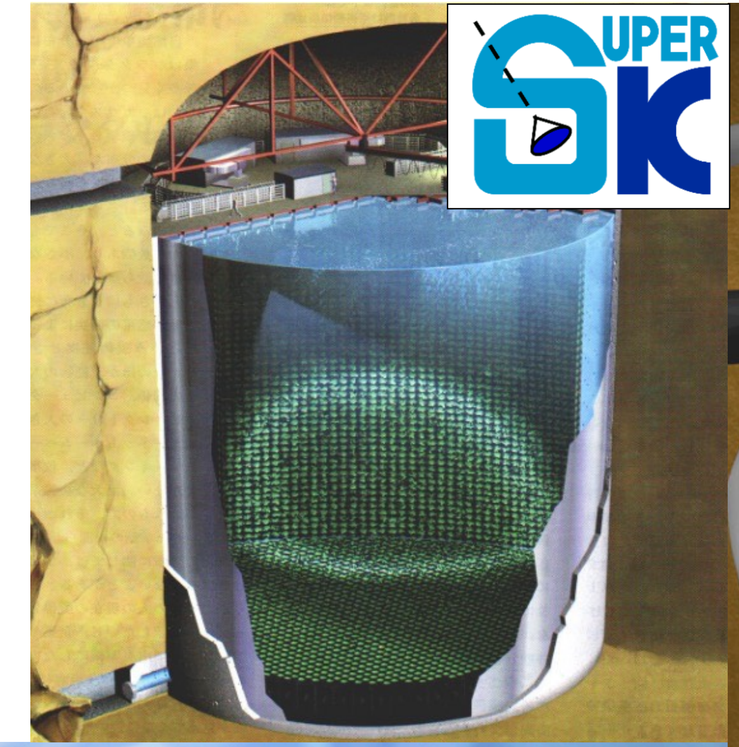
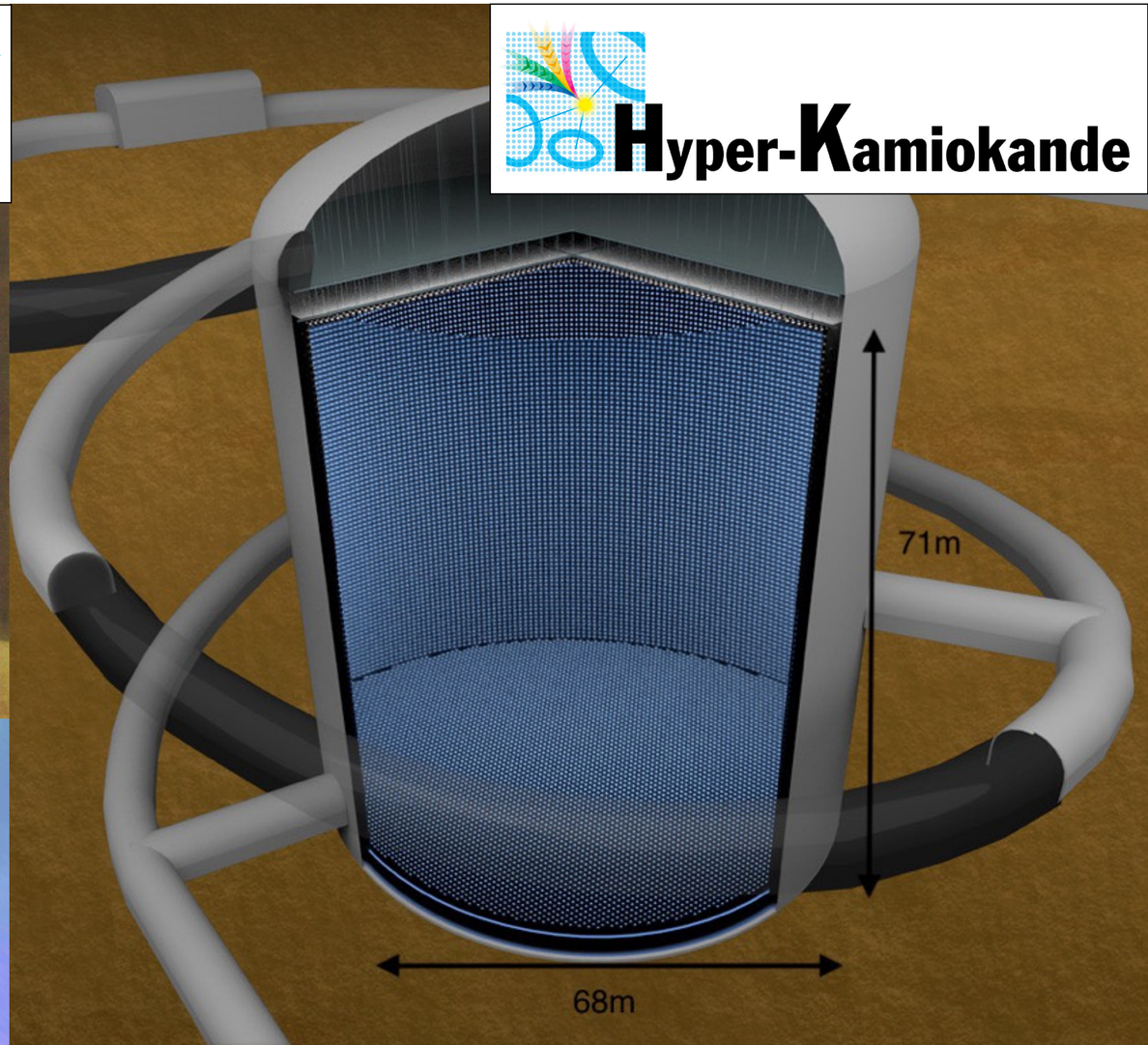
Introduction to the experiments Super-K and Hyper-K

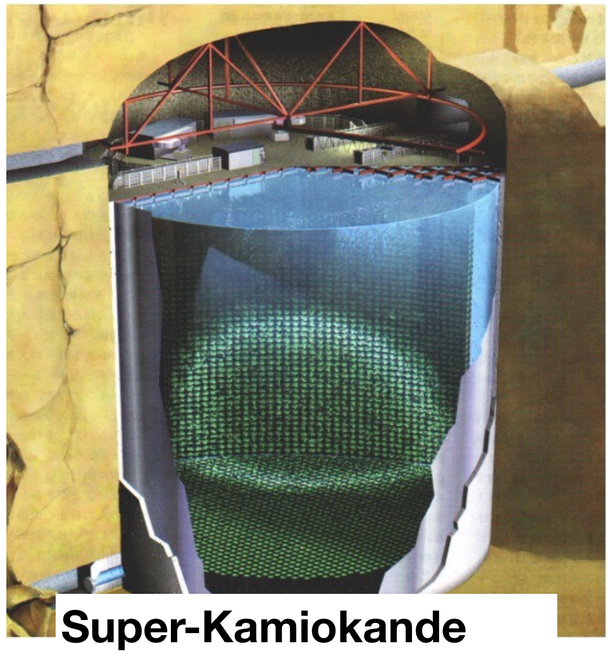
K. Okumura (ICRR, Univ. of Tokyo)





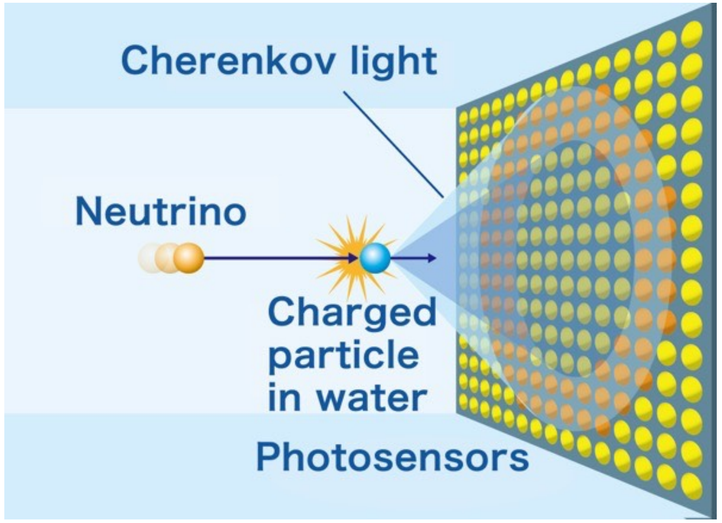
SYNERGIES AT NEW FRONTIERS AT
GAMMA-RAYS, NEUTRINOS AND GRAVITATIONAL WAVES
Institute for Cosmic Ray Research (ICRR)
Tokyo, Japan
24 -25 MARCH 2022

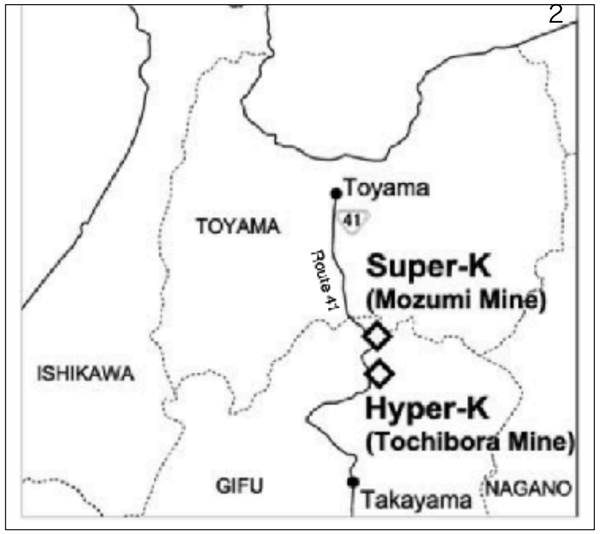
Super-K and Hyper-K



Super-Kamiokande

- Water Cherenkov detector
- Located at Ikeno-yama 1000m underground
- fiducial volume 22.5 kton
- ~11000 50cm PMTs
- ~1000 OD PMTs
- Since 1996
- SK-Gd started





1996 SK-I — Photo coverage 40%

2002 SK-II — 20%

Accident

2006 SK-III — 40%

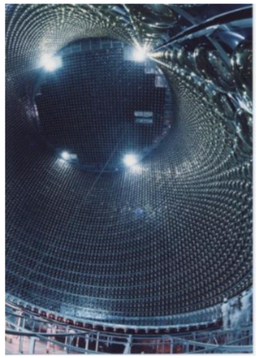
Full reconstruction

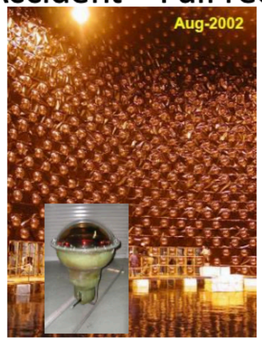
2008 SK-IV — 40%

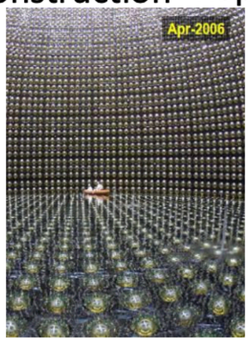
Replace electronics & DAQ system

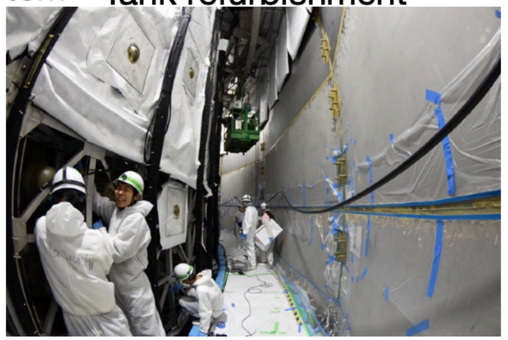
2018 SK-V SK-Gd — 40%

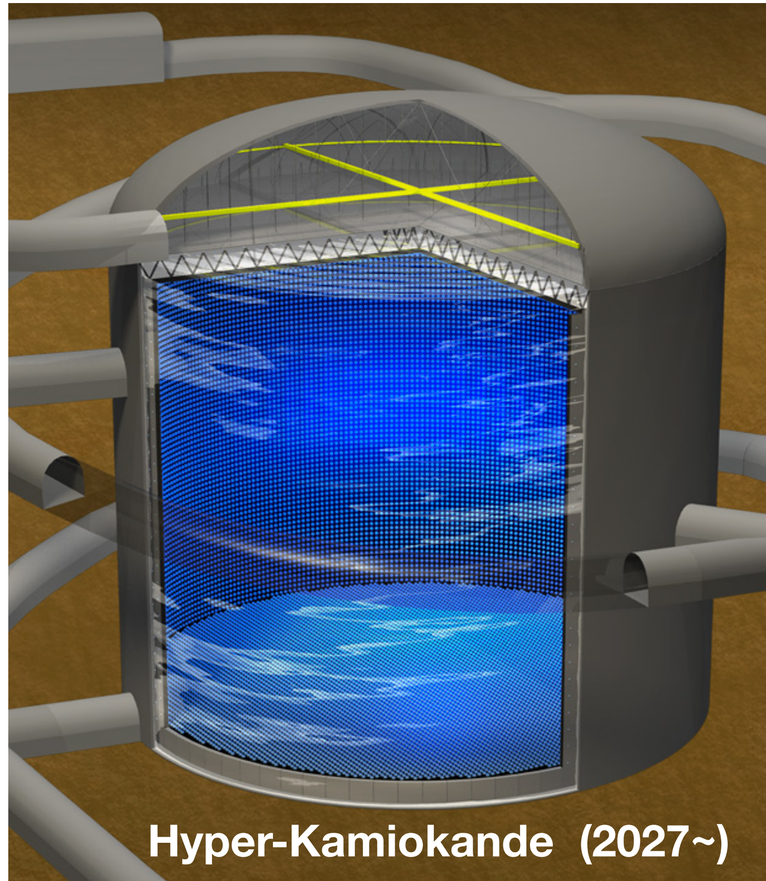
Tank refurbishment







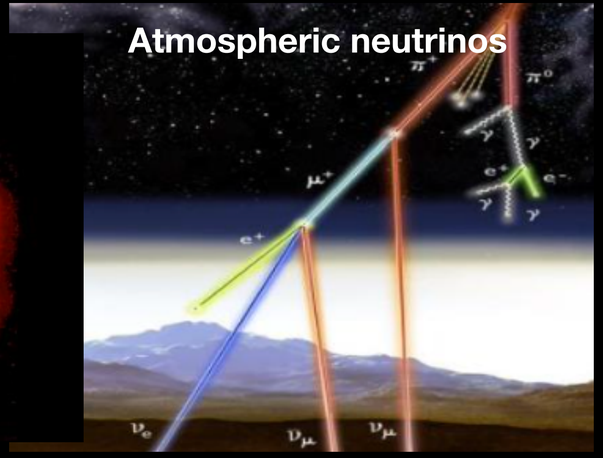




Hyper-Kamiokande (2027~)

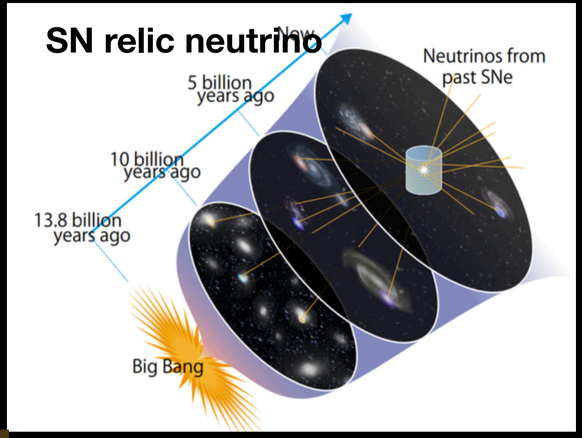
Solar neutrino

Atmospheric neutrinos

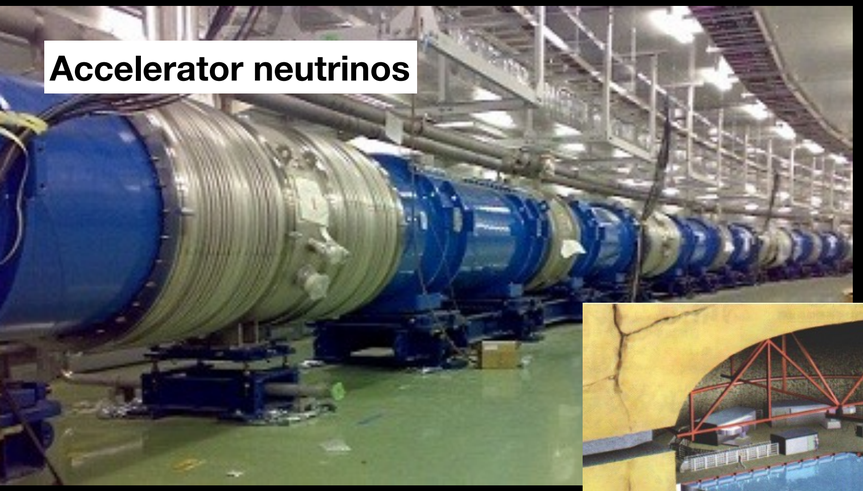


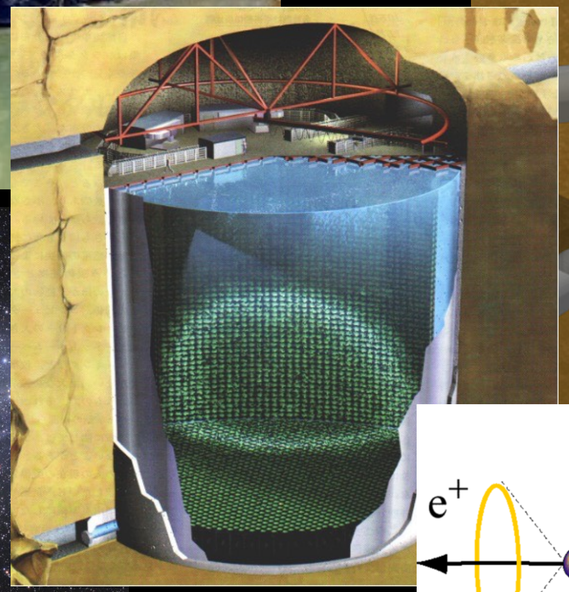
Supernova

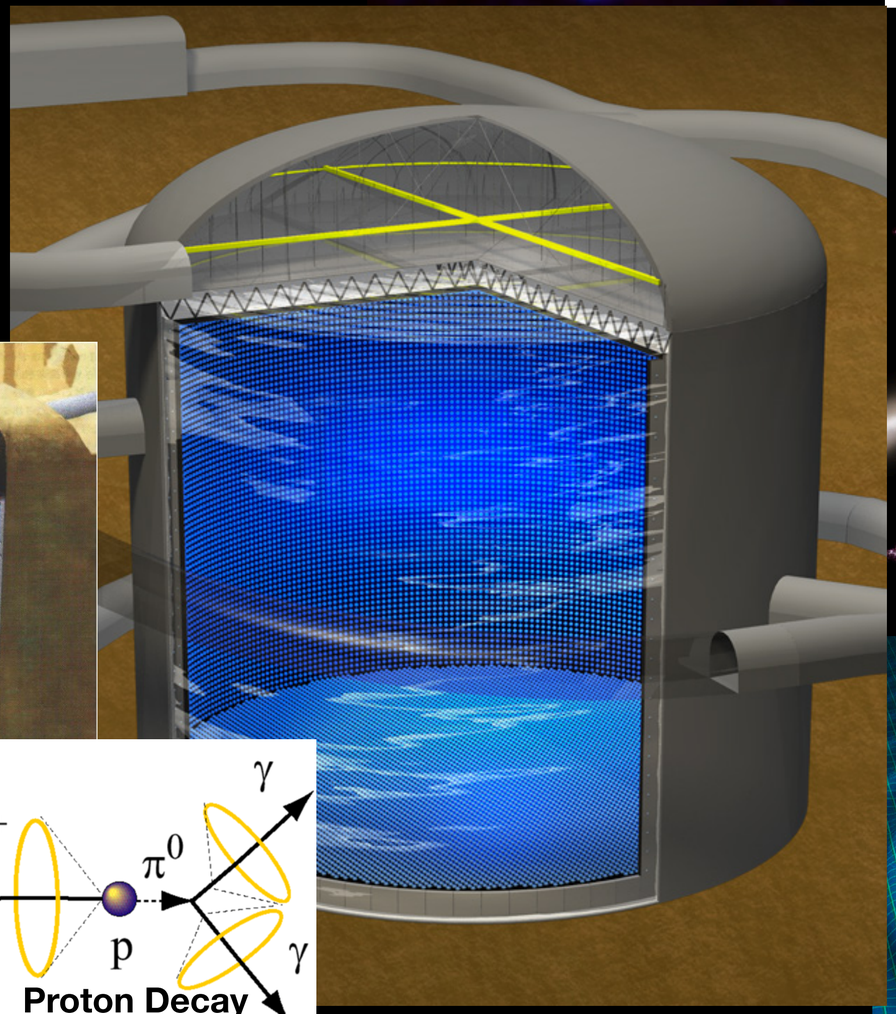
SN relic neutrino



Accelerator neutrinos



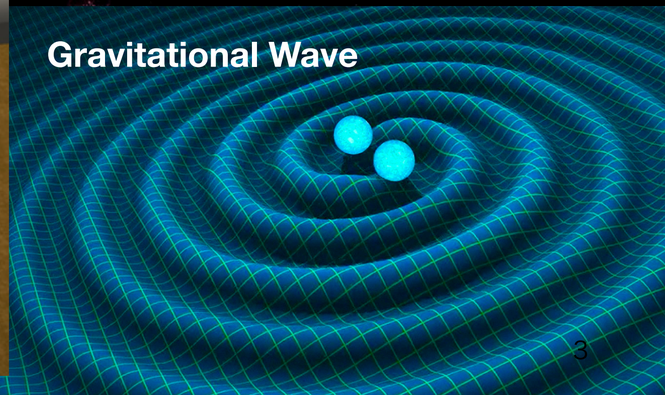




HE astro objects (AGN, GRB, ..)

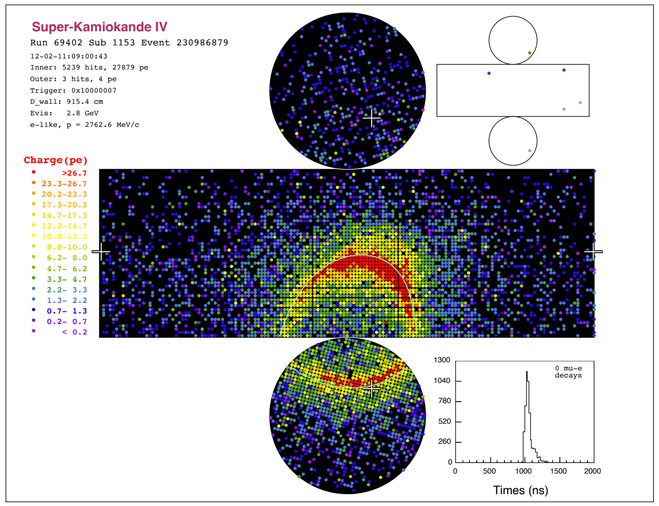
Dark Matter

Gravitational Wave

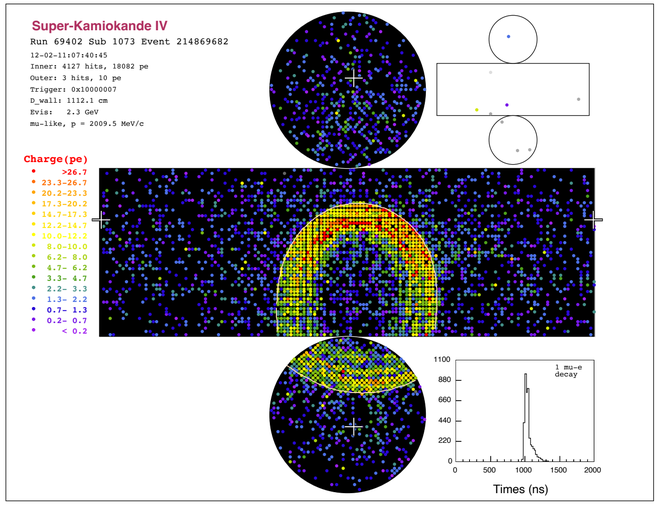


Neutrino Observation in SK / HK

e-like (ν_e / $\bar{\nu}_e$)



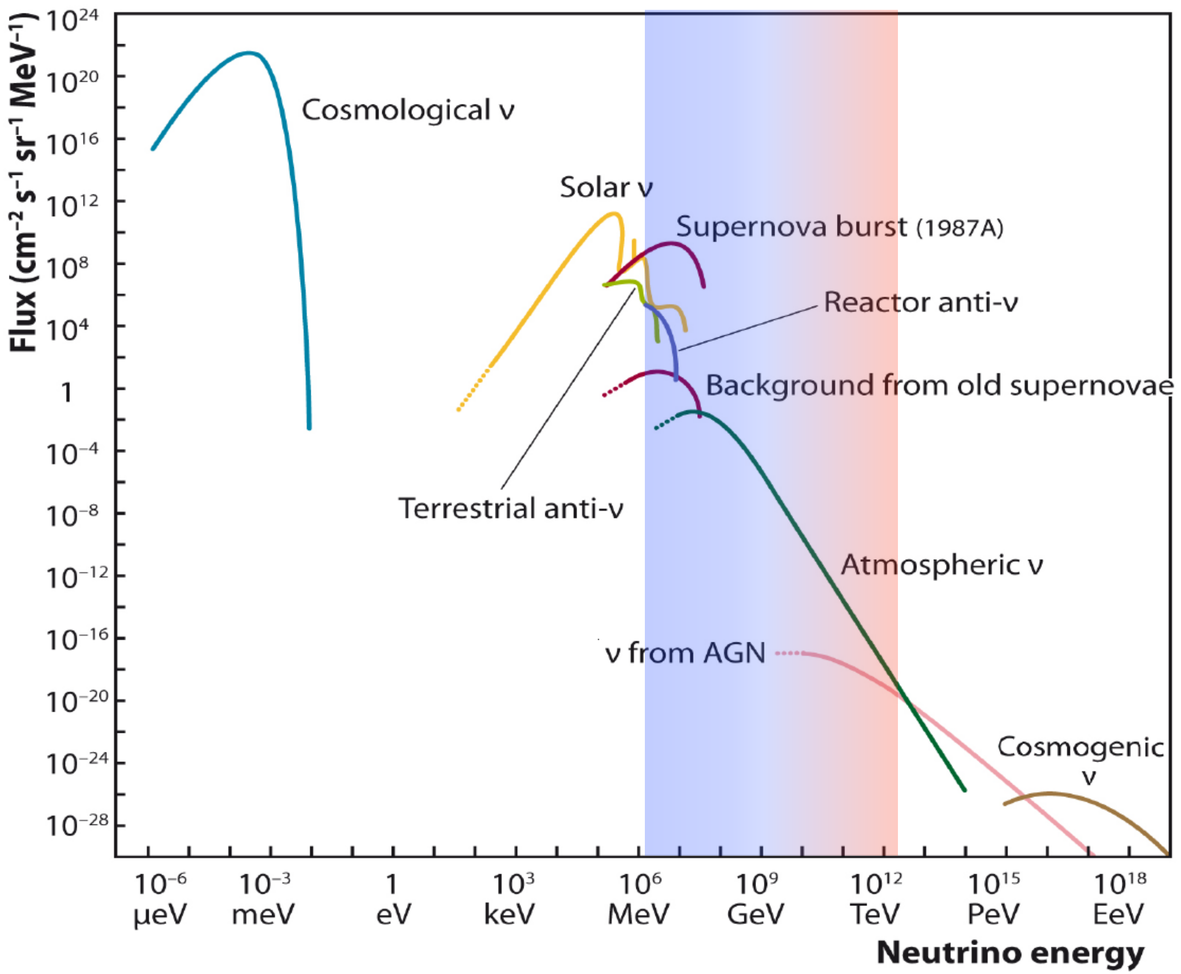
μ-like (ν_μ / $\bar{\nu}_\mu$)



- **Observables in SK / HK**
  - Event timing
    vertex reconstruction
  - Energy
    inferred by #(Cherenkov photons)
    (number of hits or PMT charge)
  - Direction
    Cherenkov ring direction
  - Particle ID
    Cherenkov ring pattern

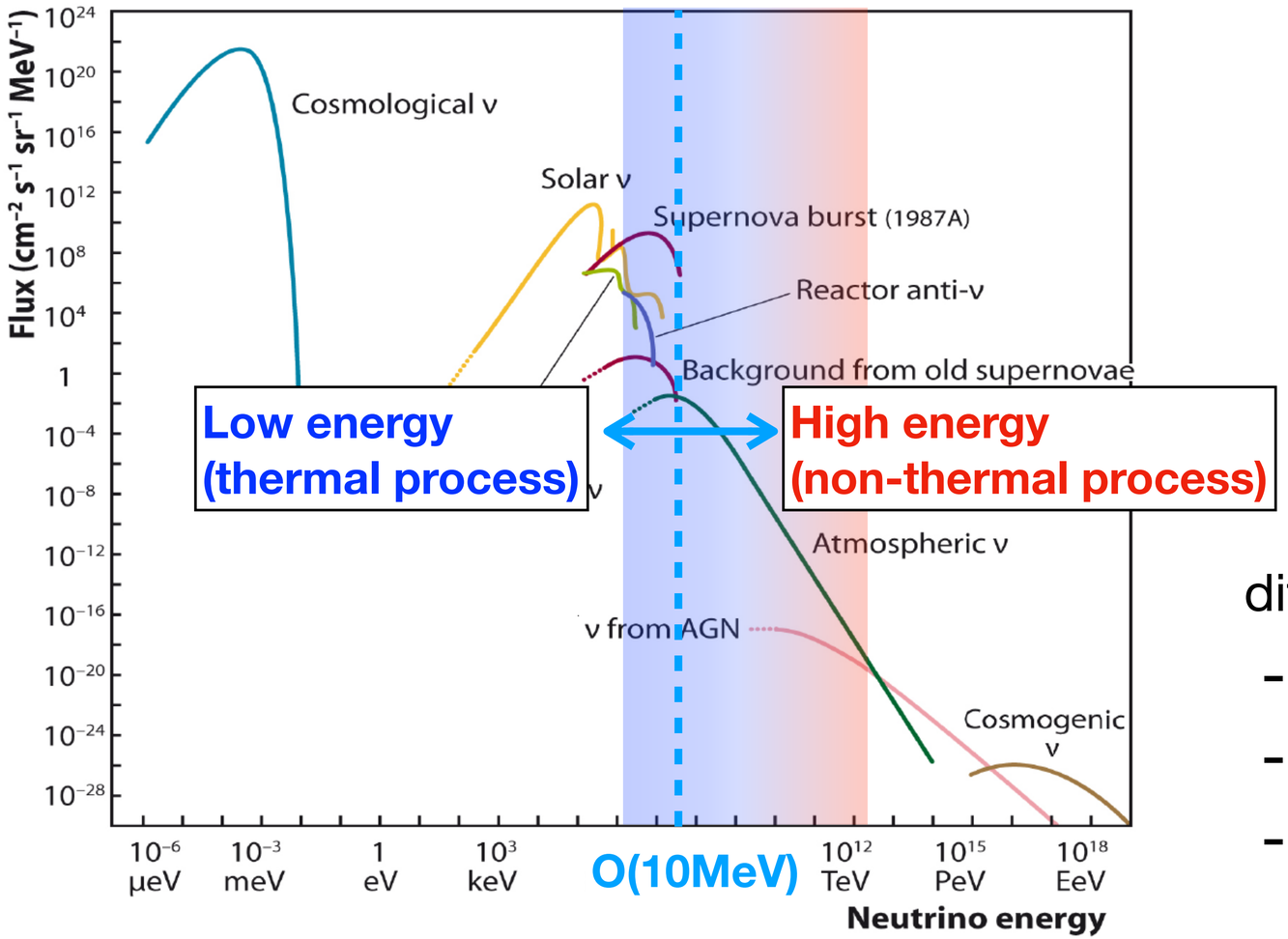
Neutrino Observation in SK / HK

MeV GeV TeV



Neutrino Observation in SK / HK

MeV GeV TeV



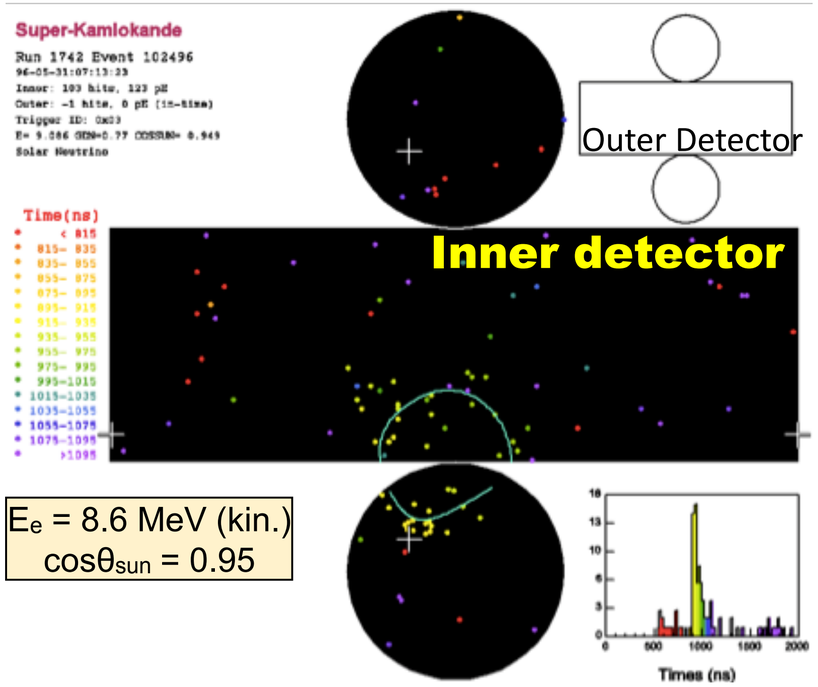
different …

- neutrino interaction
- backgrounds
- analysis method

Neutrino Observation in SK / HK

MeV GeV TeV

Low energy observation
(E < several 10 MeV)



E_e = 8.6 MeV (kin.)
$\cos\theta_{sun}$ = 0.95

- **Electron elastic scattering**

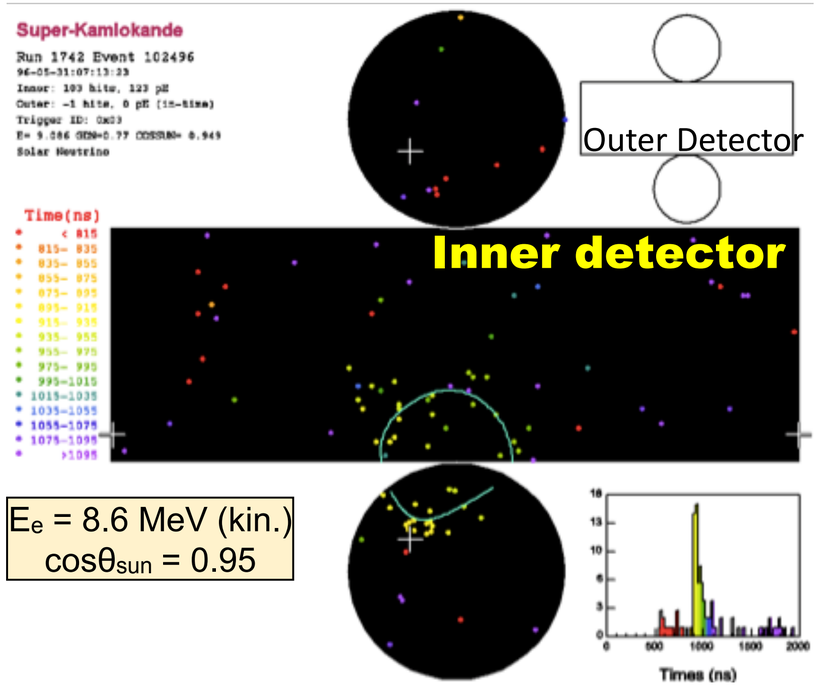
$$\nu_x + e^- \rightarrow \nu_x + e^-$$

  - all neutrinos are sensitive
  - good directionality
  - smaller cross sections

Neutrino Observation in SK / HK

MeV **GeV** **TeV**

Low energy observation
(E < several 10 MeV)



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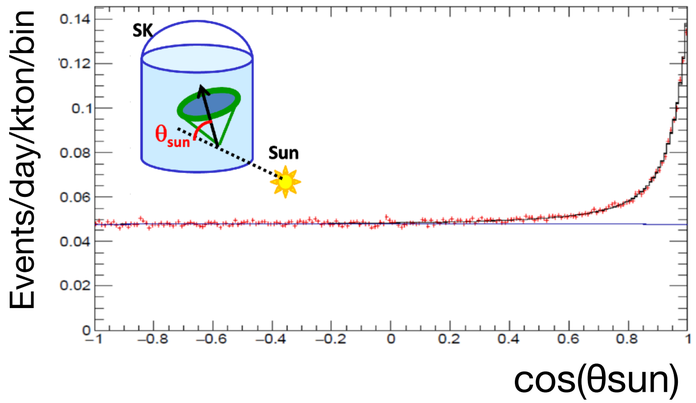
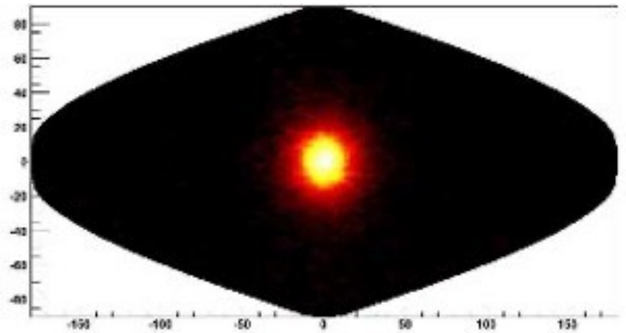
Solar neutrino observation

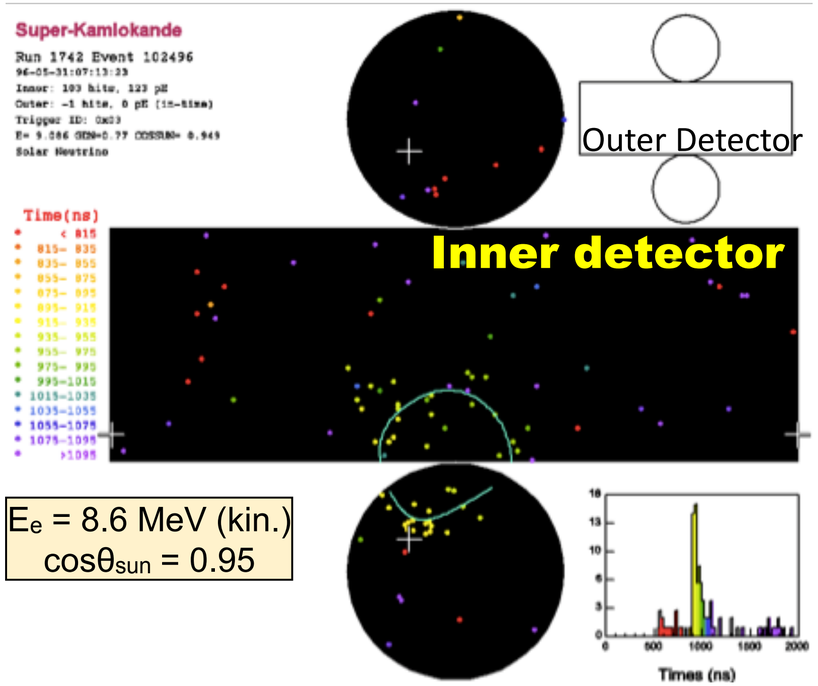




Neutrino Observation in SK / HK

MeV GeV TeV

Low energy observation
(E < several 10 MeV)



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  - smaller cross sections

- **Inverse beta reaction**

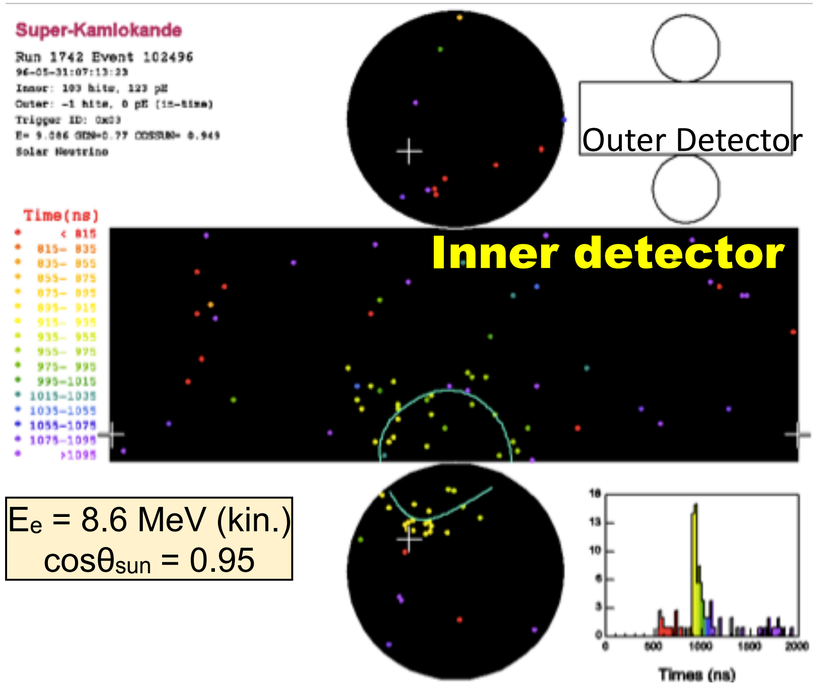
$$\bar{\nu}_e + p \rightarrow e^+ + n$$

  - larger cross section
  - sensitive only for $\bar{\nu}_e$
  - directionality ×

Neutrino Observation in SK / HK

MeV **GeV** **TeV**

Low energy observation
(E < several 10 MeV)



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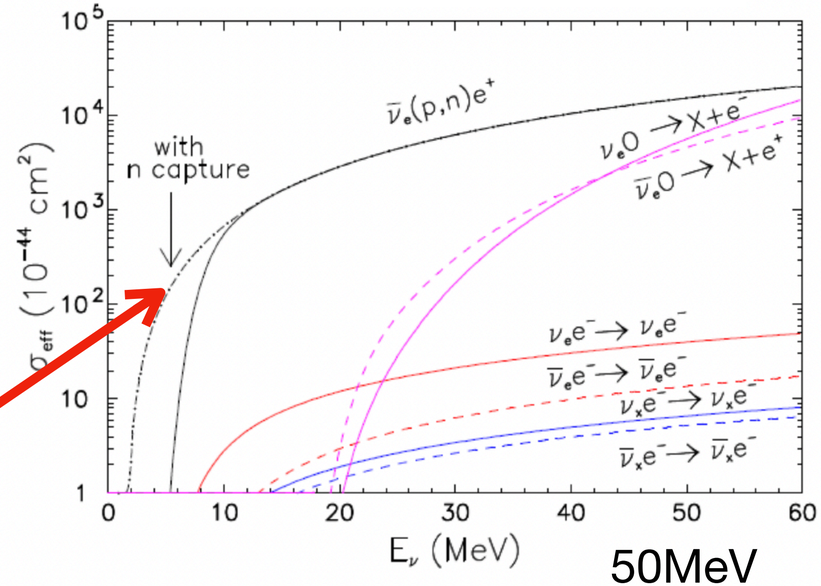
Low-E neutrino cross sections

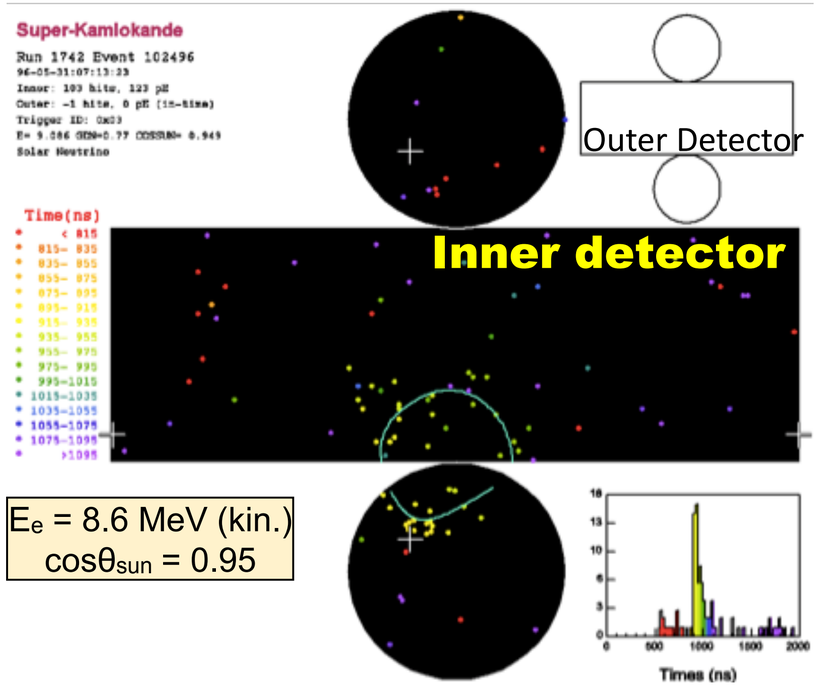


50MeV

Neutrino Observation in SK / HK

MeV GeV TeV

Low energy observation
(E < several 10 MeV)



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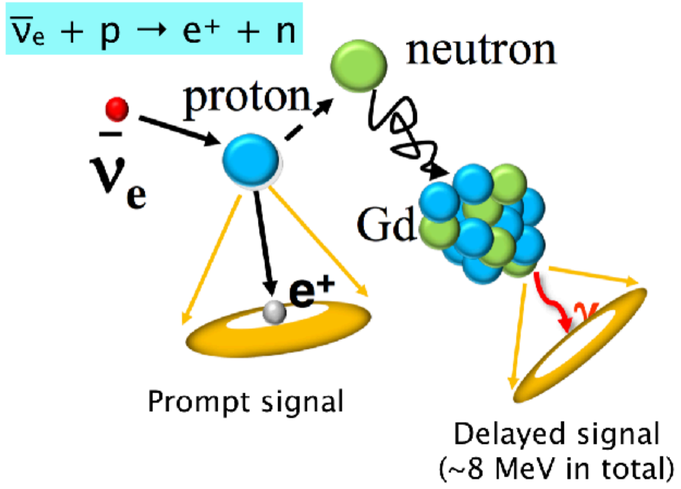
$$\bar{\nu}_e + p \rightarrow e^+ + n$$

  - larger cross section
  - sensitive only for $\bar{\nu}_e$
  - directionality ×

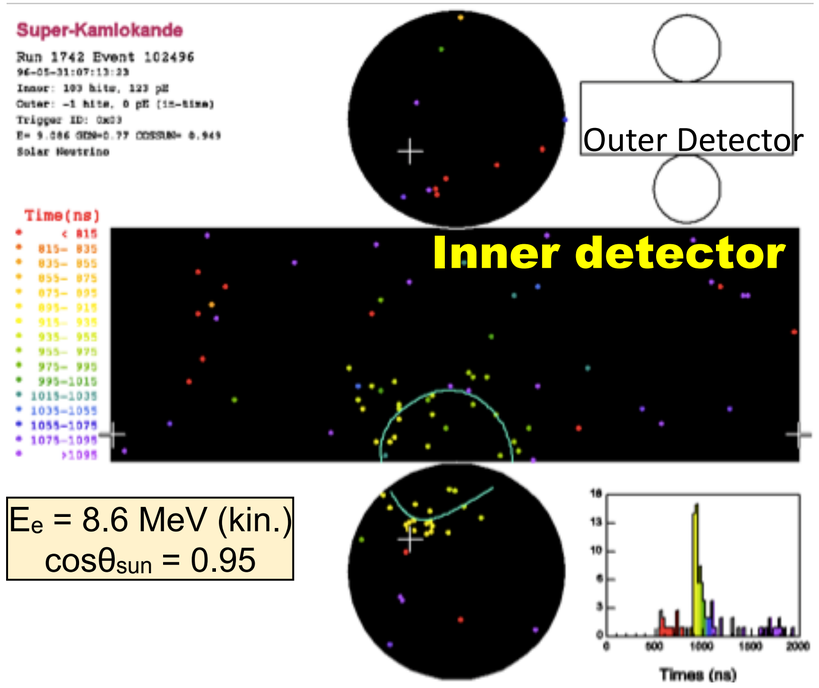
- recoiled neutron is useful for $\bar{\nu}_e$ identification
  - n + H : 2.2 MeV γ (eff. ~ 20%)
  - n + Gd : ~8MeV γ (eff. 50~90%)



Neutrino Observation in SK / HK

MeV GeV TeV

Low energy observation
(E < several 10 MeV)



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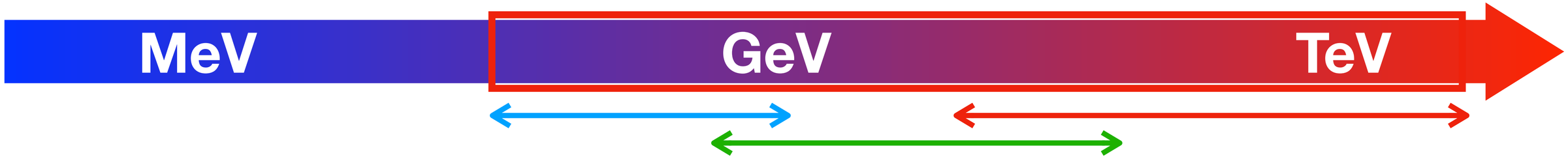
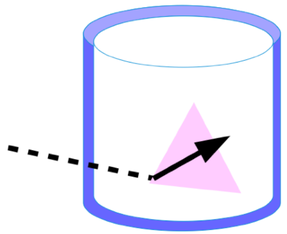
  - sensitive only for $\bar{\nu}_e$
  - directionality ×

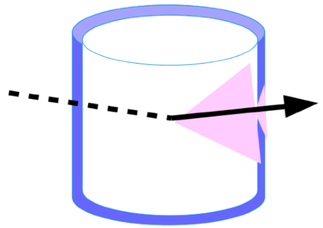
- Backgrounds for astro observation
  - radioactivity
  - spallation produced by cosmic muons
  - random noise
  - other neutrinos (solar, SN, reactor, terrestrial)

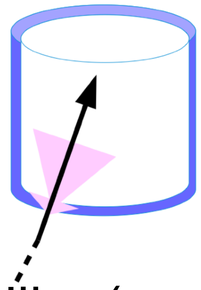
Neutrino Observation in SK / HK



- Fully-contained (FC)
- Partially-contained (PC)
- Upward-going muon (UPMU)

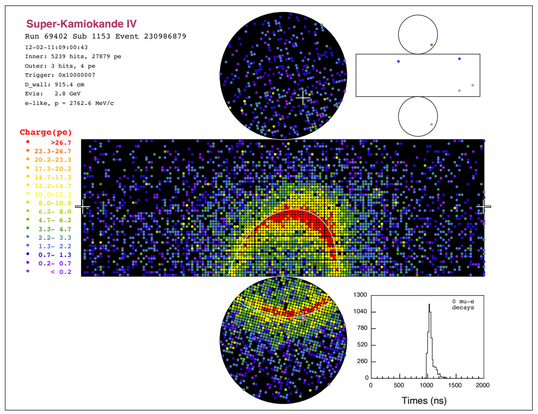


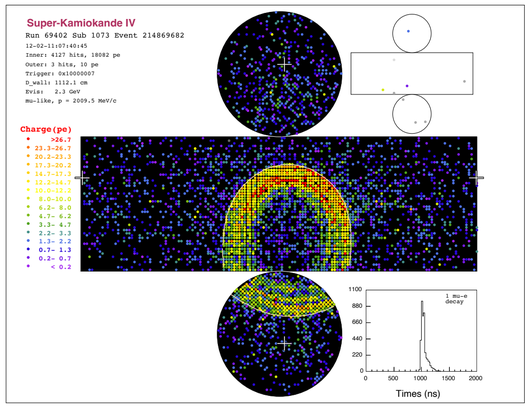




e-like (ν_e / $\bar{\nu}_e$)

μ-like (ν_μ / $\bar{\nu}_\mu$)





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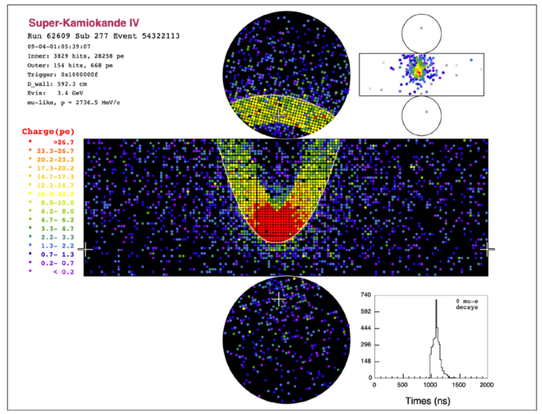

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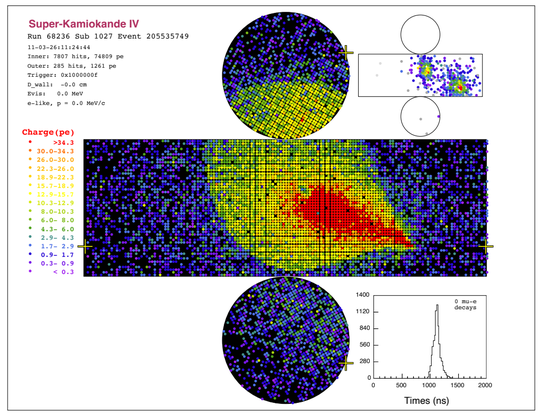
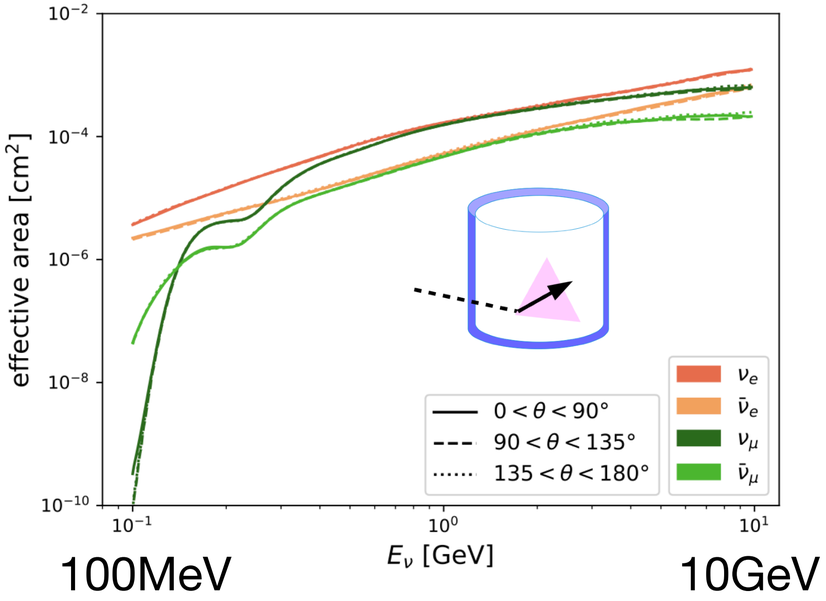


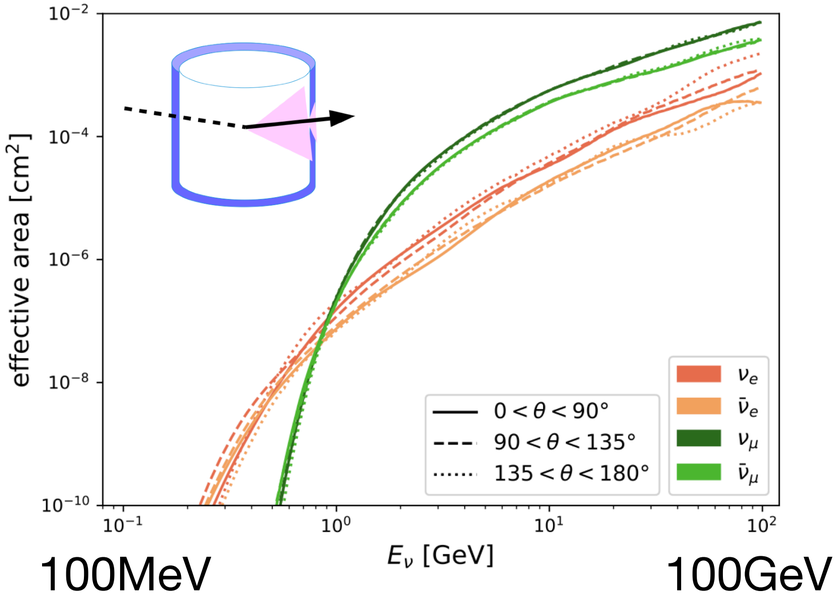
Neutrino Observation in SK / HK

MeV GeV TeV

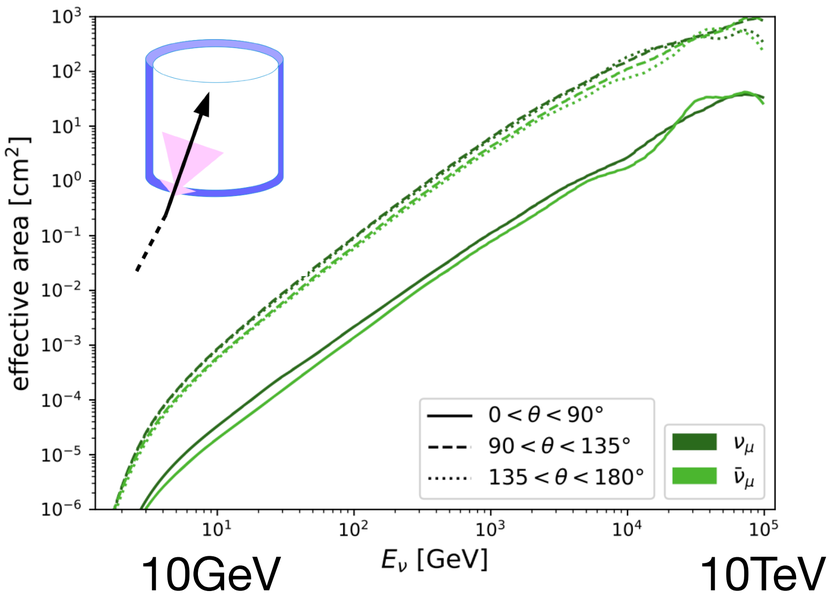
- **Effective area**
  - Fully-contained (FC)
  - Partially-contained (PC)
  - Upward-going muon (UPMU)



(a) FC



(b) PC

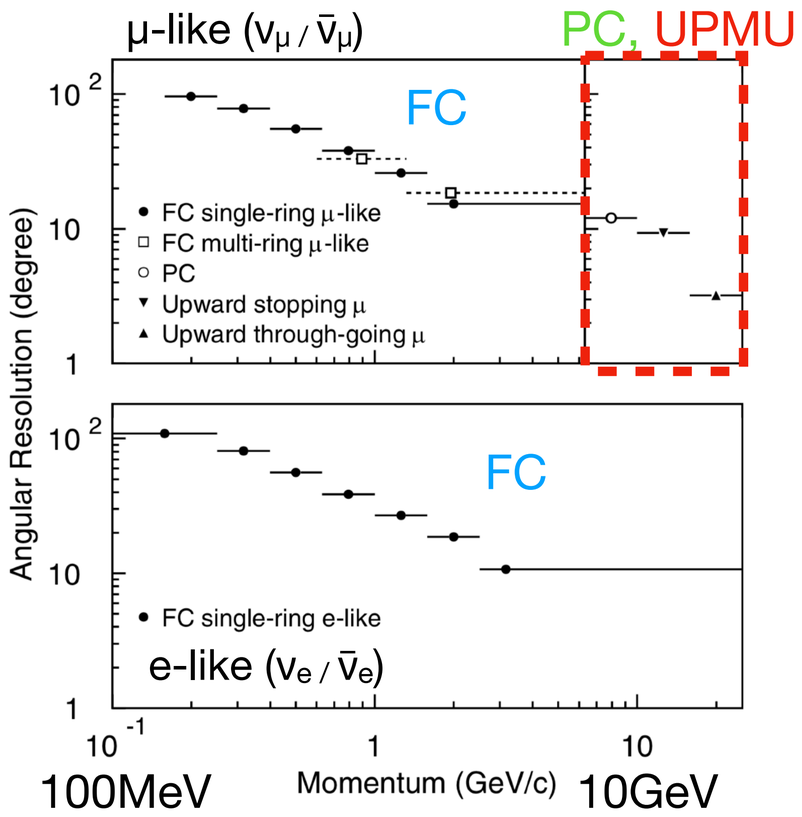


(c) UPMU

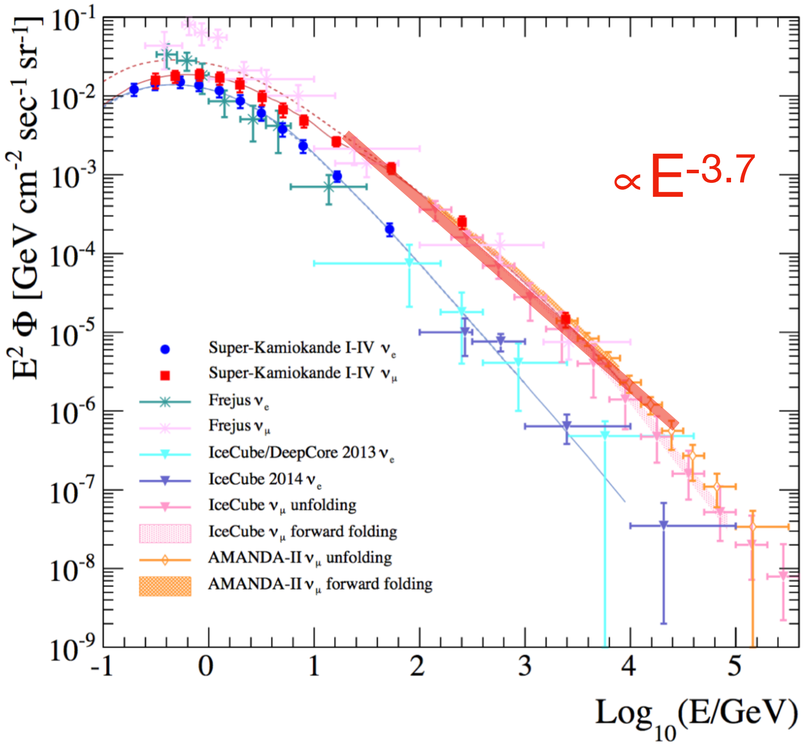
Neutrino Observation in SK / HK

MeV **GeV** **TeV**

- **Angular resolution**



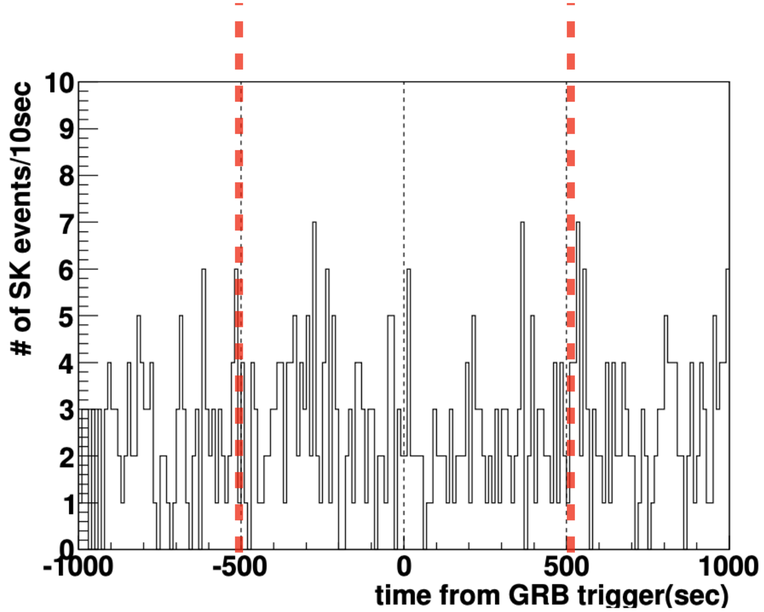
- **Background (atmospheric ν)**

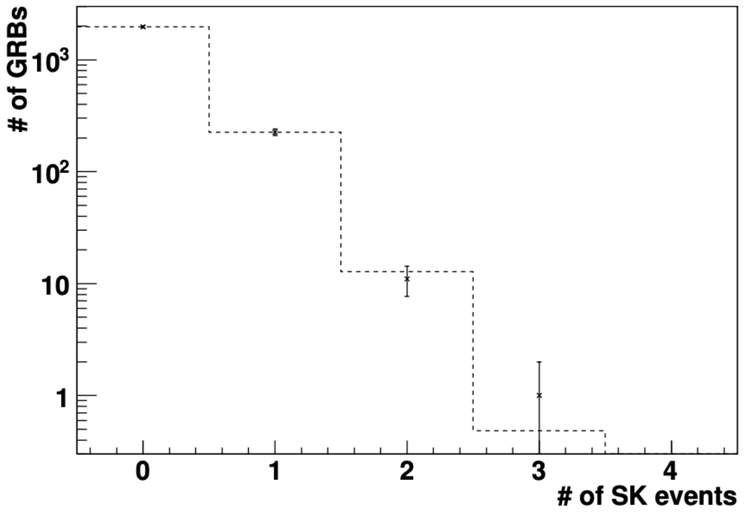


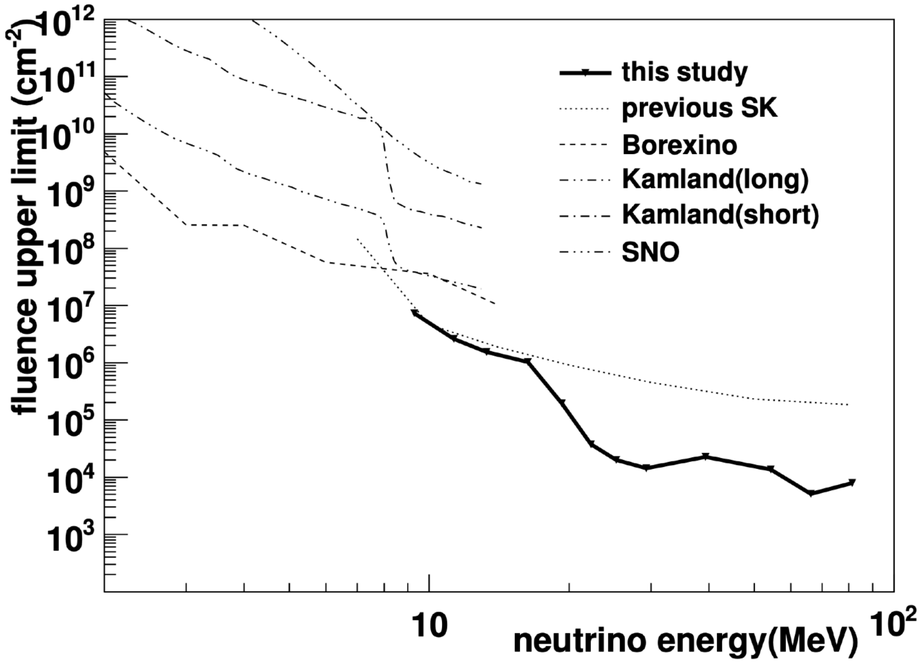
Sensitivity becomes better for higher energies

- larger effective area
- better angular resolution
- smaller backgrounds

Search for O(10MeV) neutrinos from GRB





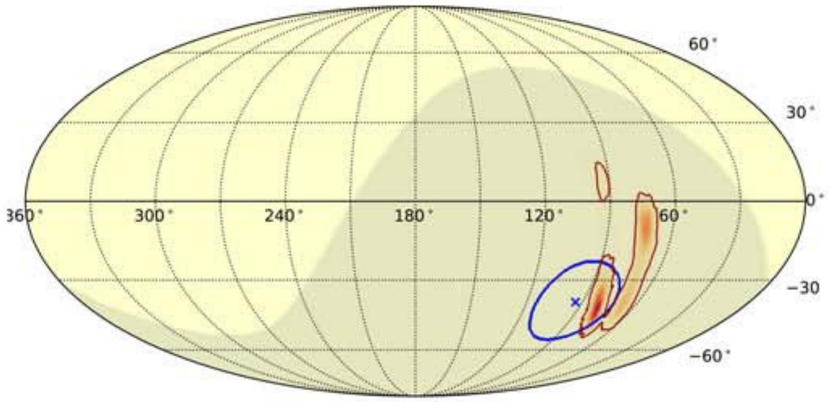


- Dec. 2008 ~ Mar. 2017
- Coincidence with 2208 GRBs
- Search window of ±500 sec around GRB trigger time
- No statistically significant excess was observed
- Fluence upper limit is given

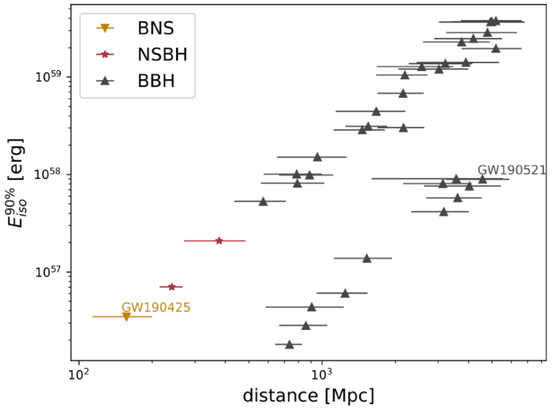
→ See more detail “SuperK/HyperK GRBs” by Motoyasu Ikeda

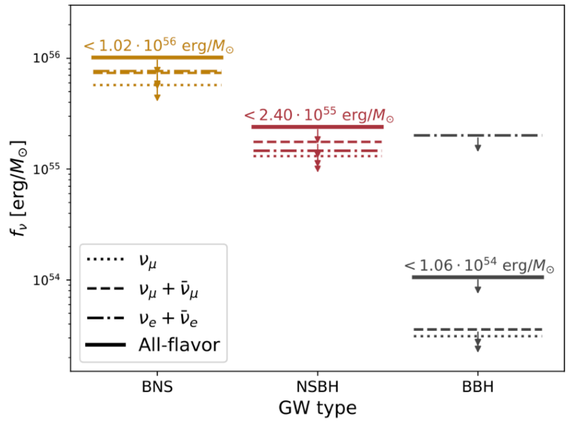
ApJ 918 78, 2021

Search for coincidence with O3a GW events

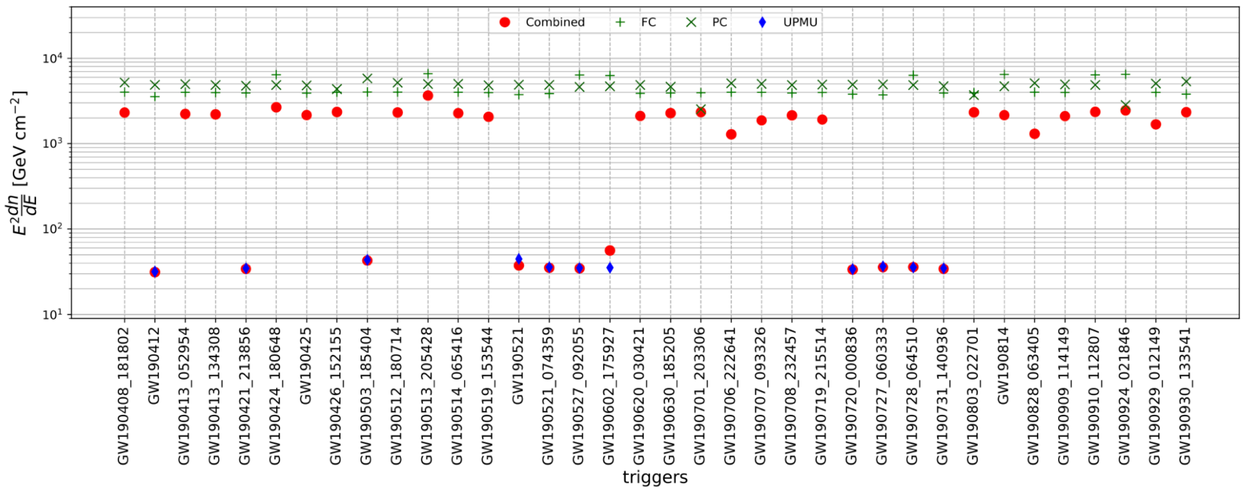


(e) GW190602_175927 (FC)





(b) Limits on $E_{\rm iso}^{\rm all-flavors}$



- Follow-ups 36 GW events in O3a catalogue
- Search timing coincidence within ±500 seconds
- 10 HE neutrinos (exp'd 4.8)
- 24 LE events (exp'd 25.0)
- No significant excess
- Max p-value: 4.8% (1.4σ)
- Constrain on isotropically-emitted neutrino energy

→ "Multi-messenger Super-Kamiokande" by Hiroaki Menjo

ApJL 887 L6, 2019

ν search from blazer TXS0506+056

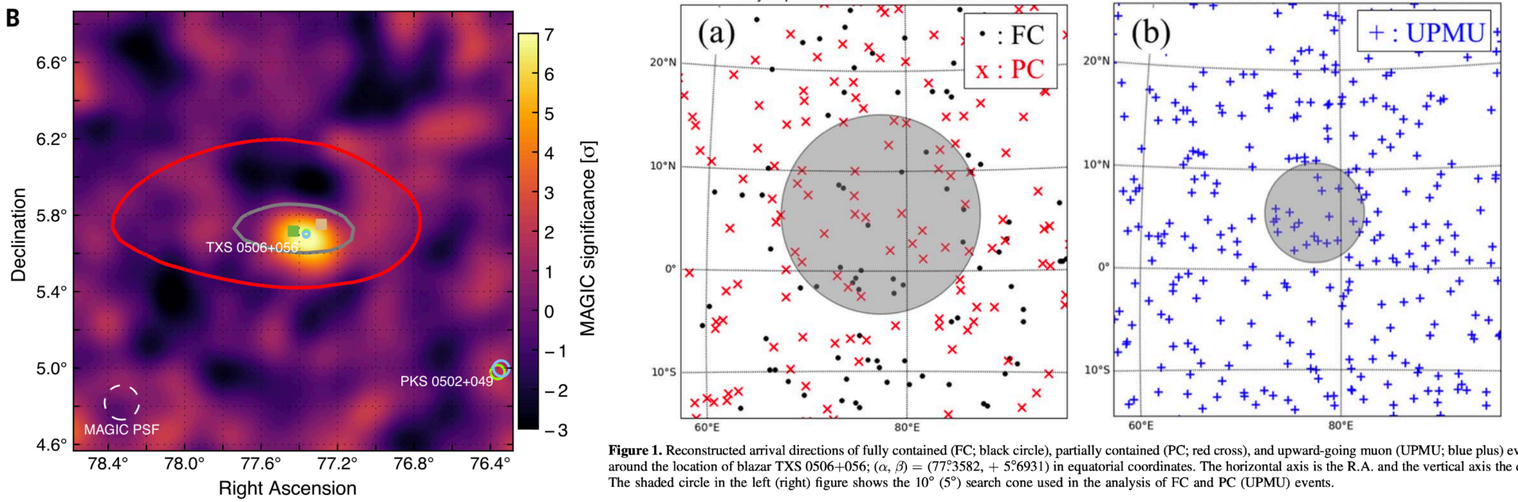


Figure 1. Reconstructed arrival directions of fully contained (FC; black circle), partially contained (PC; red cross), and upward-going muon (UPMU; blue plus) events around the location of blazar TXS 0506+056; $(\alpha, \beta) = (77.^{\circ}3582, +5.^{\circ}6931)$ in equatorial coordinates. The horizontal axis is the R.A. and the vertical axis the decl. The shaded circle in the left (right) figure shows the 10° (5°) search cone used in the analysis of FC and PC (UPMU) events.

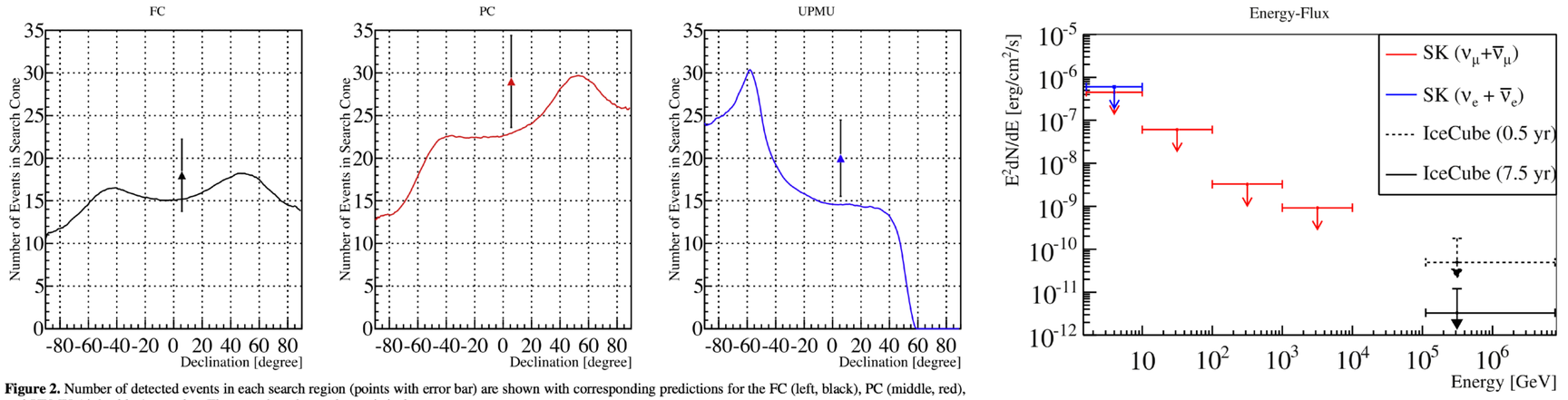
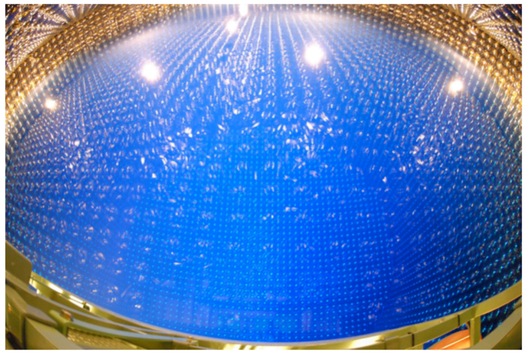


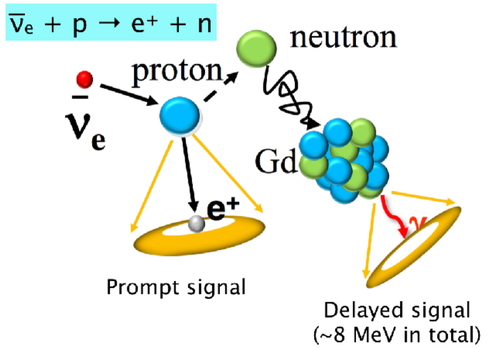
Figure 2. Number of detected events in each search region (points with error bar) are shown with corresponding predictions for the FC (left, black), PC (middle, red), and UPMU (right, blue) samples. The error bar shows the statistical error.

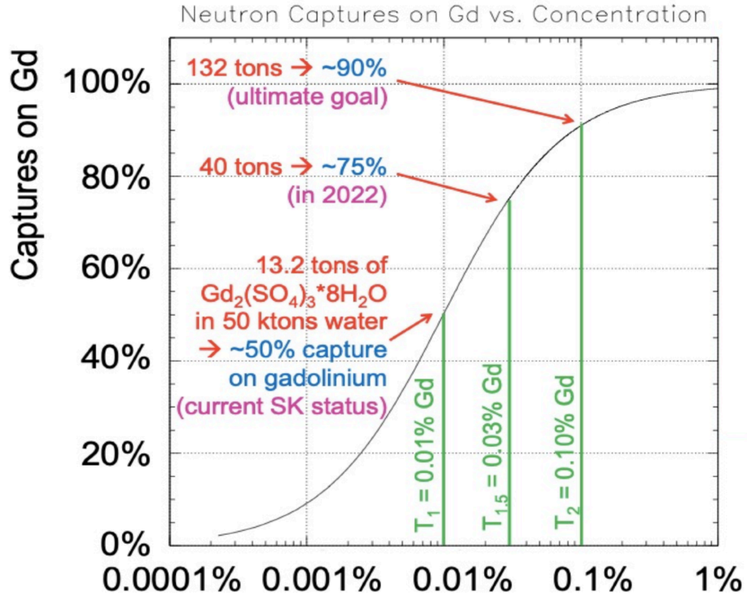
- BL Lac blazer (z~0.34).
- 290 TeV neutrino detected by IceCube.
  - Also possible excess in past data.
- SK searches event excess in blazer direction using 22 yrs data.
- No significant excess found and consistent with background.

SuperK-Gd

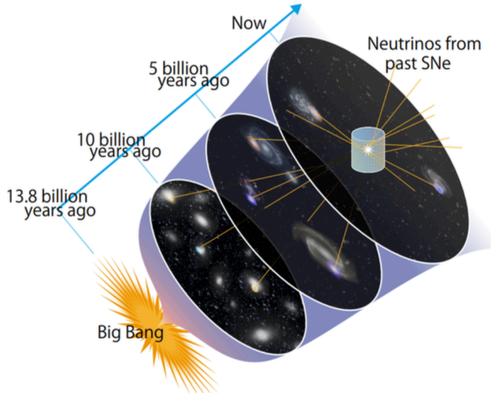
+



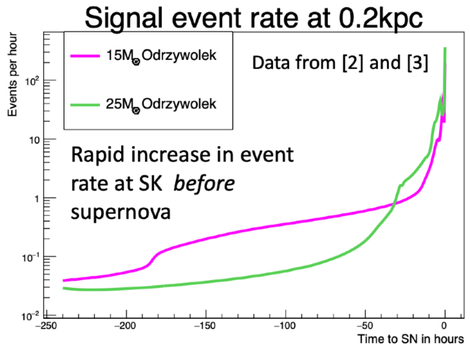


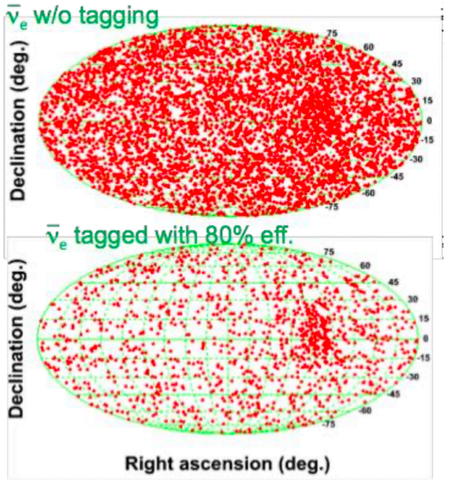


- **Supernova relic neutrino**



- **Precursor of nearby SN by Si-buring**





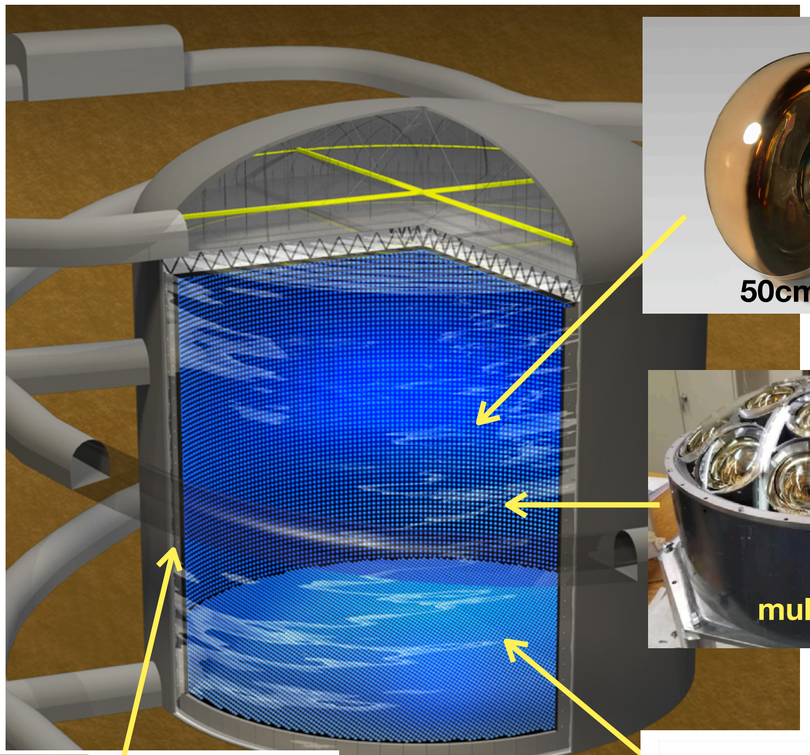
- **Improvement of pointing accuracy in Supernova burst**

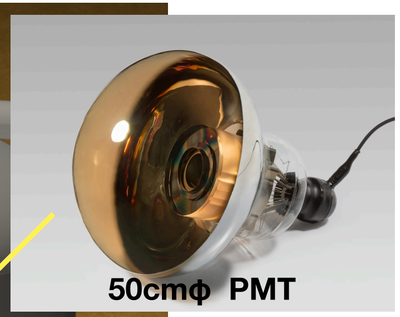
Other physics

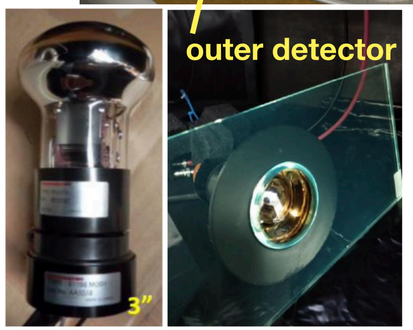
- ν / anti-ν discrimination in LBL and atmospheric neutrinos
- background rejection in proton decay searches

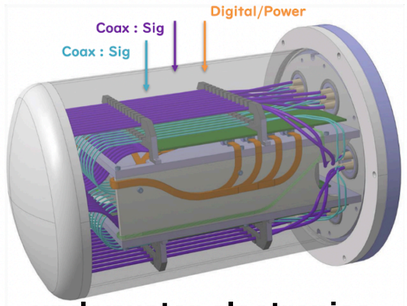
→ “Supernovae detection with SuperK/HyperK” by Guillaume Pronost
“Galactic supernova detection with EGADS/HEIMDALL” by Lluis Marti-Margo

Hyper-Kamiokande





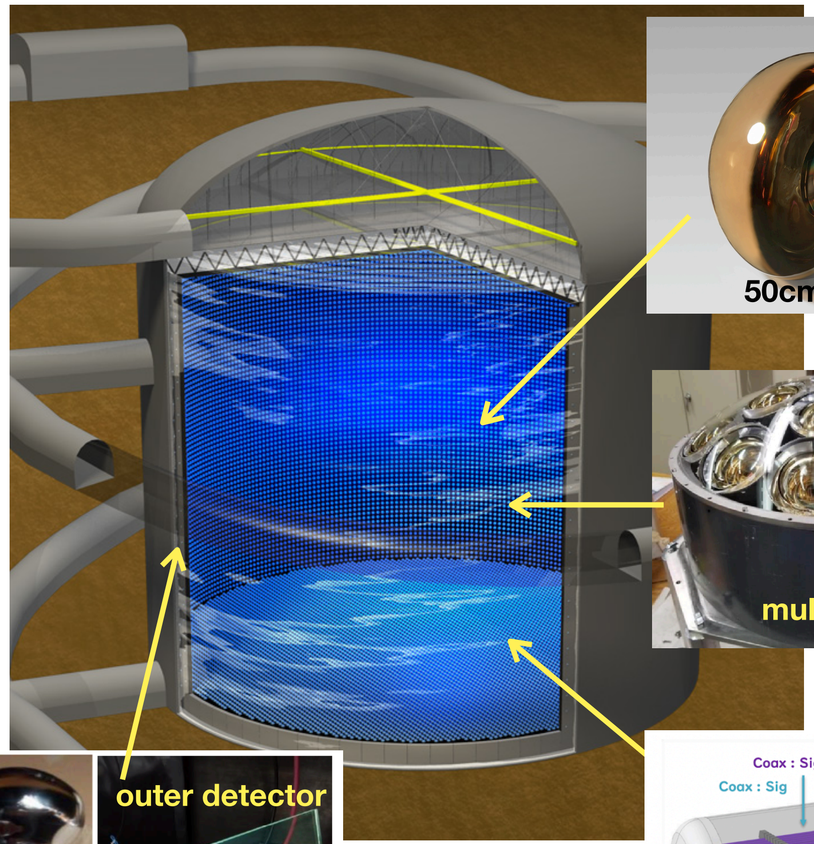


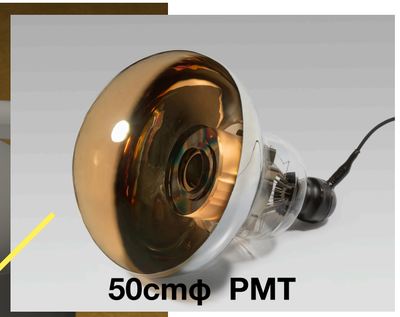


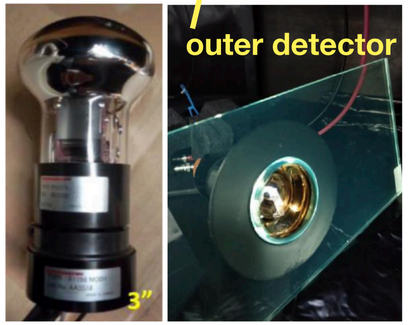
underwater electronics

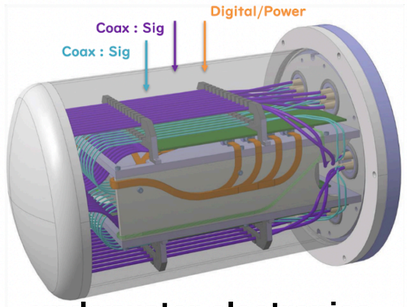
Hyper-Kamiokande

Hyper-Kamiokande









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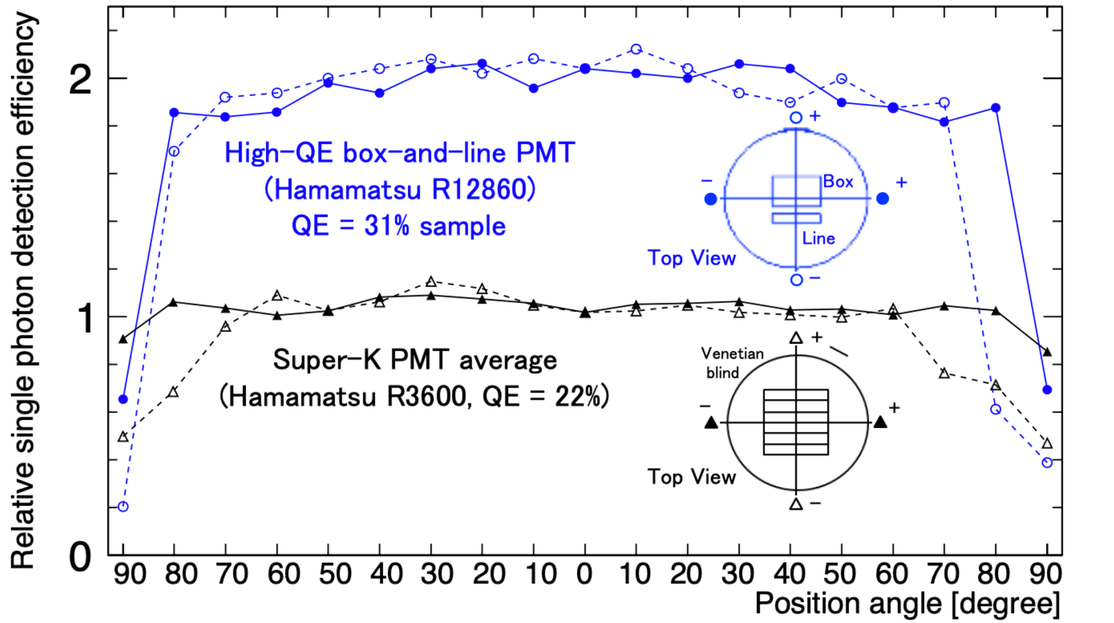
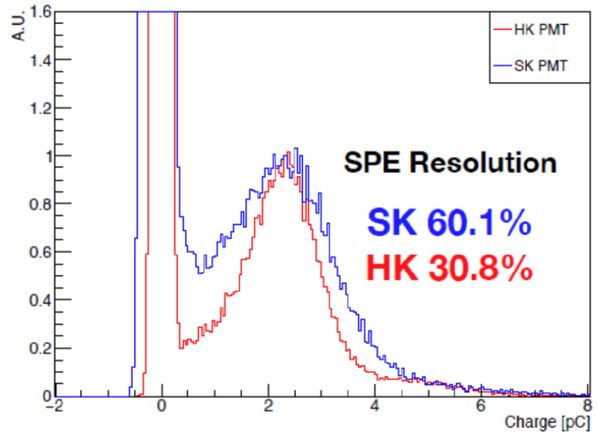
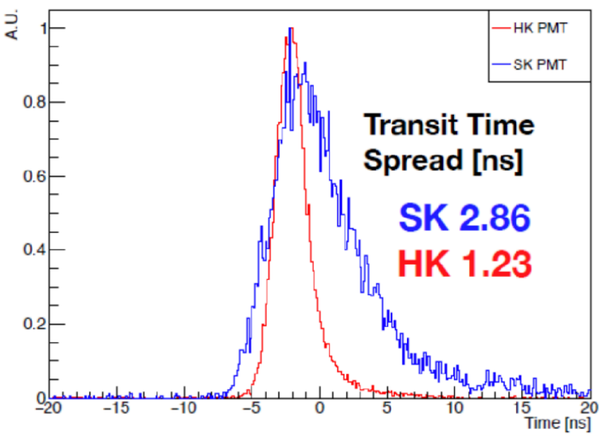
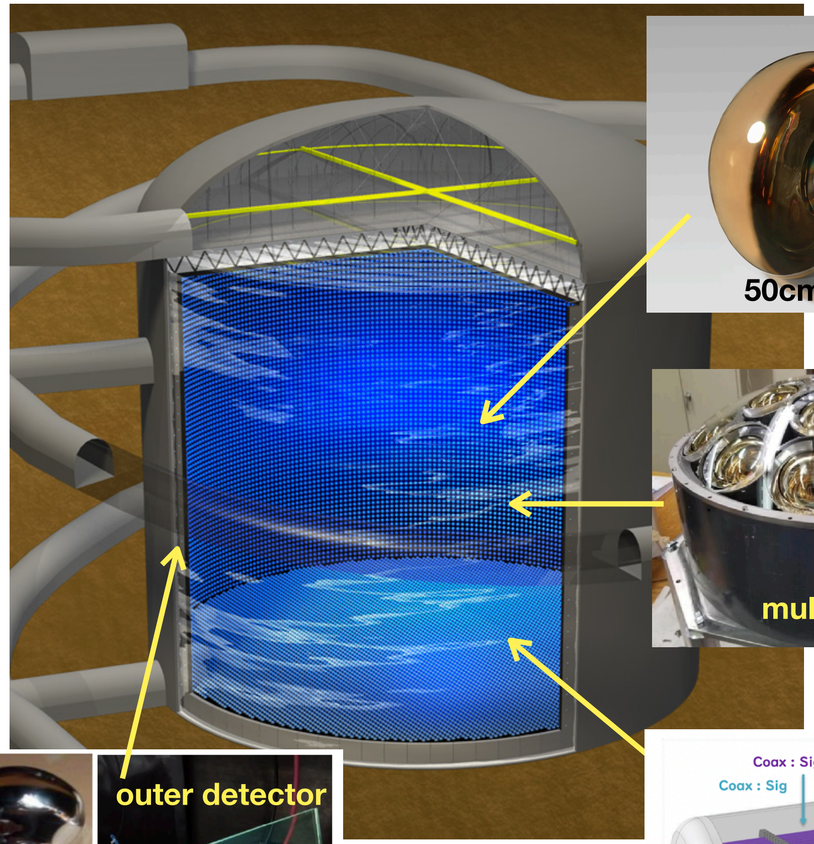


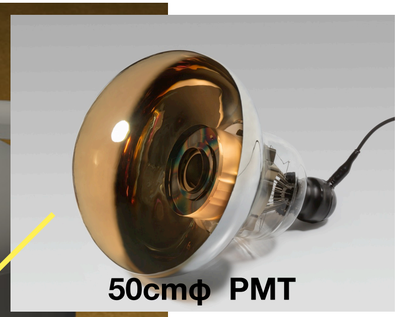


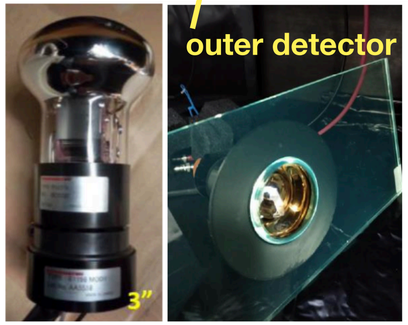


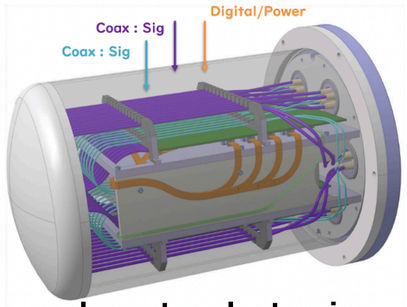
Hyper-Kamiokande

Hyper-Kamiokande









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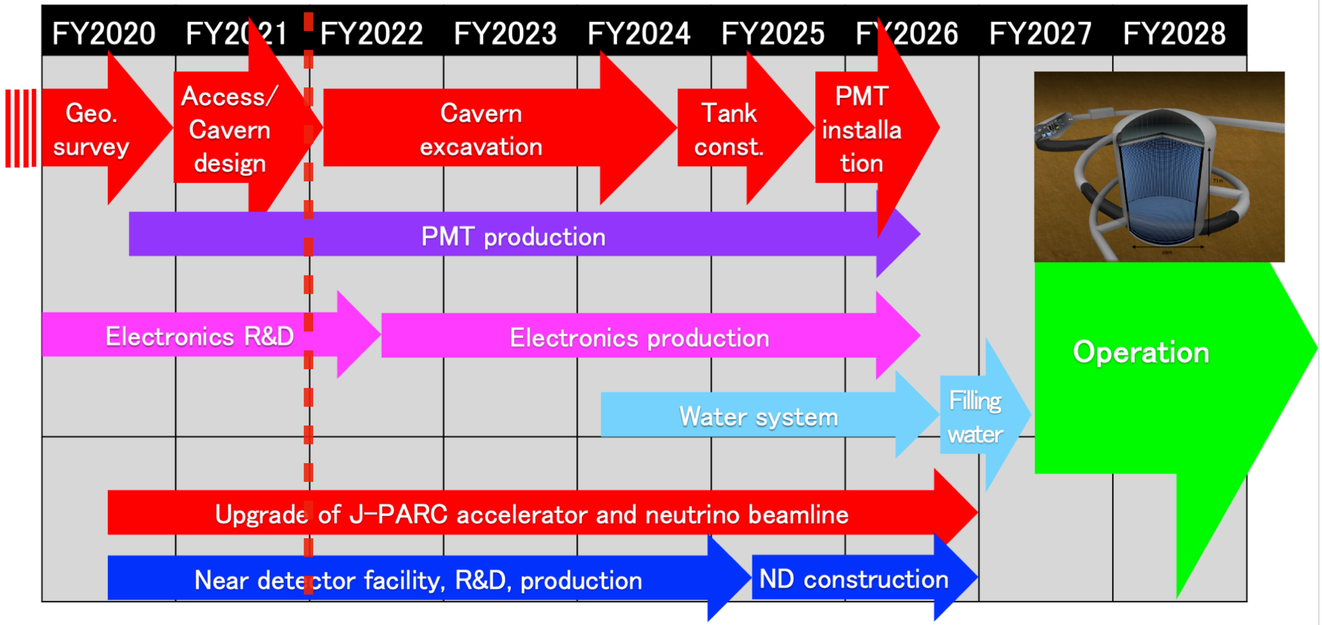
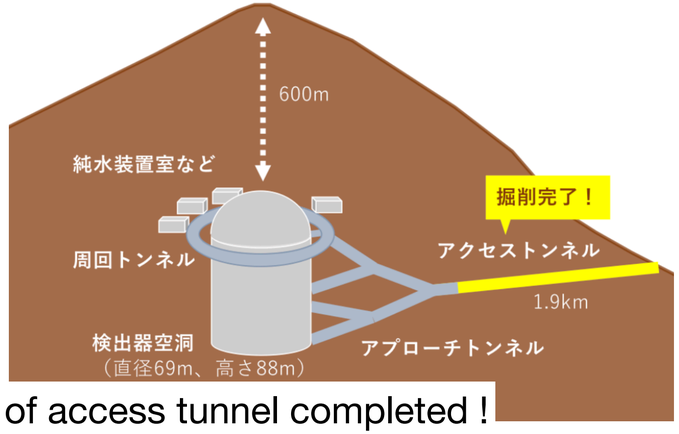
Present



アクセストンネル終端部



(2022.02.25) Excavation of access tunnel completed !

Summary

- Super-K / Hyper-K are multi-purpose and rich-physics detectors.
- Covering wide range of neutrino energies from MeV up to TeV.
- Several features are different between low energy and high energy regions.
- Sensitivities for astro observations depends on event sample.
- Discriminate astro neutrino by energy, direction, event timing, and neutrino flavor.
- Waiting for neutrinos from a variety of astro targets: SN, GRB, AGN, GW, …
- Anti neutrino detection is enhanced in SK-Gd by delayed coincidence of Gd capture signal.
- Construction of Hyper-K is on-going. plan to operate from 2027.