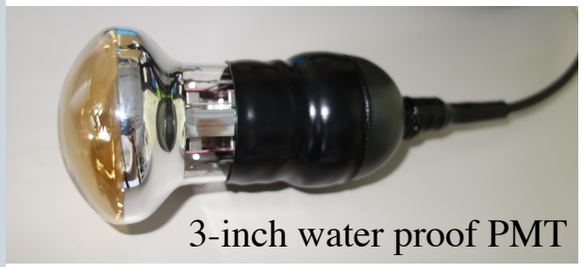
mPMT in Memphyno water tank in France



Box&Line PMT in Super-K

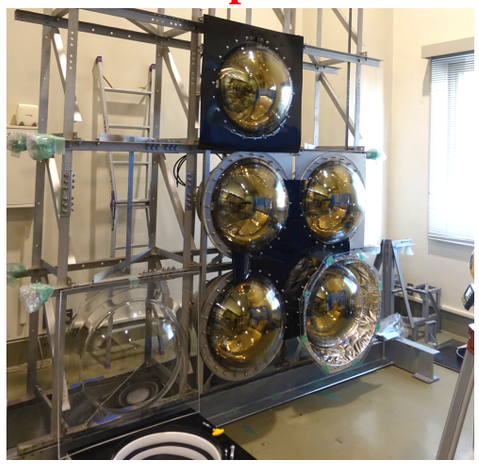
Outer detector:
PMT + WLS plate (UK)



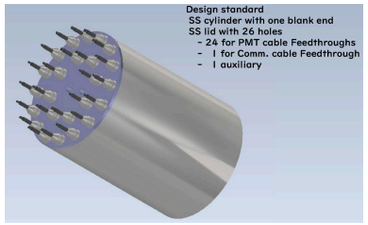


3-inch water proof PMT

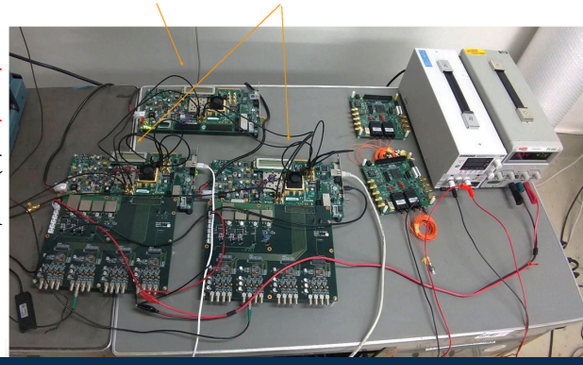
ID mockup at ICRR



Underwater electronics:
Case design and feedthrough



Sync and clock system
test bench at TokyoTech



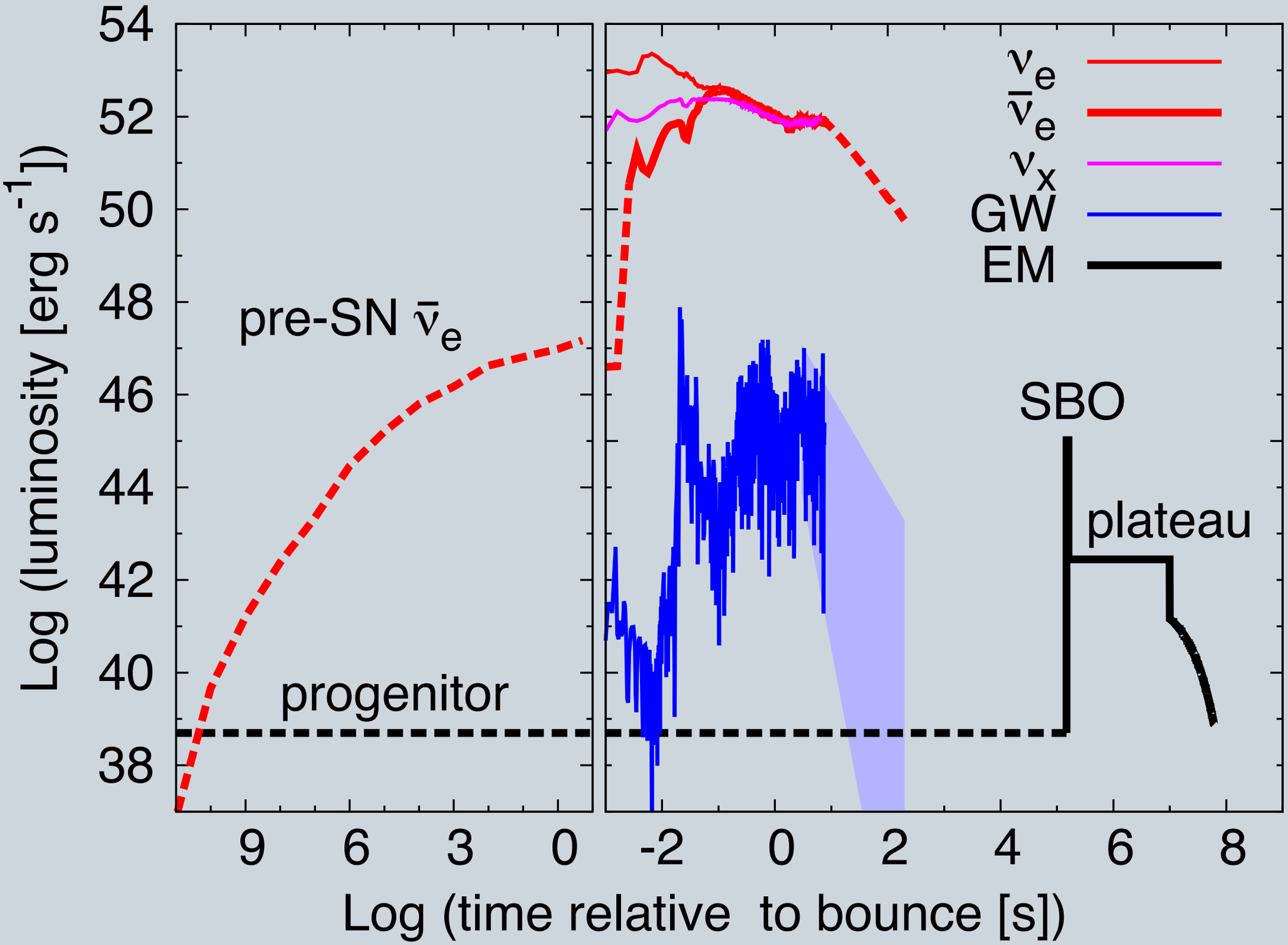
PMT cover
in Spain

From slides by M. Ishitsuka (Neutrino 2020)

Physics Goals

- Precision measurements of neutrino oscillation parameters (including δ_{CP})
- Proton decay searches (reaching ~10^{35} years)
- Neutrino Astronomy
  - Supernova Neutrinos
  - Multi-Messenger Astronomy
  - Solar neutrinos (~100 events per day)
  - Indirect searches for Dark Matter annihilating/decaying into neutrinos
- … and more!

Supernova Neutrino Signal

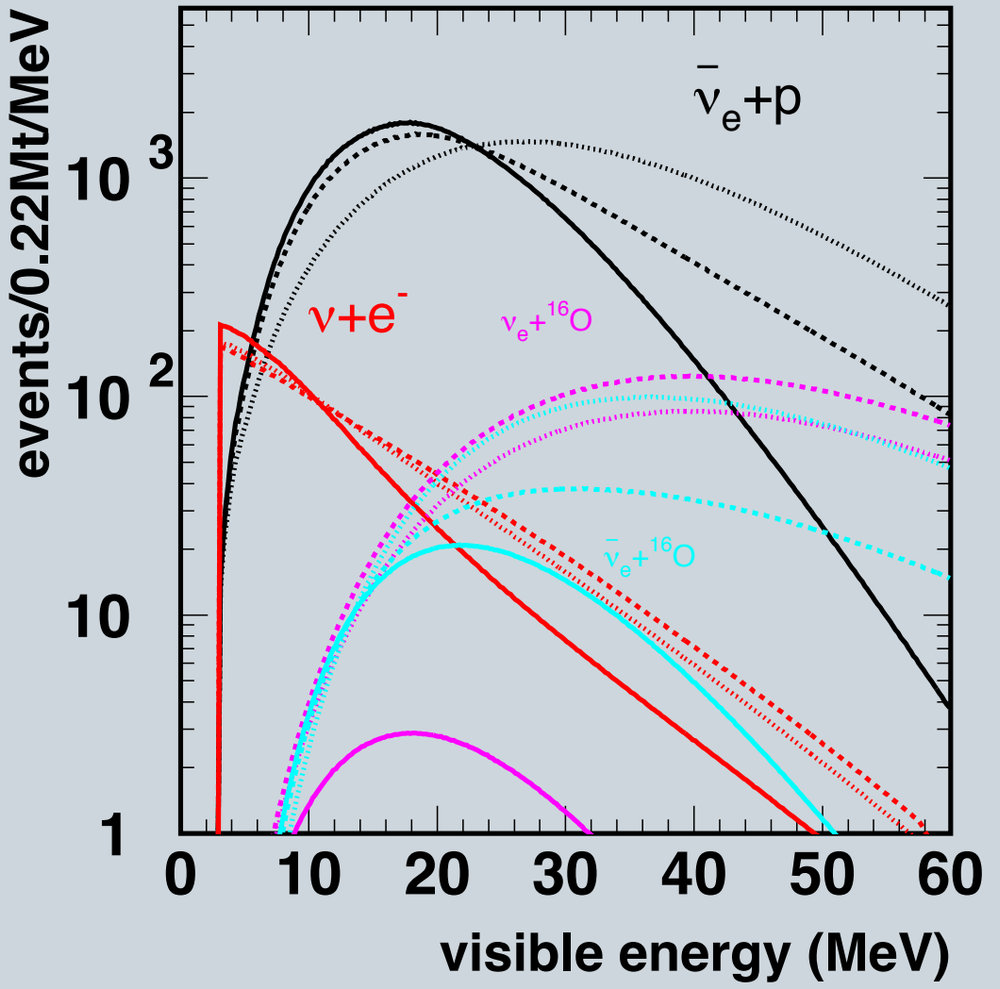


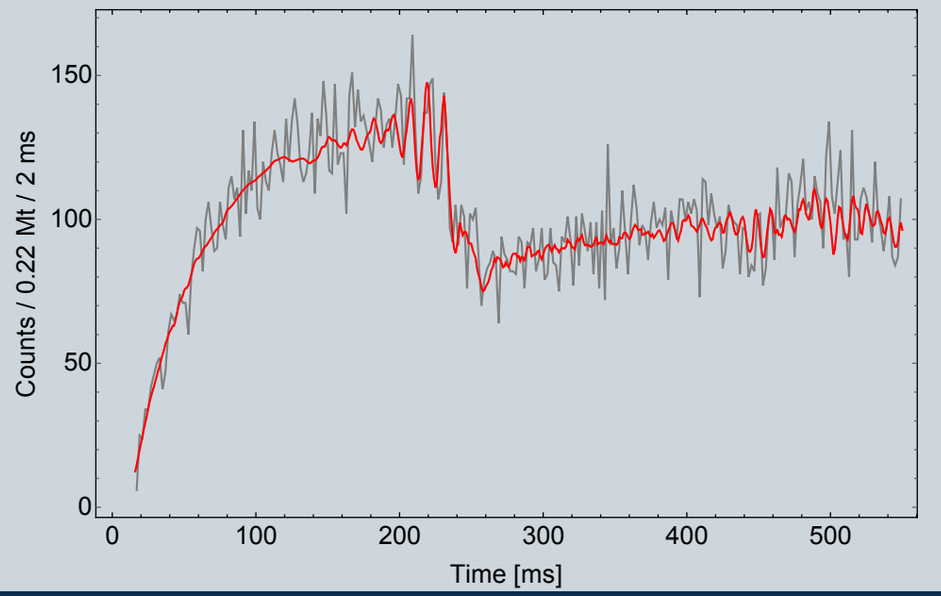
arXiv:1602.03028

Supernova ν Burst

- At 10 kpc: O(10^5) events in ~10 s
- Precise event-by-event time & energy information (cf. IceCube, KM3NeT)
- Directionality: ~1° (via νe-scattering)
- Most sensitive to $\bar{\nu}_e$ (~90% inverse beta decay on H)

➔ Detailed information on SN explosion mechanism (e.g. Standing Accretion Shock Instability – SASI)





Supernova Model Discrimination

- To understand explosion mechanism, need to compare observation with simulations
  - Look for specific features (e.g. SASI: Lund et al. arXiv:1006.1889)
  - Compare full t & E dependence (JM, arXiv:2002.01649 & 2101.05269)

> "There is a rather long list of numerical challenges and code verification issues yet to be met collectively by the world's supernova modelers.
> The results of different groups are still too far apart to lend ultimate credibility to any one of them."
>
> — Skinner, Burrows, Dolence (arXiv:1512.00113)

Supernova Model Discrimination

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  - Look for specific features (e.g. SASI: Lund et al. arXiv:1006.1889)
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- Use 5 supernova models
- 1000 MC data sets per model using new event generator https://github.com/JostMigenda/sntools
- Full detector simulation & reconstruction toolchain
- Unbinned likelihood: Which model best matches the reconstructed t & E distribution?

(Details in backup slides.)

True model (100 events*)	Identified as: Couch	Nakazato	Tamborra	Totani	Vartanyan
Couch	795	57	122	12	14
Nakazato	33	**961**	3	1	2
Tamborra	84	0	853	33	30
Totani	4	0	16	**979**	1
Vartanyan	0	1	17	3	**979**

True model (300 events*)	Identified as: Couch	Nakazato	Tamborra	Totani	Vartanyan
Couch	**982**	2	16	0	0
Nakazato	1	**999**	0	0	0
Tamborra	16	0	**980**	2	2
Totani	0	0	0	**1000**	0
Vartanyan	0	0	0	0	**1000**

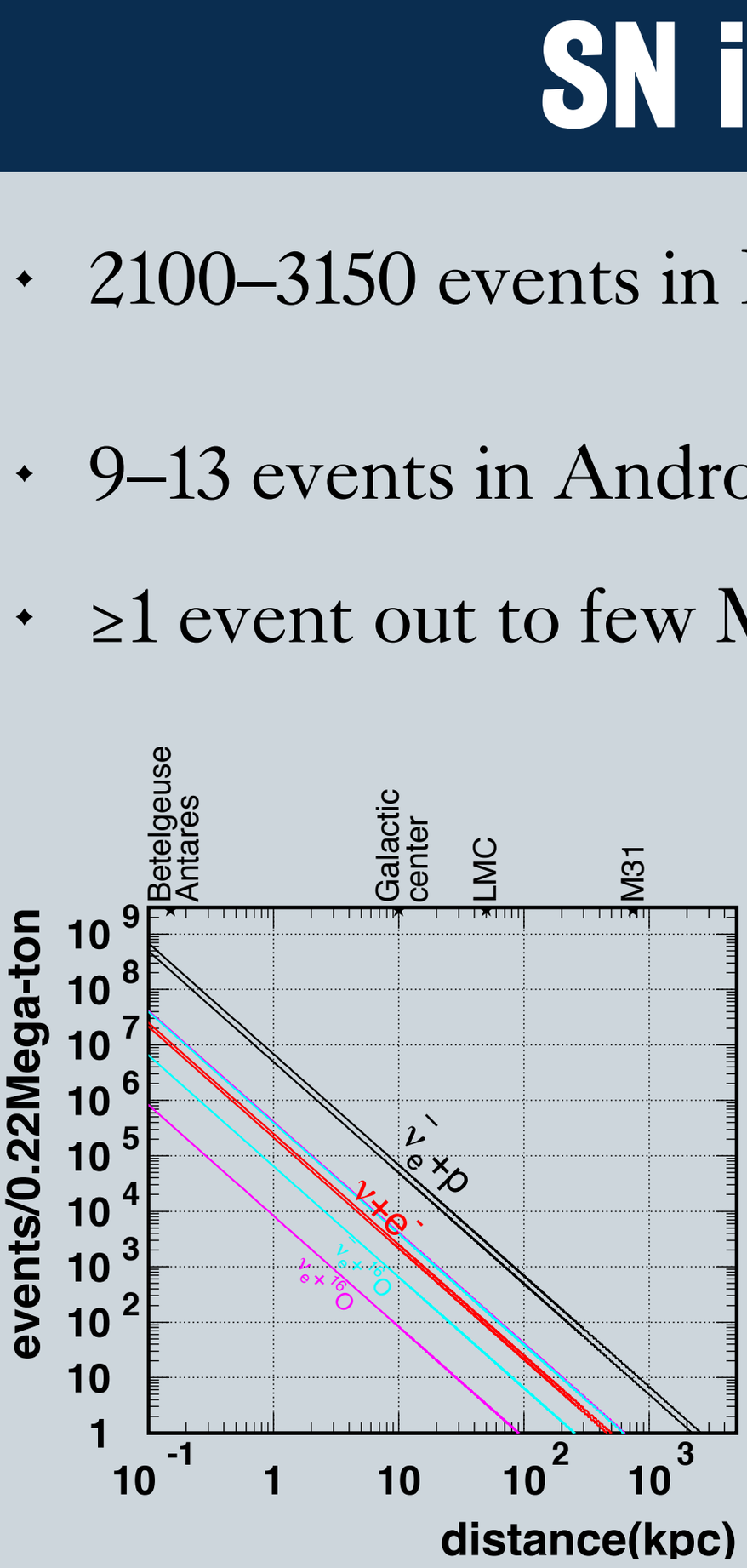
* during 20–520ms after core bounce, assuming Normal Ordering

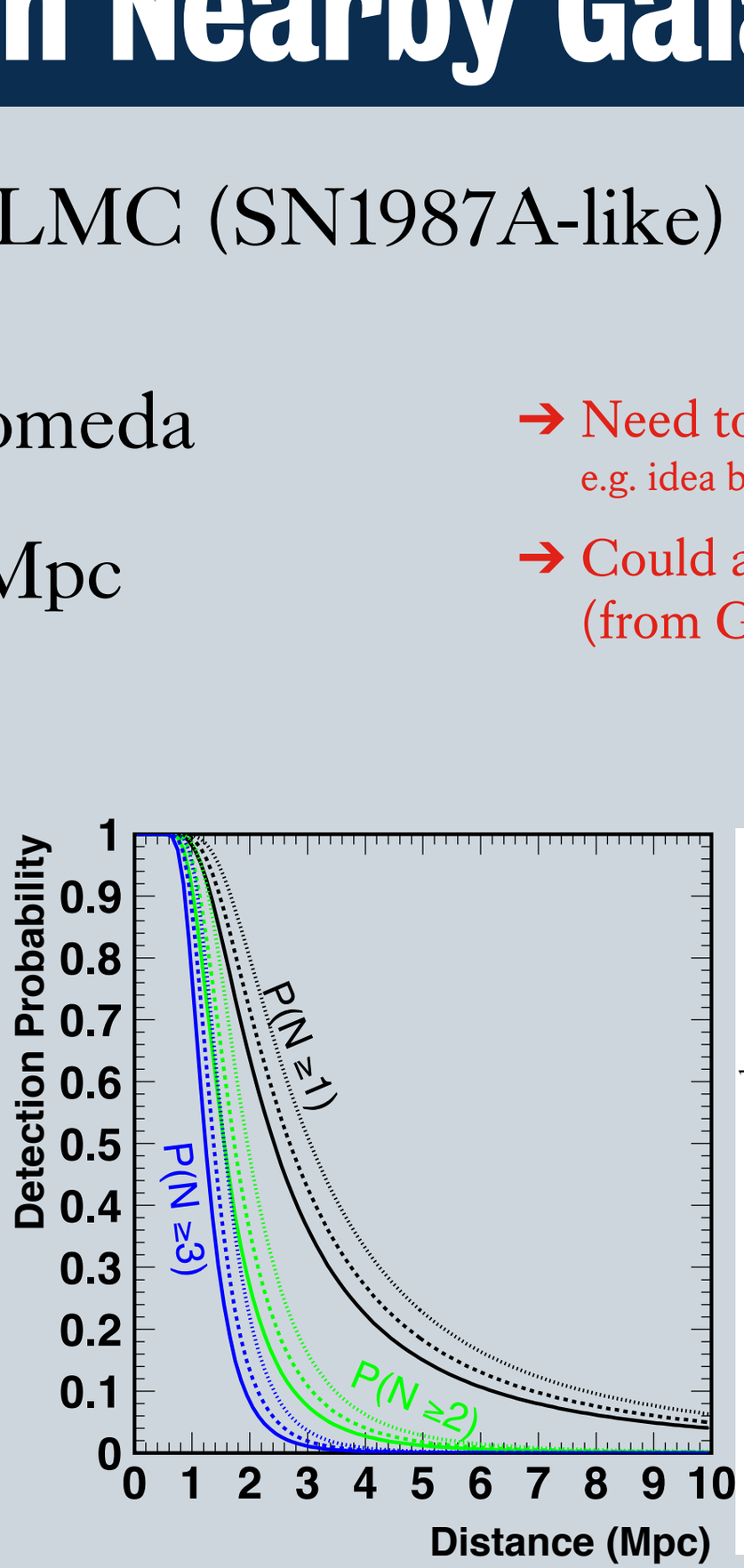
SN in Nearby Galaxy

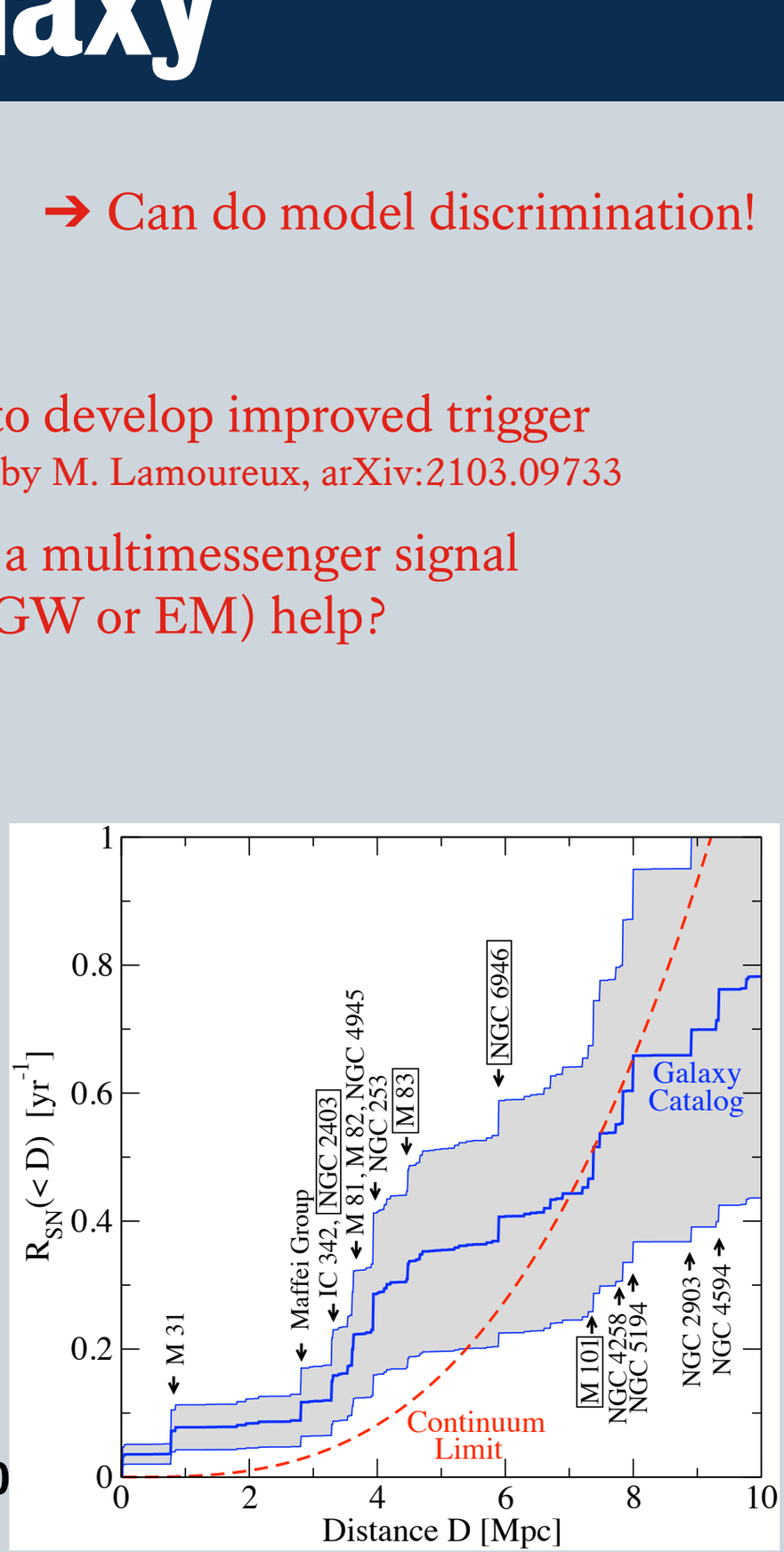
- 2100–3150 events in LMC (SN1987A-like) ➔ Can do model discrimination!
- 9–13 events in Andromeda
- ≥1 event out to few Mpc

➔ Need to develop improved trigger
e.g. idea by M. Lamoureux, arXiv:2103.09733

➔ Could a multimessenger signal (from GW or EM) help?

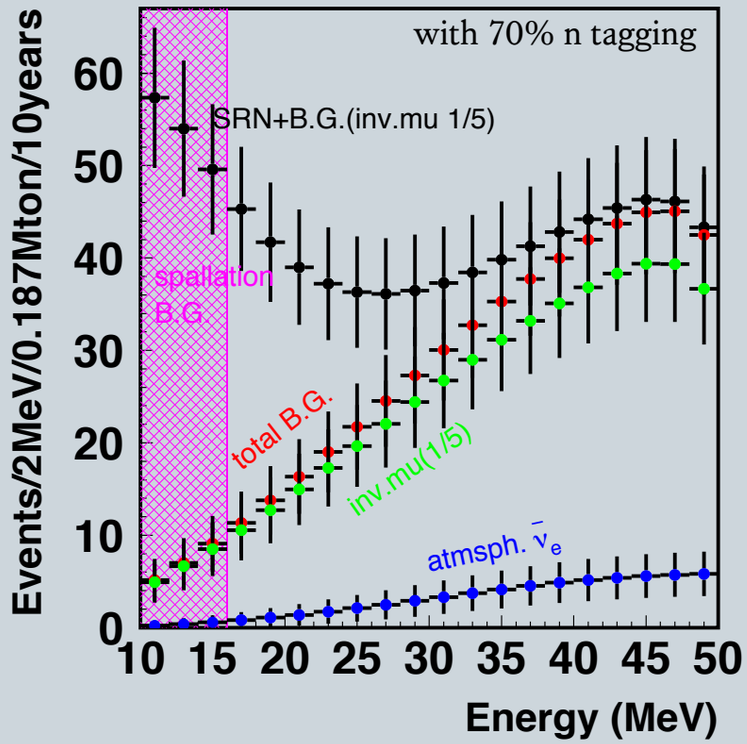


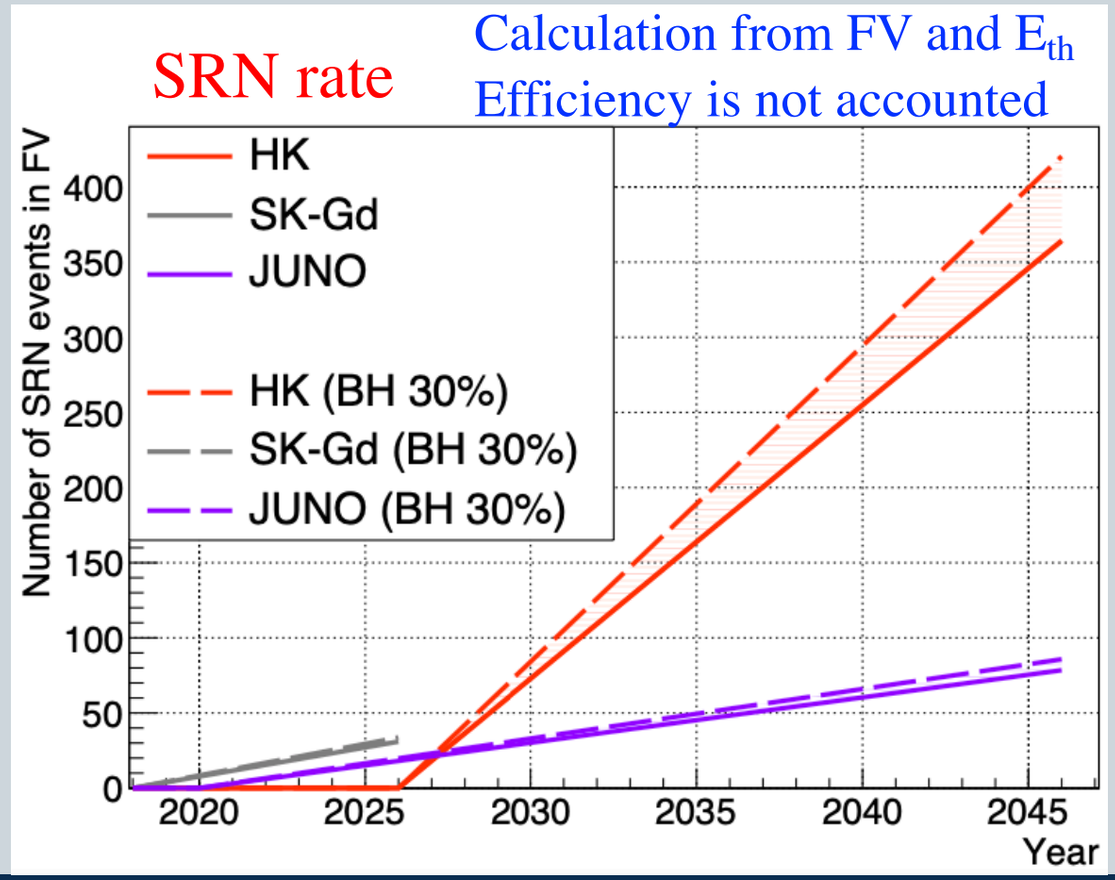


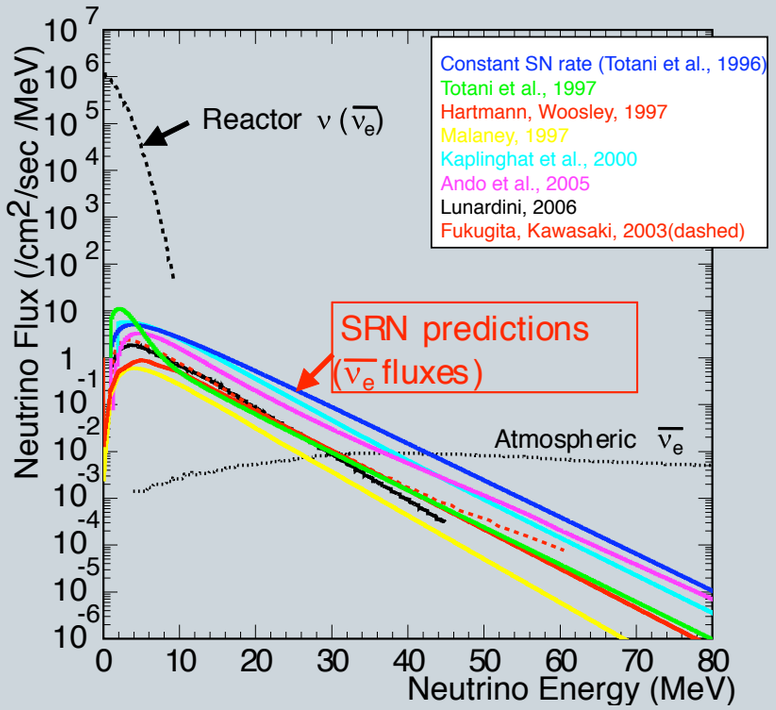


Supernova Relic Neutrinos

- a.k.a. Diffuse Supernova Neutrino Background (DSNB)
- ν from all SN integrated over the history of the universe
  - Encode history of star formation
  - Information on dim SNe & black hole formation (➔ talk by MDV yesterday)
- SK-Gd: First detection — HK: first spectrum







Multi-Messenger Astronomy

- Expect an order-of-magnitude improvement over Super-K, mainly due to increased detector volume

- Wide range of transient sources:
  - Gamma-Ray Bursts
    - Tens of MeV scale (SK result: arXiv:2101.03480)
    - GeV–PeV scale (if efficient UHECR acceleration in GRBs)
  - Binary mergers (SK results: arXiv:1608.08745, arXiv:1802.04379, arXiv:2104.09196)
  - Blazars like TXS 0506+056 (SK result: arXiv:1910.07680)
  - SN shock wave interacting with circumstellar material
    - e.g. Eta Carinae: large CSM mass, expect ~300 high-energy neutrinos in HK over ~months
  - High-energy neutrinos from solar flares (prediction: arXiv:0812.4592)

Conclusions

- Hyper-Kamiokande is a next-gen neutrino detector
  - Excavation has begun, data-taking starts 2027
- Unique capabilities for neutrino astronomy
  - SN: High statistics (~10^5 events at 10kpc), event-by-event time & energy information
    - Model discrimination possible out to ~100 kpc
  - Multi-messenger astronomy from MeV to TeV
  - Solar neutrinos, indirect DM searches, ...