

スーパーカミオカンデ 超新星ニュートリノ観測による 爆発天体の早期特定



小汐由介（岡山大学）

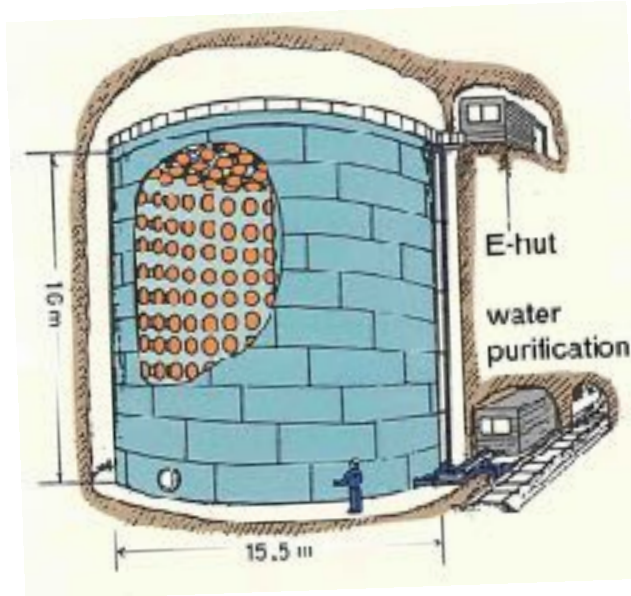


第16回光赤外線天文学大学間連携（OISTER）ワークショップ

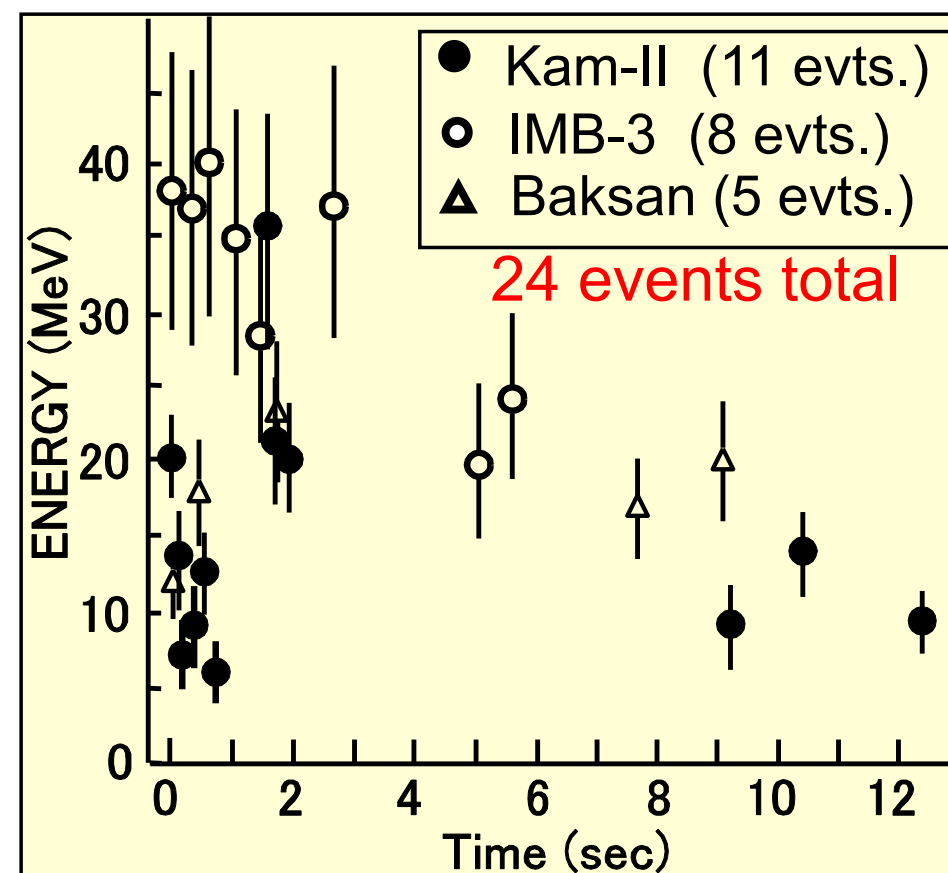
鹿児島大学, 21-23 October, 2025

Three generations of “Kamiokande”

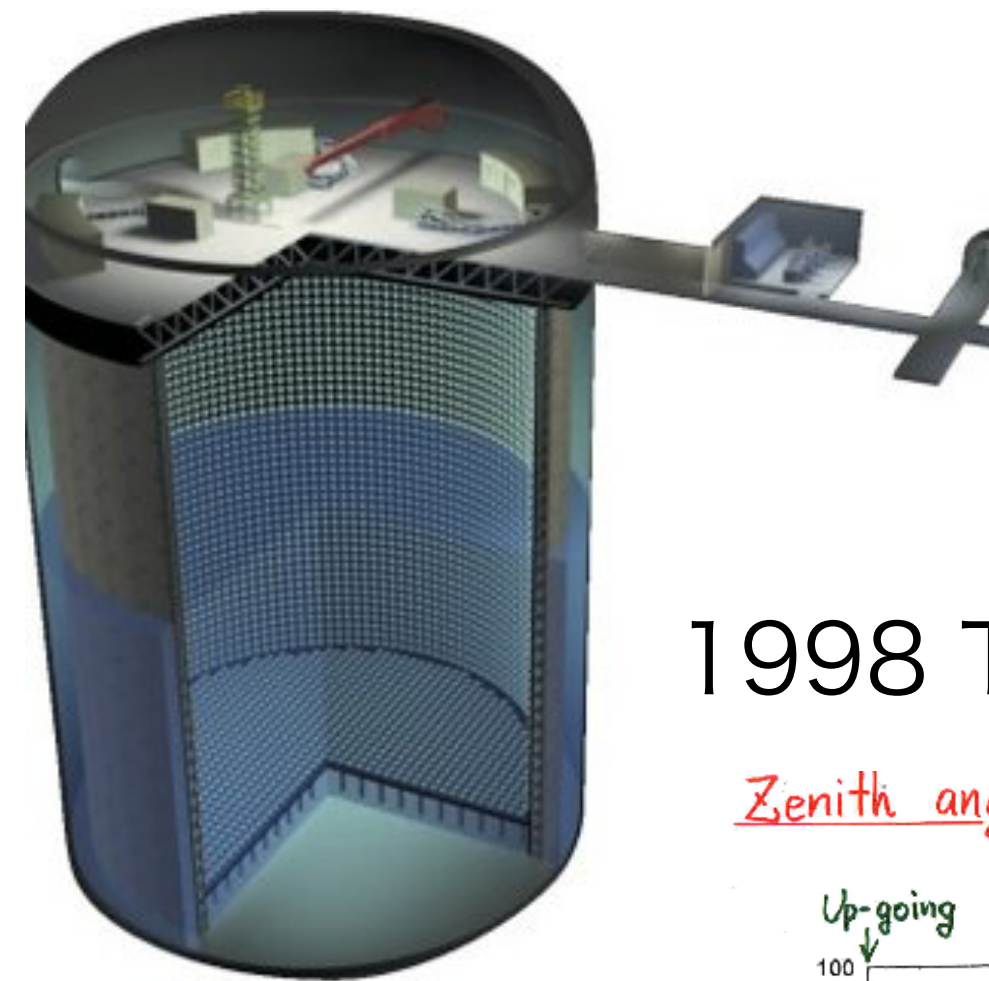
Kamiokande
(1983-1995)



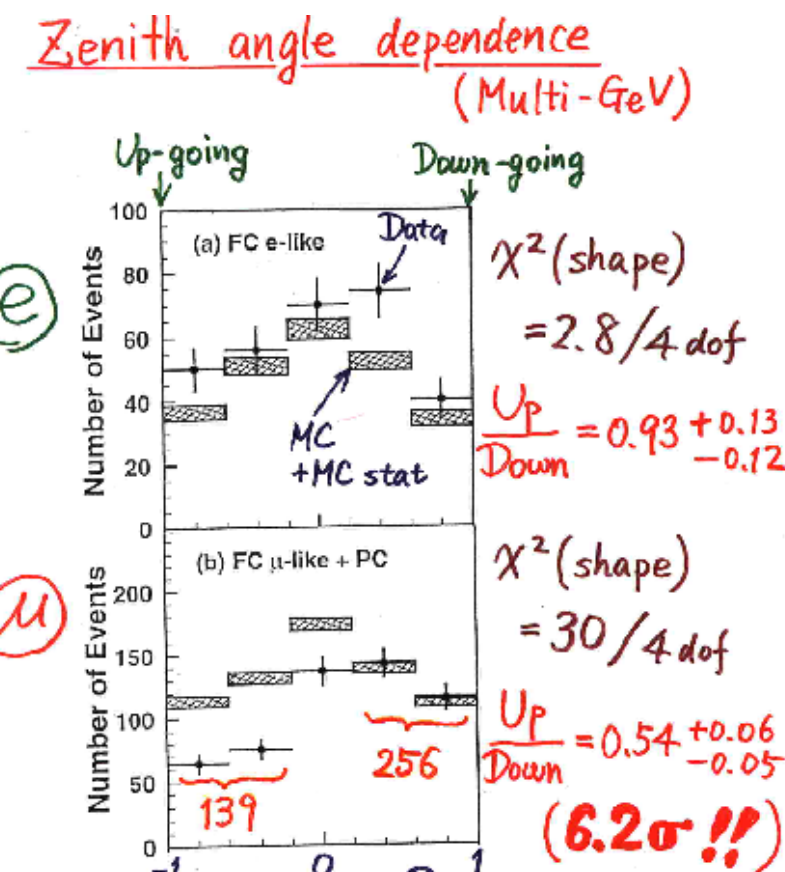
SN1987A



Super-Kamiokande (1996-)



1998 Takayama

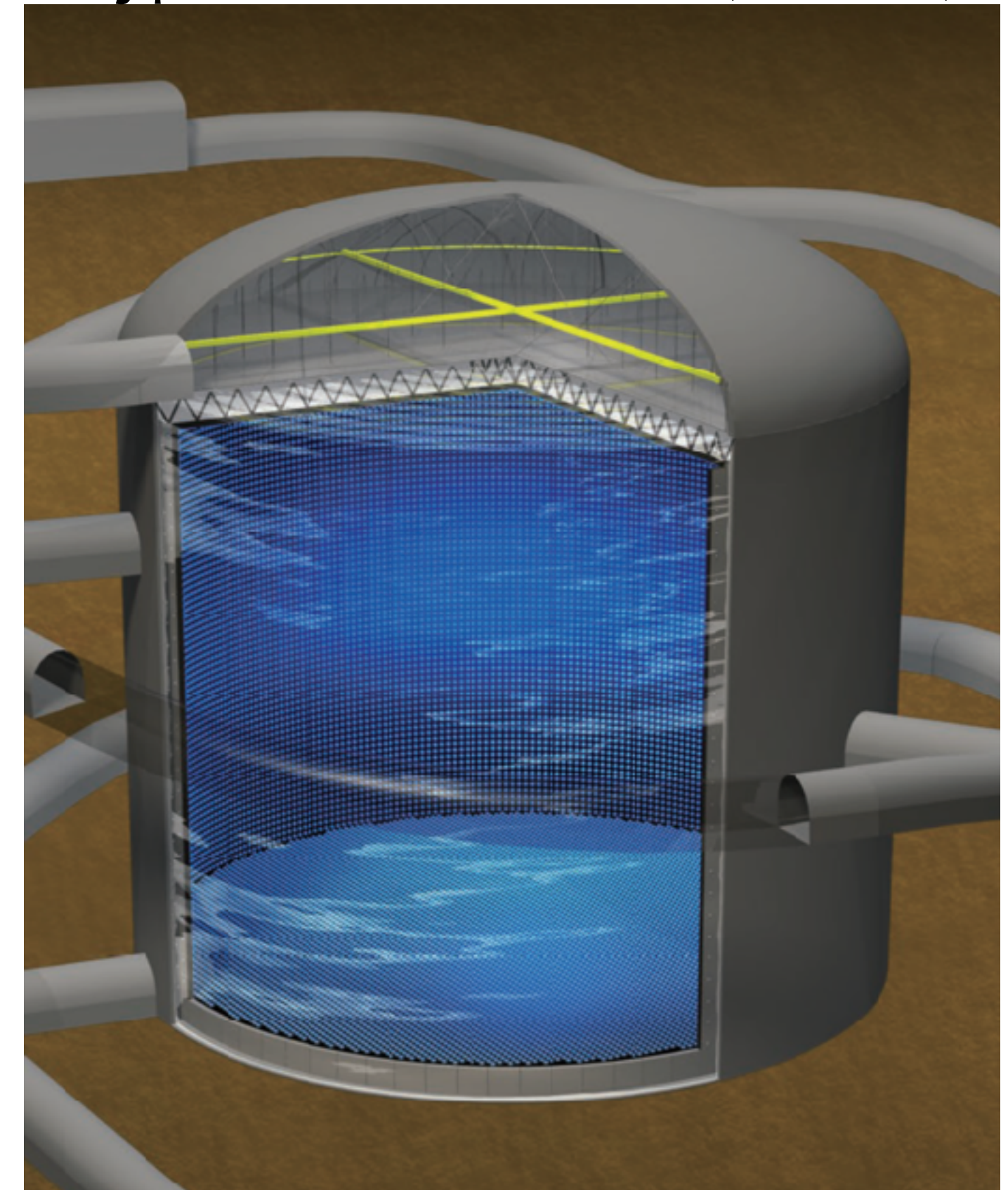


* Up/Down syst. error for μ -like

Prediction (flux calculation $\leq 1\%$
1km rock above SK 1.5%) 1.8%

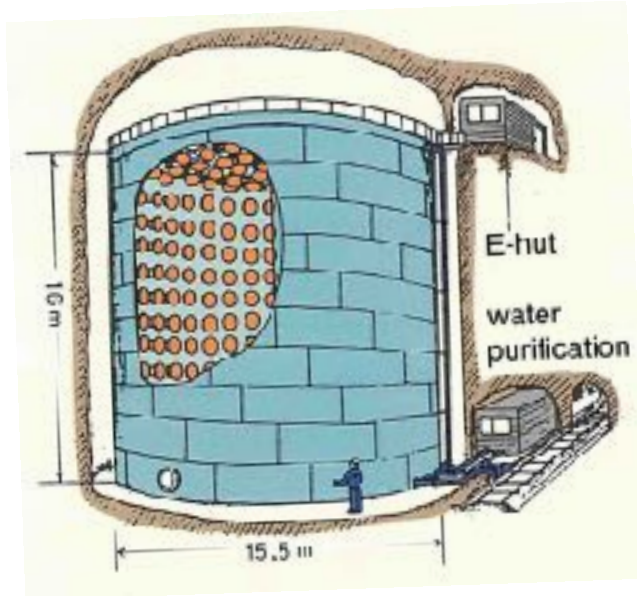
Data (Energy calib. for $\uparrow\downarrow$ 0.7%
Non ν Background < 2%) 2.1%

Hyper-Kamiokande (2028-)

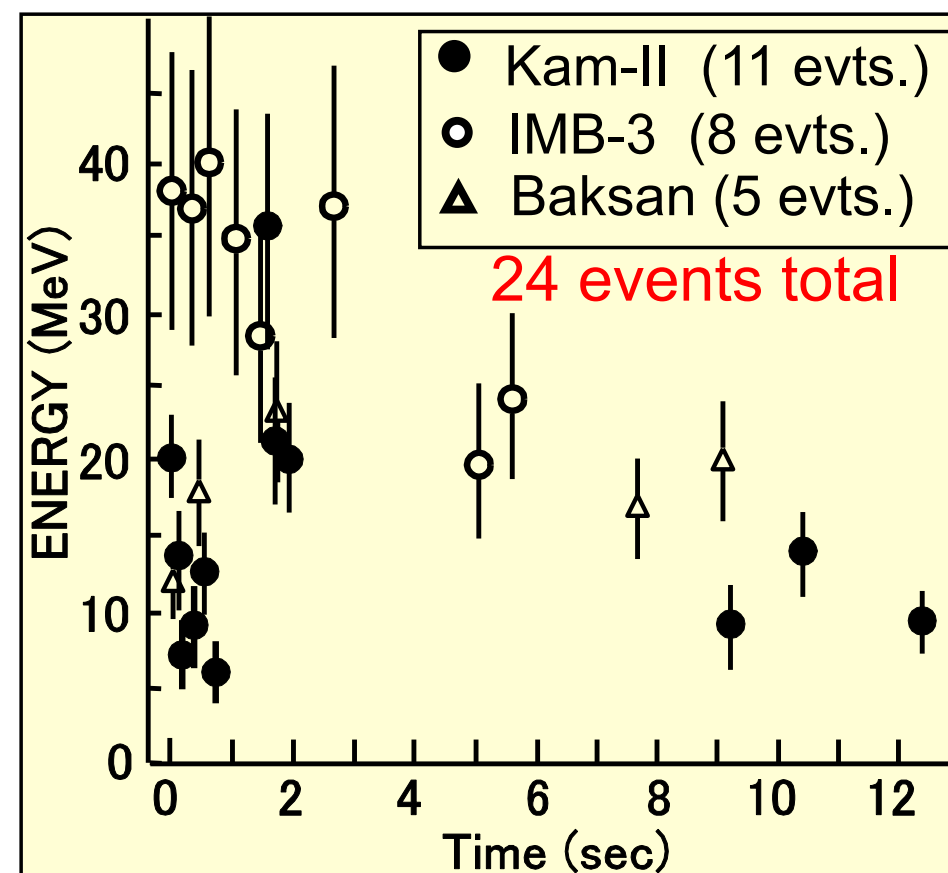


Three generations of “Kamiokande”

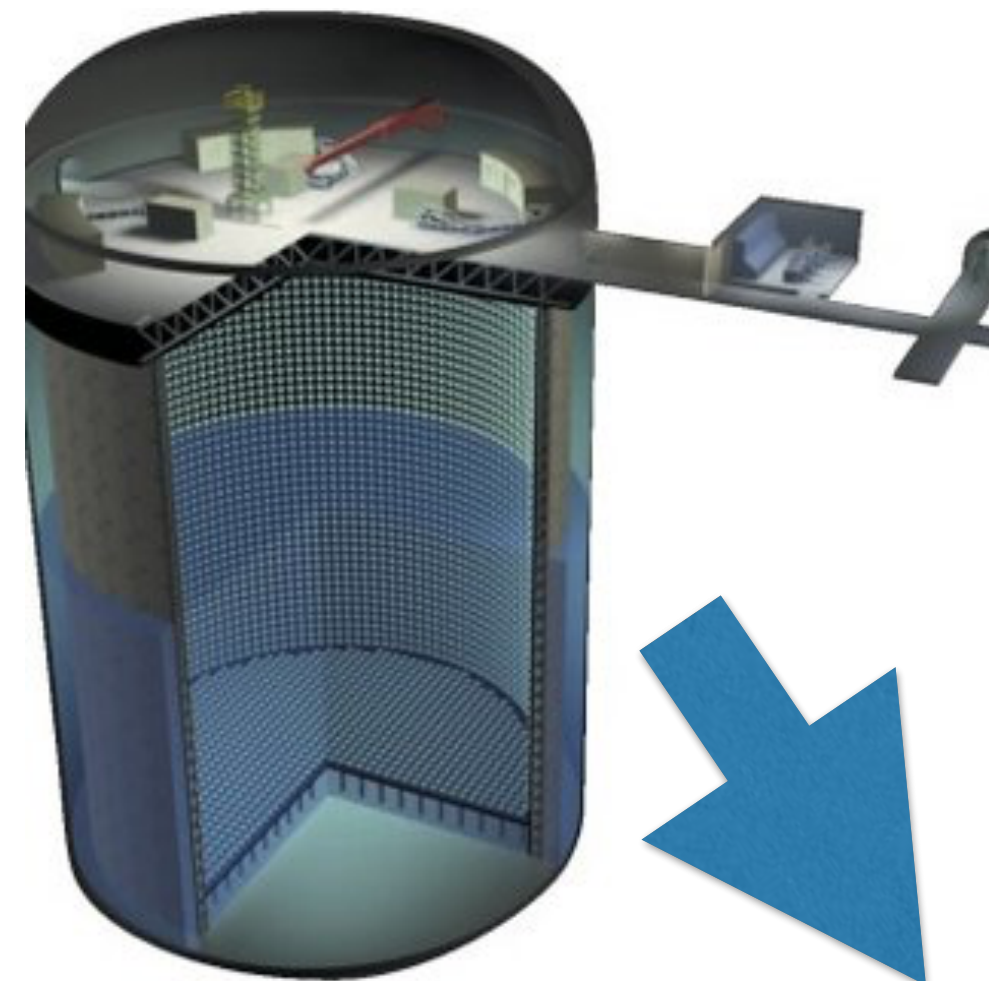
Kamiokande
(1983-1995)



SN1987A



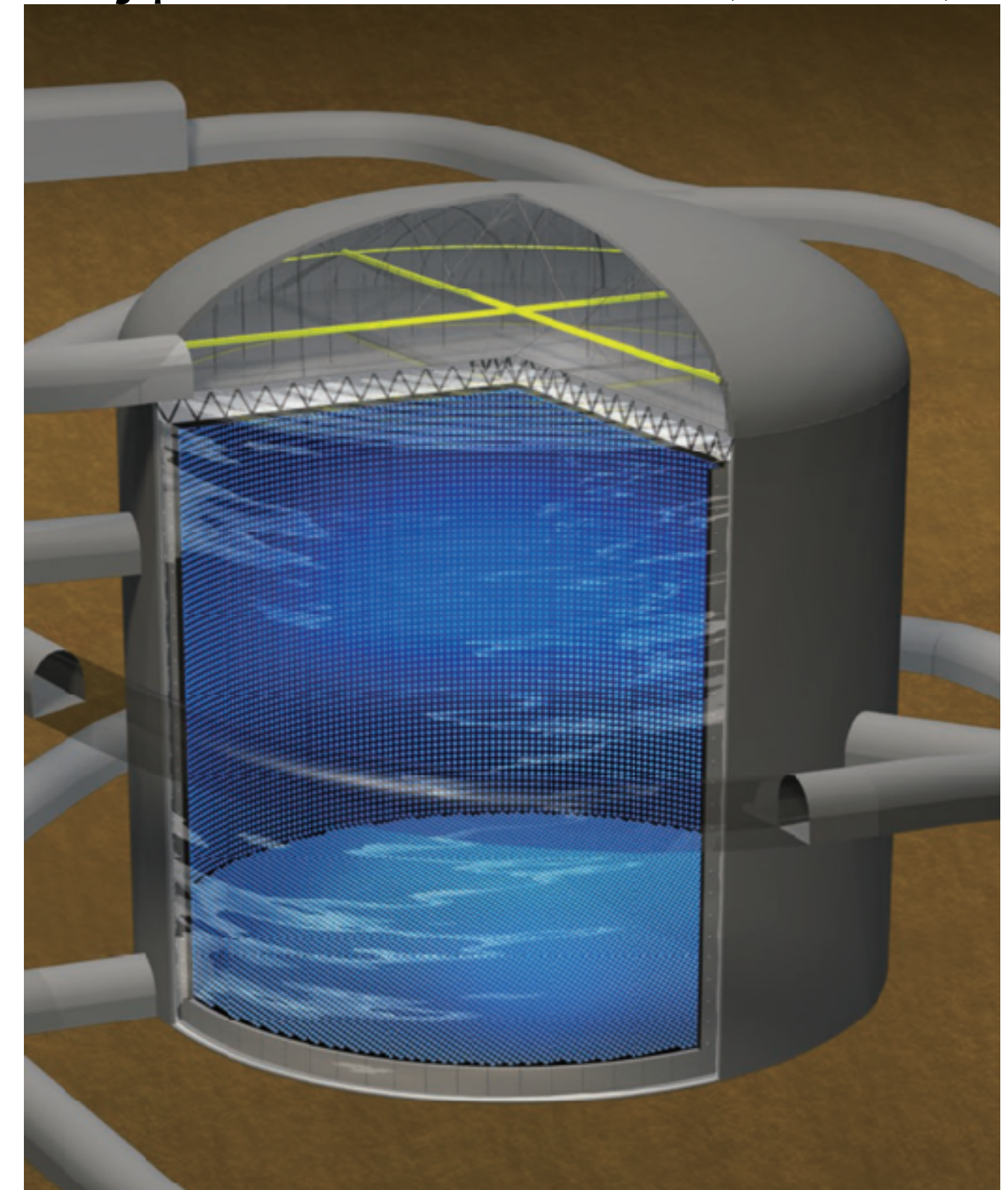
Super-Kamiokande (1996-)



SK-Gd (2020-)

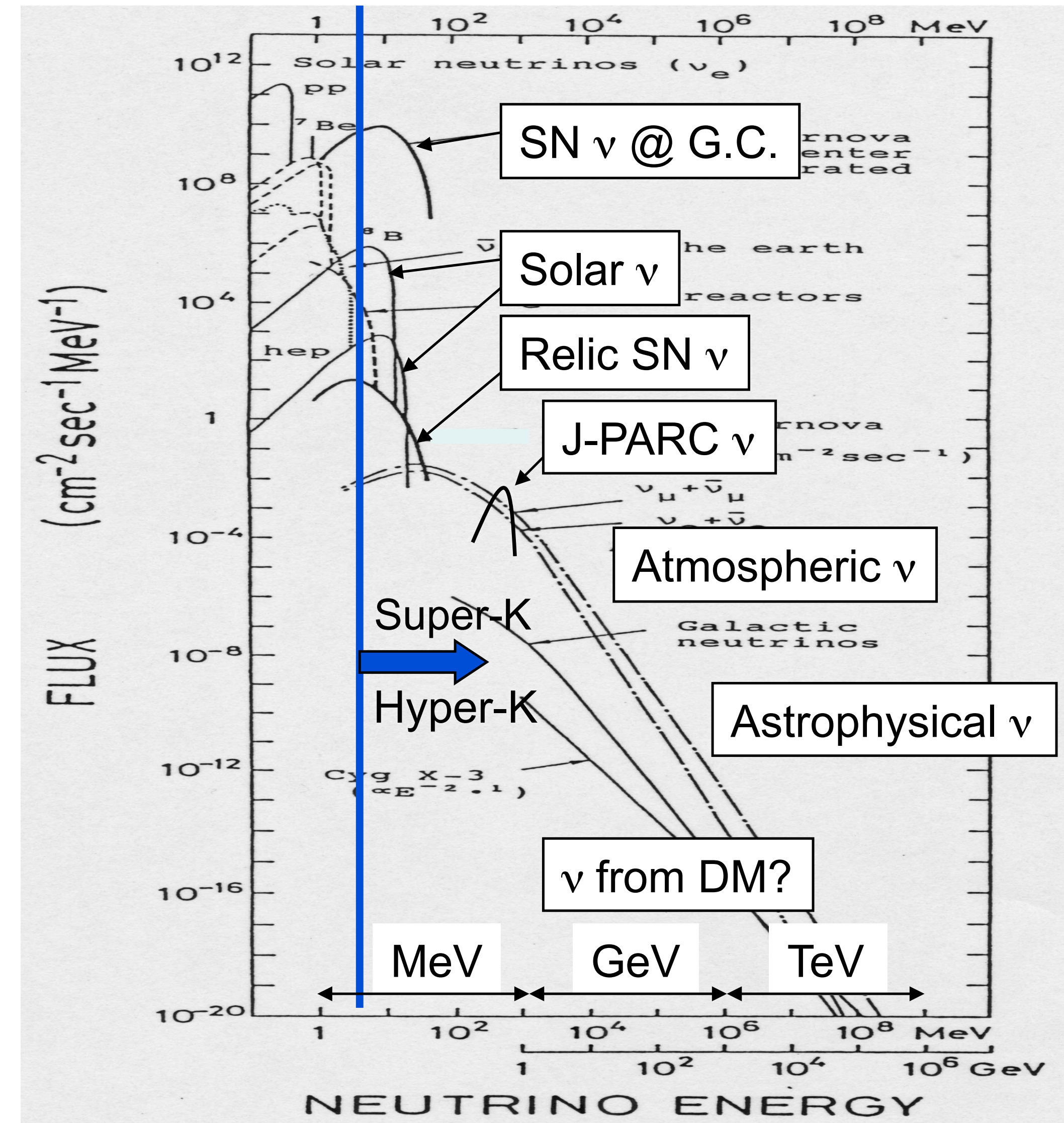


Hyper-Kamiokande (2028-)

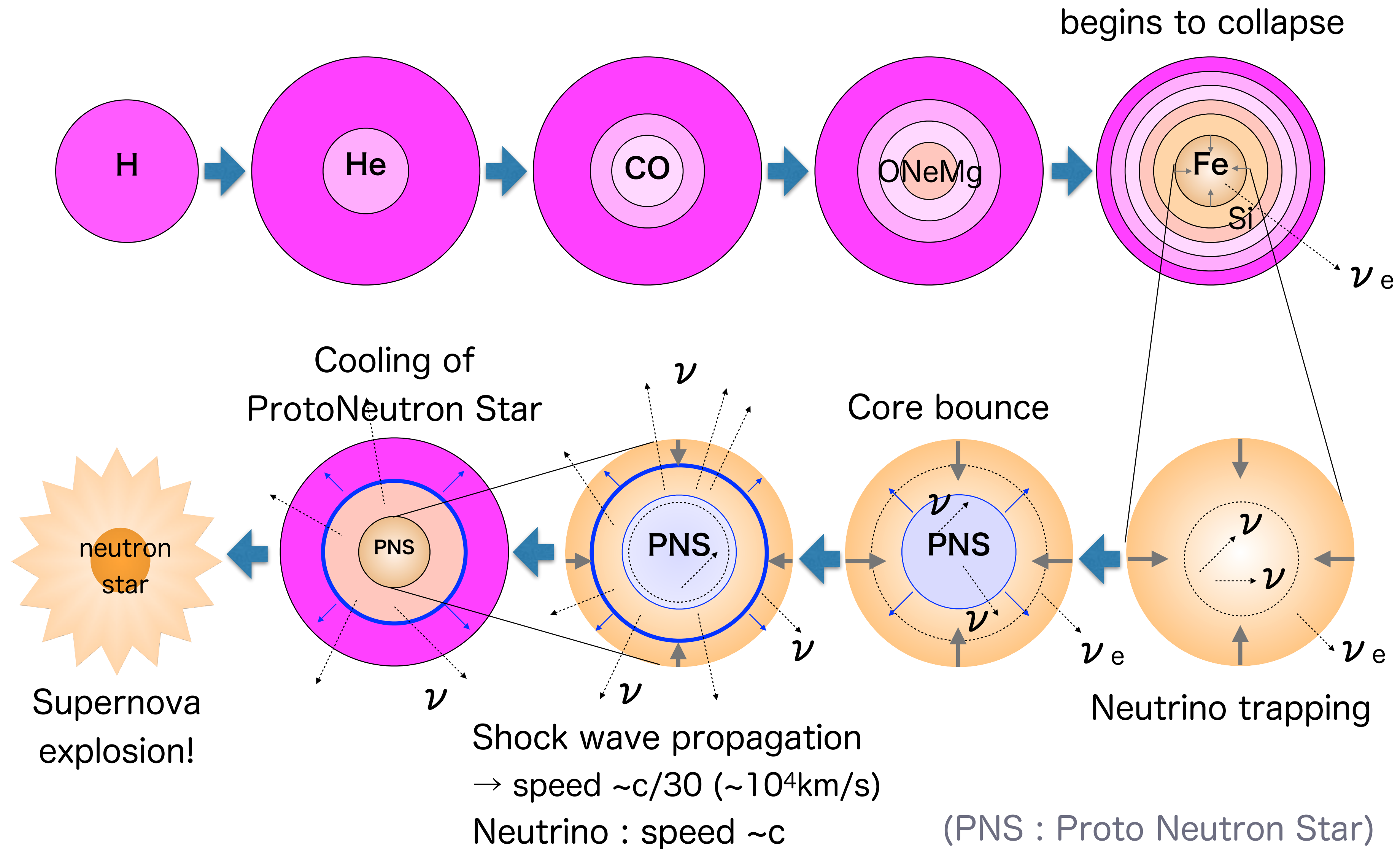


Physics targets multi-purpose detector

- Neutrino physics
 - Accelerator, Atmospheric neutrinos : neutrino oscillation (CP violation, Mass ordering)
 - Solar neutrinos : Non-standard oscillations and interactions
- Neutrino astrophysics
 - Supernova, Solar, Astronomical objects
- Beyond standard model
 - Nucleon decay
 - Dark matter, sterile neutrino, etc.

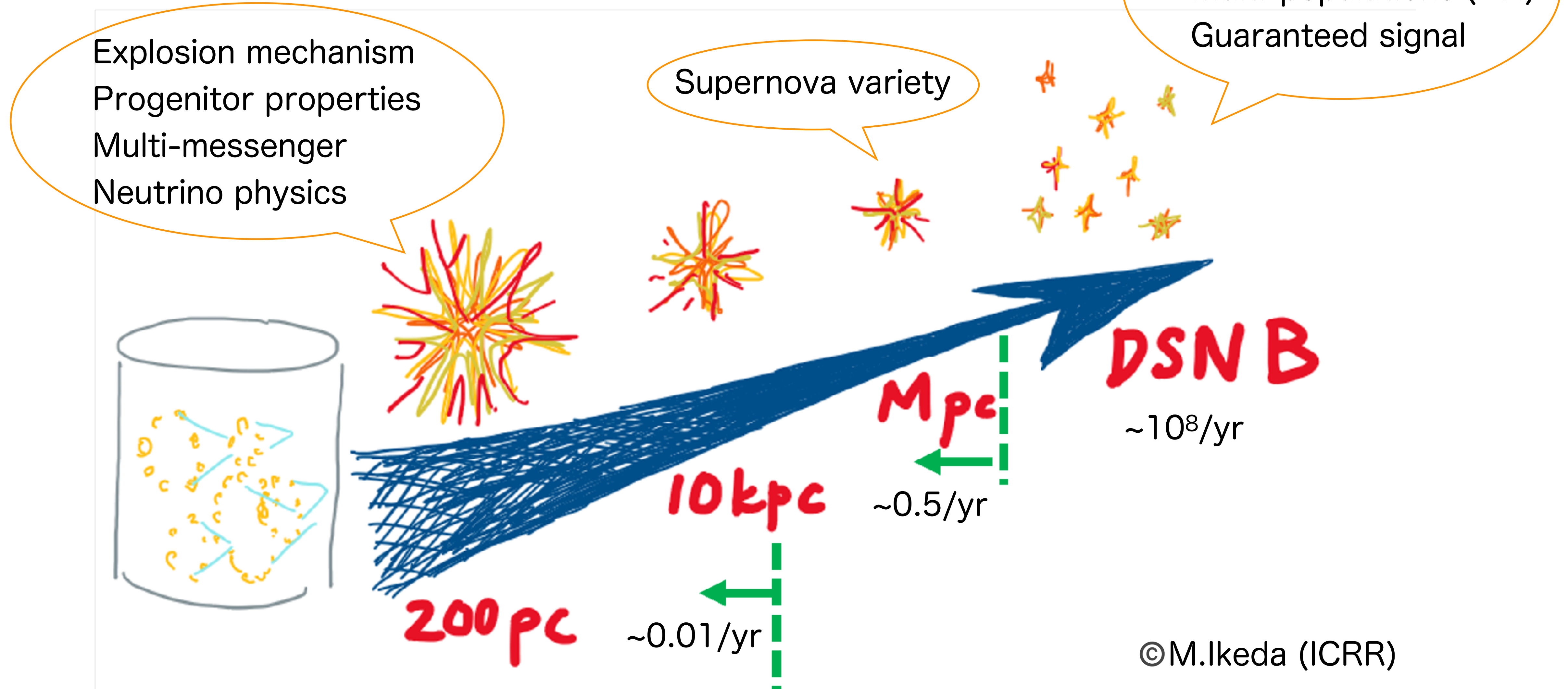


Core-collapse supernova



Supernova neutrinos

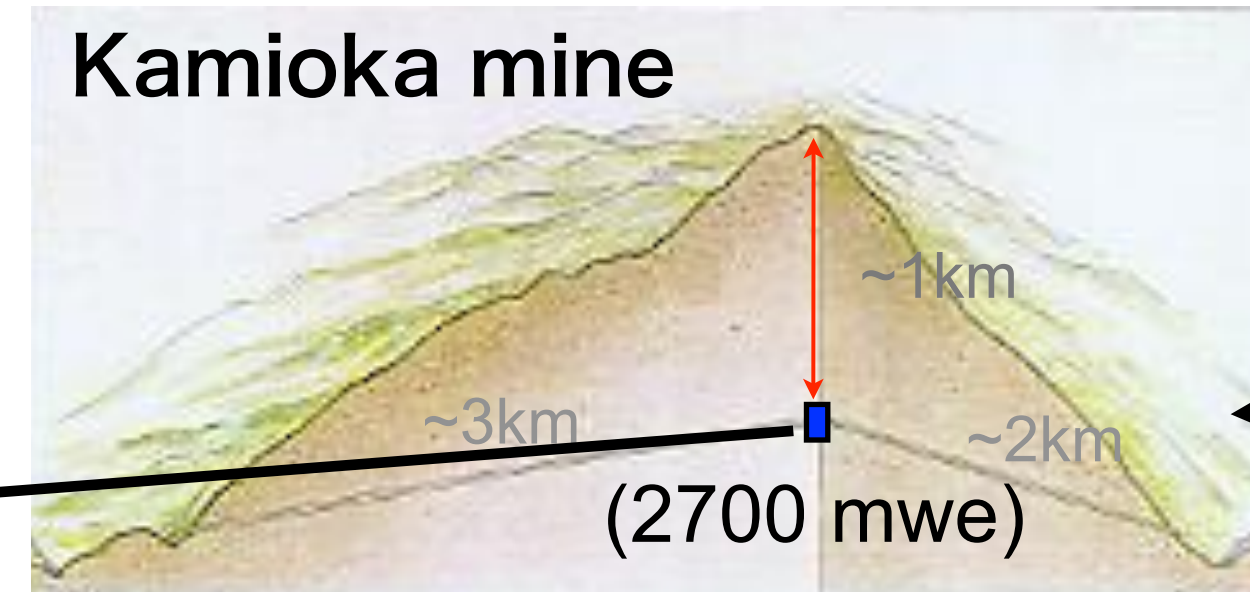
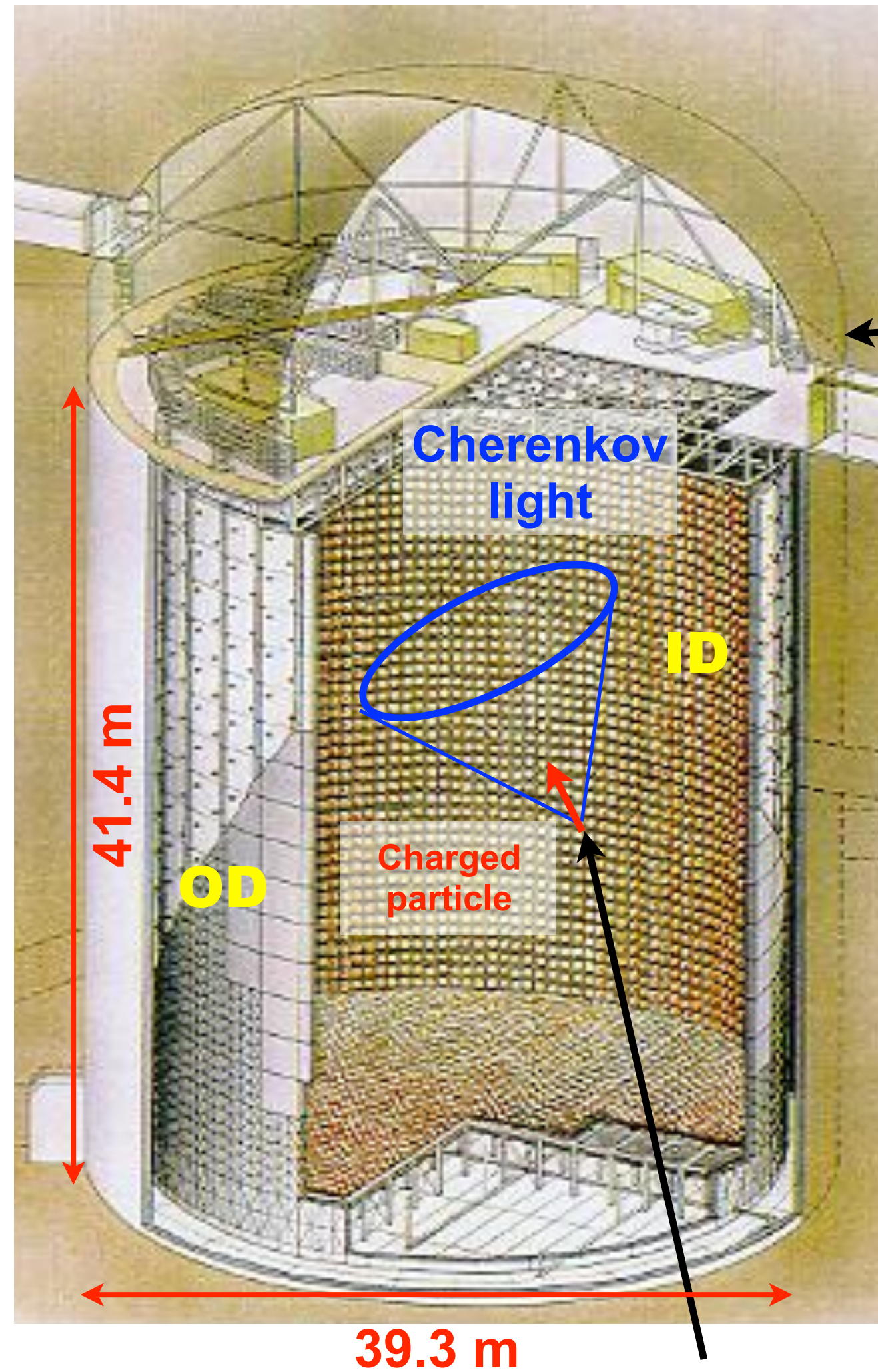
distance scales and physics outcomes



Super-Kamiokande

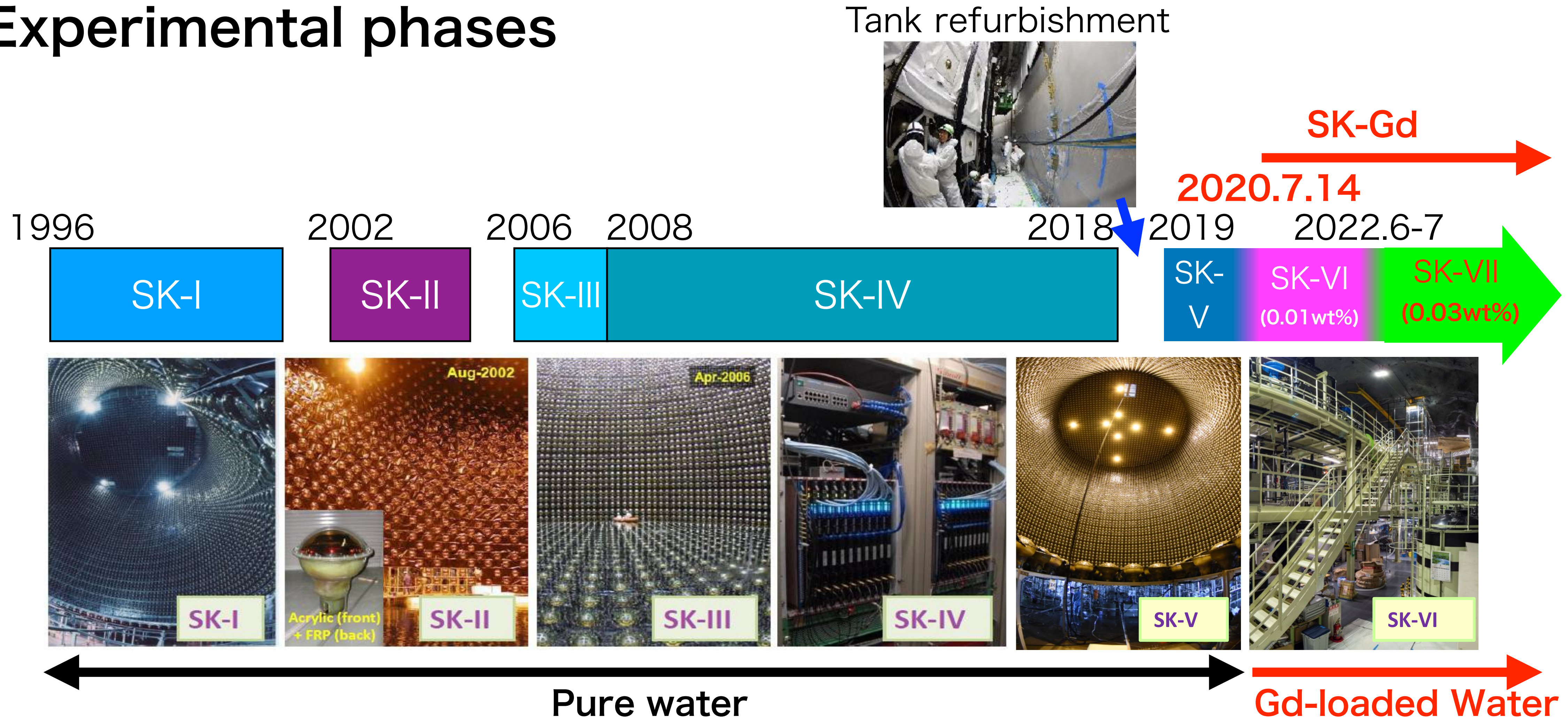
Super-Kamiokande

50,000 tons of Water Cherenkov detector



History of Super-Kamiokande

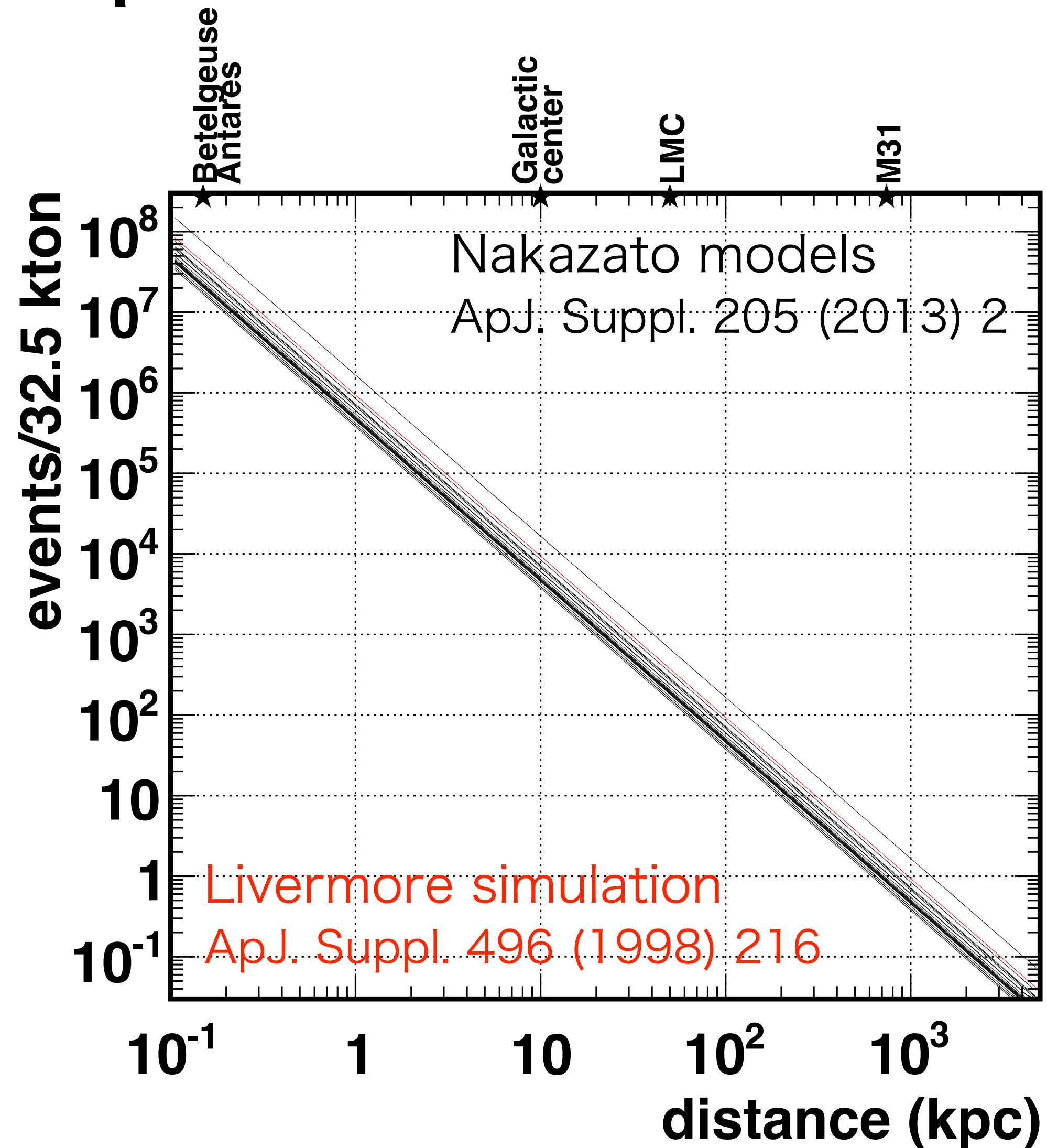
Experimental phases



‘SK-Gd’ is a broad and general term for the experiment after the start of the Gd-loading

Supernova burst neutrino

Expected number of events



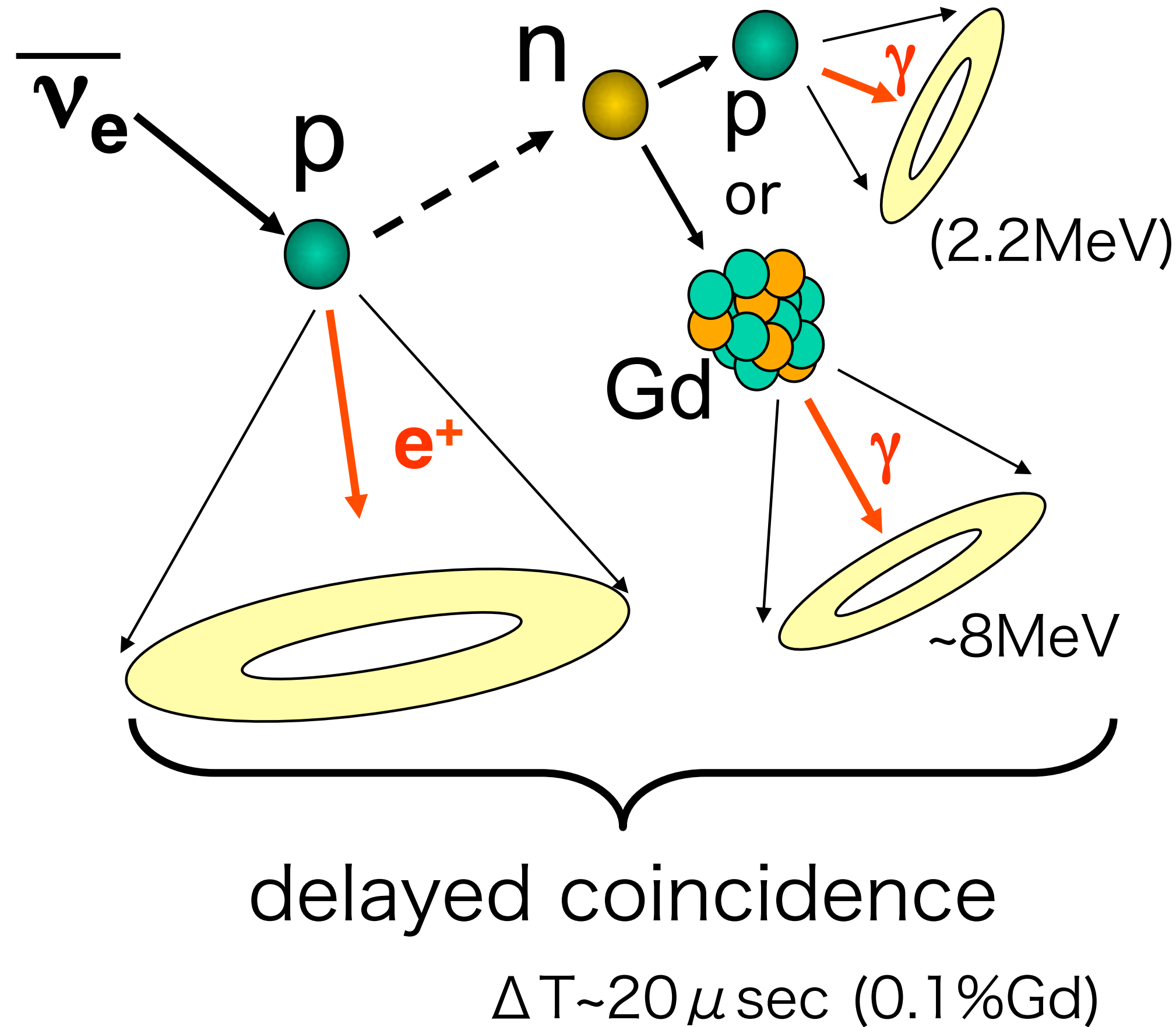
	Nakazato (SN)	Nakazato (BH)	Livermore
Betelgeuse (150pc)	16.7~37.7 M	73.8 M	41.8 M
at 10kpc (Galactic center)	3.76~8.49 k	16.6 k	9.40 k
LMC (50kpc)	150~340	664	376
M31 (740kpc)	0.69~1.55	3.0	1.72

32.5 kton, 5MeV threshold, Normal mass ordering

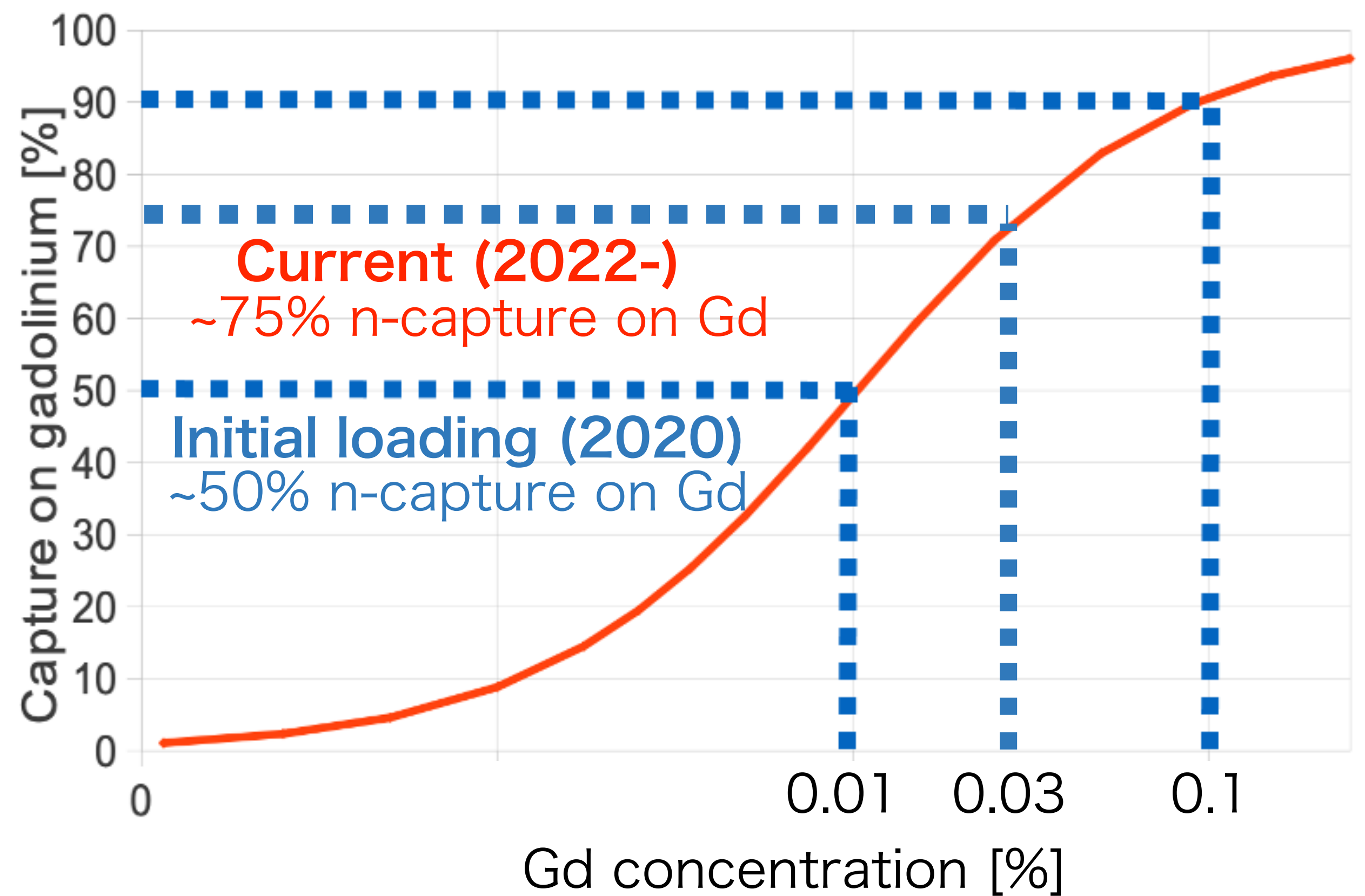
SK-Gd

Dissolving Gd to enhance neutron detection capability

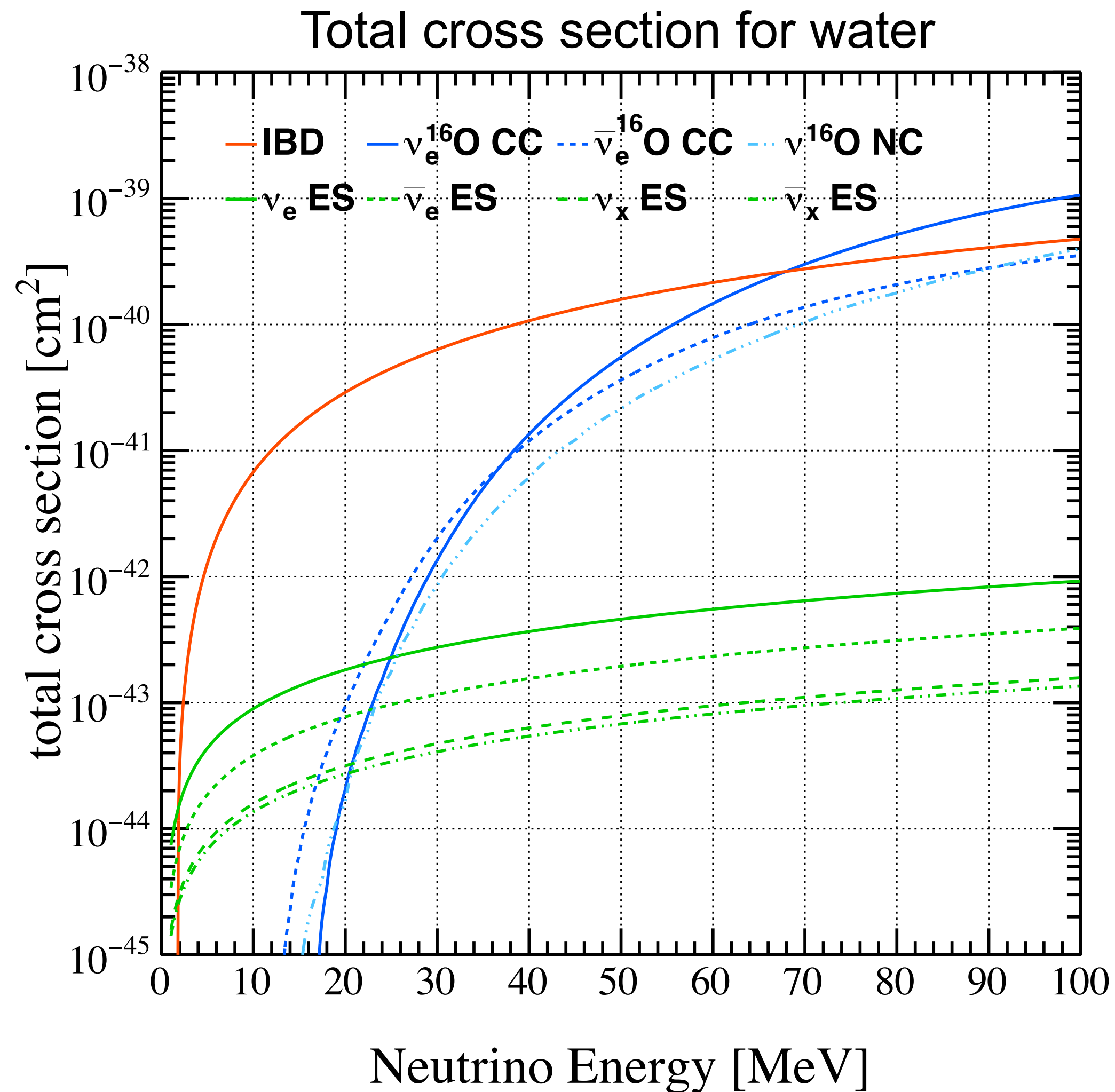
Inverse Beta Decay (IBD)



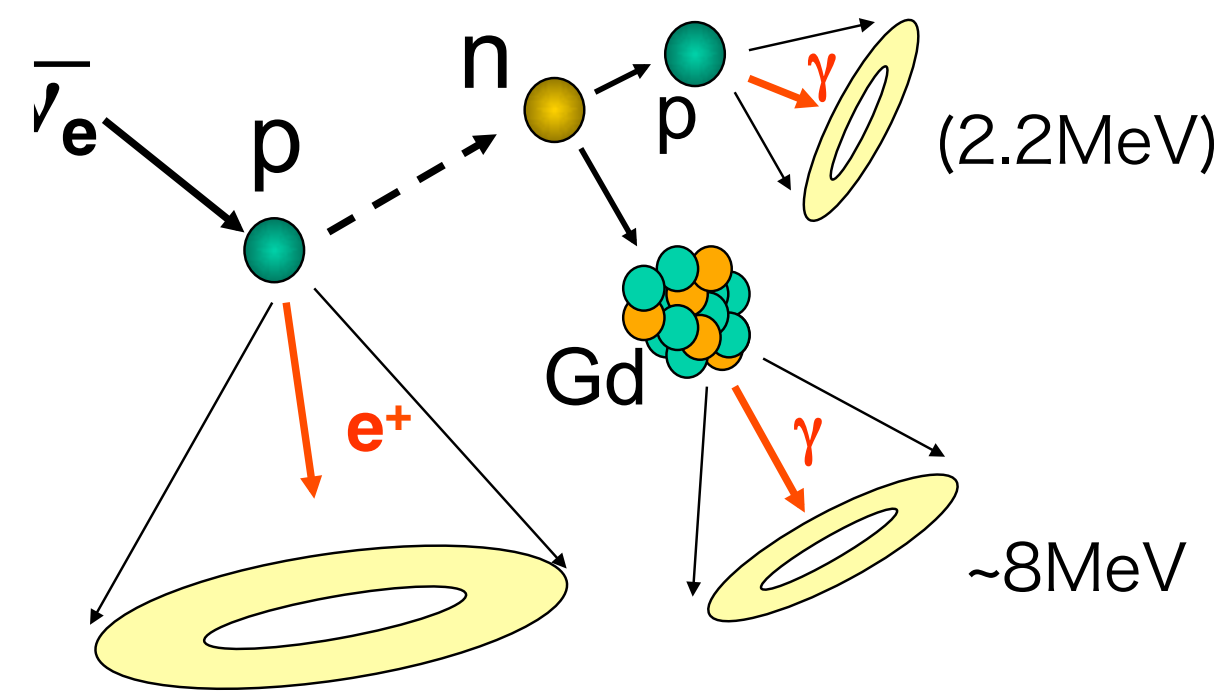
Neutron capture efficiency on Gd



Supernova burst neutrino Pointing accuracy

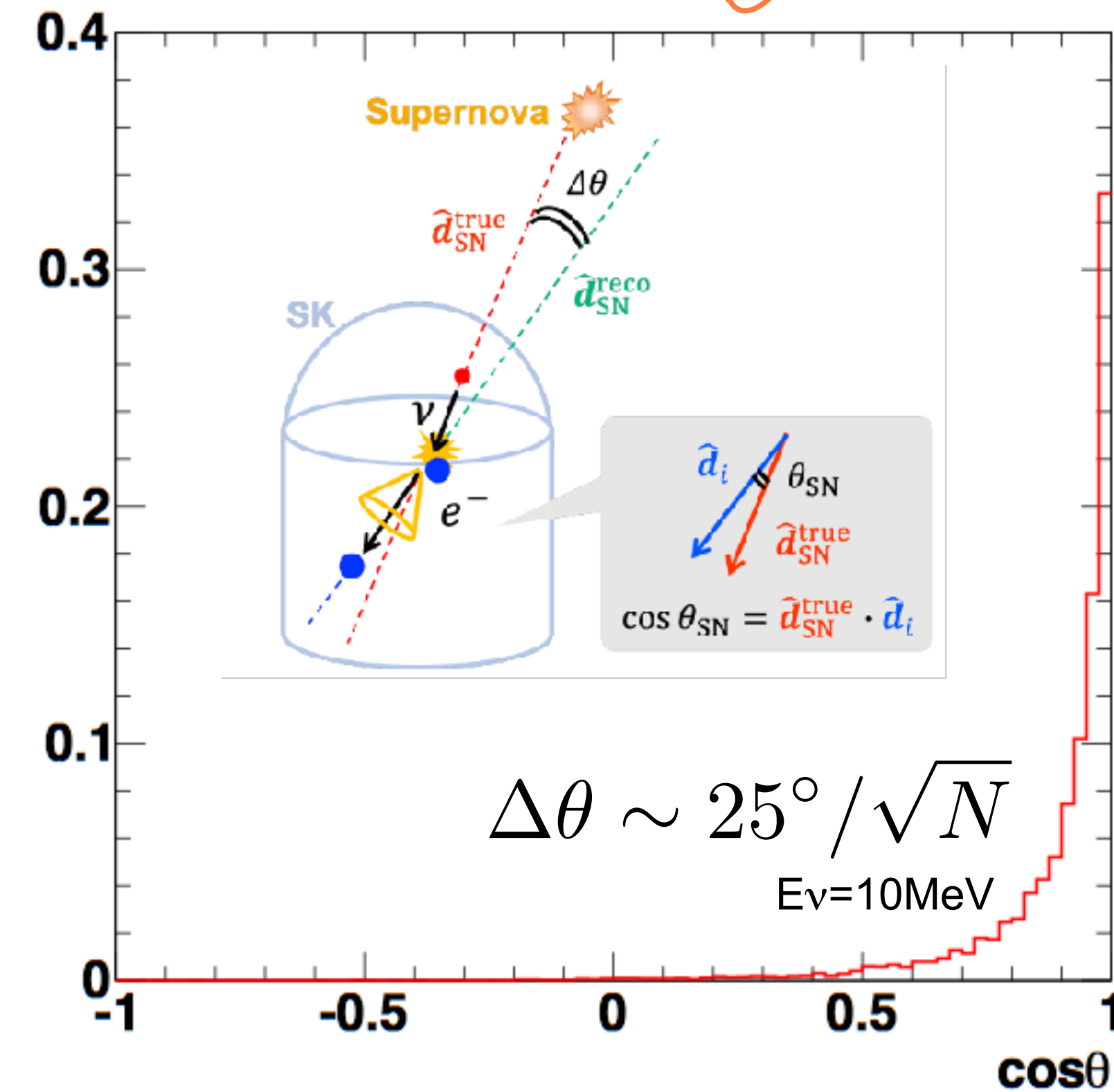
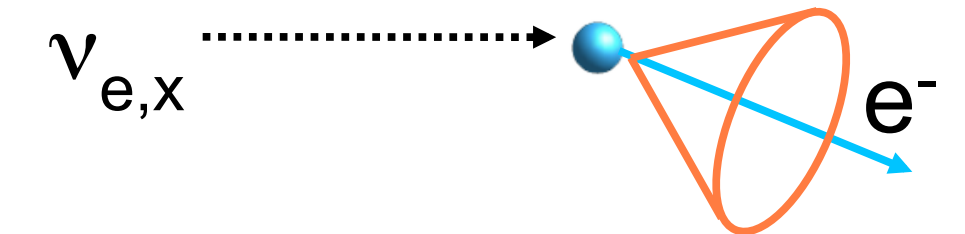


IBD (dominant)



No directionality
Neutron tagged

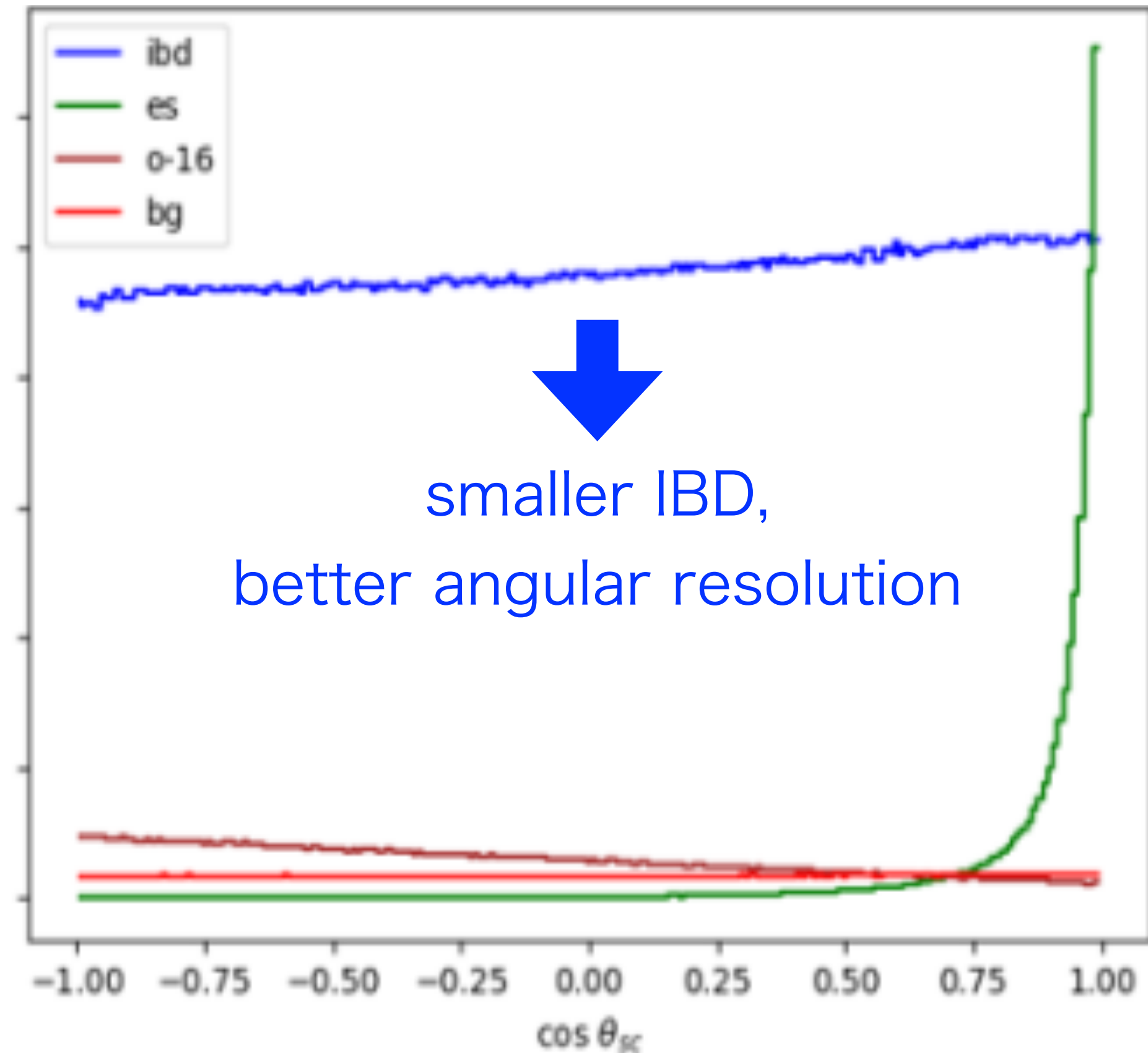
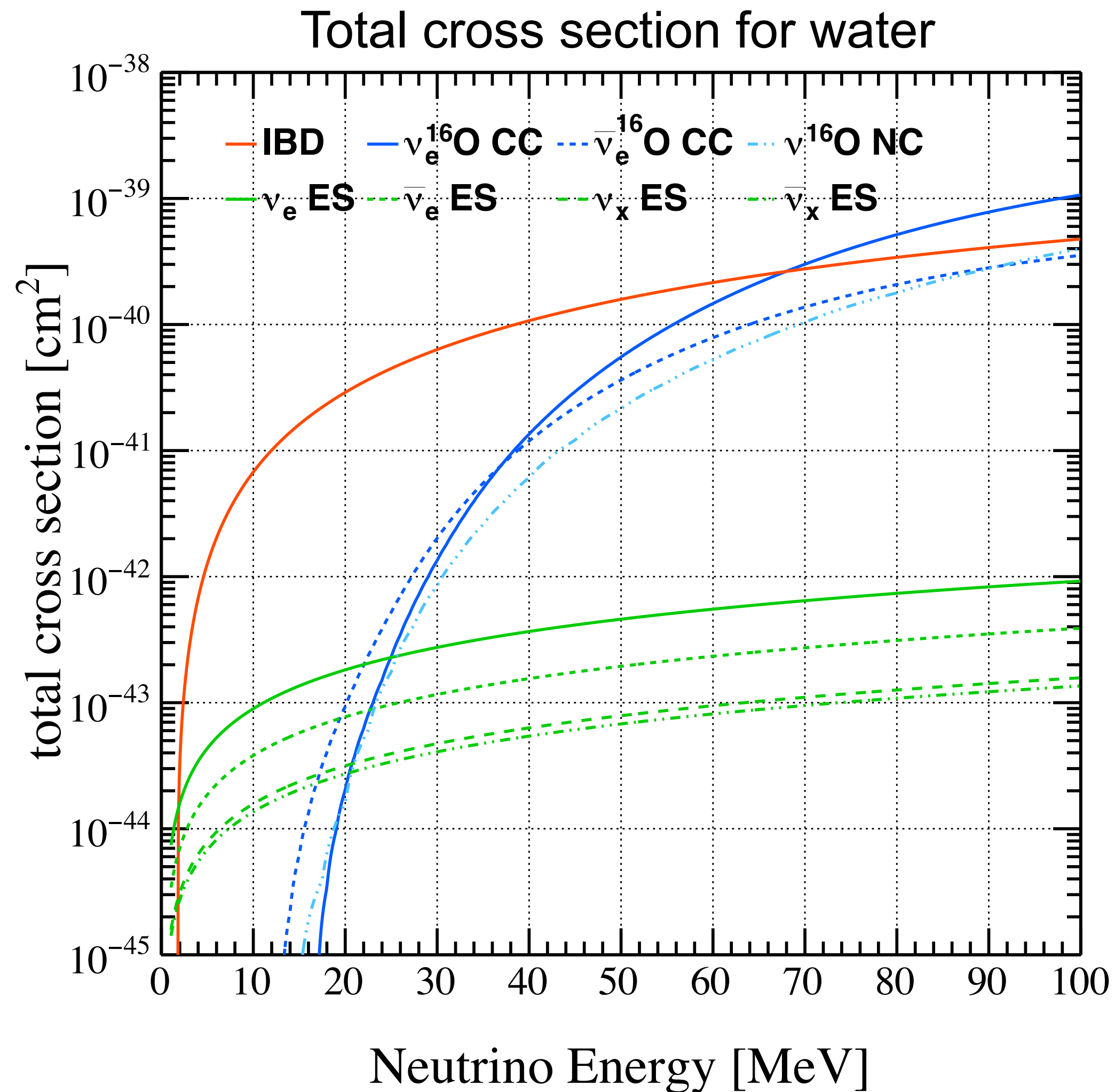
Elastic scattering



Strong directionality
No neutron tagged

Supernova burst neutrino

Pointing accuracy

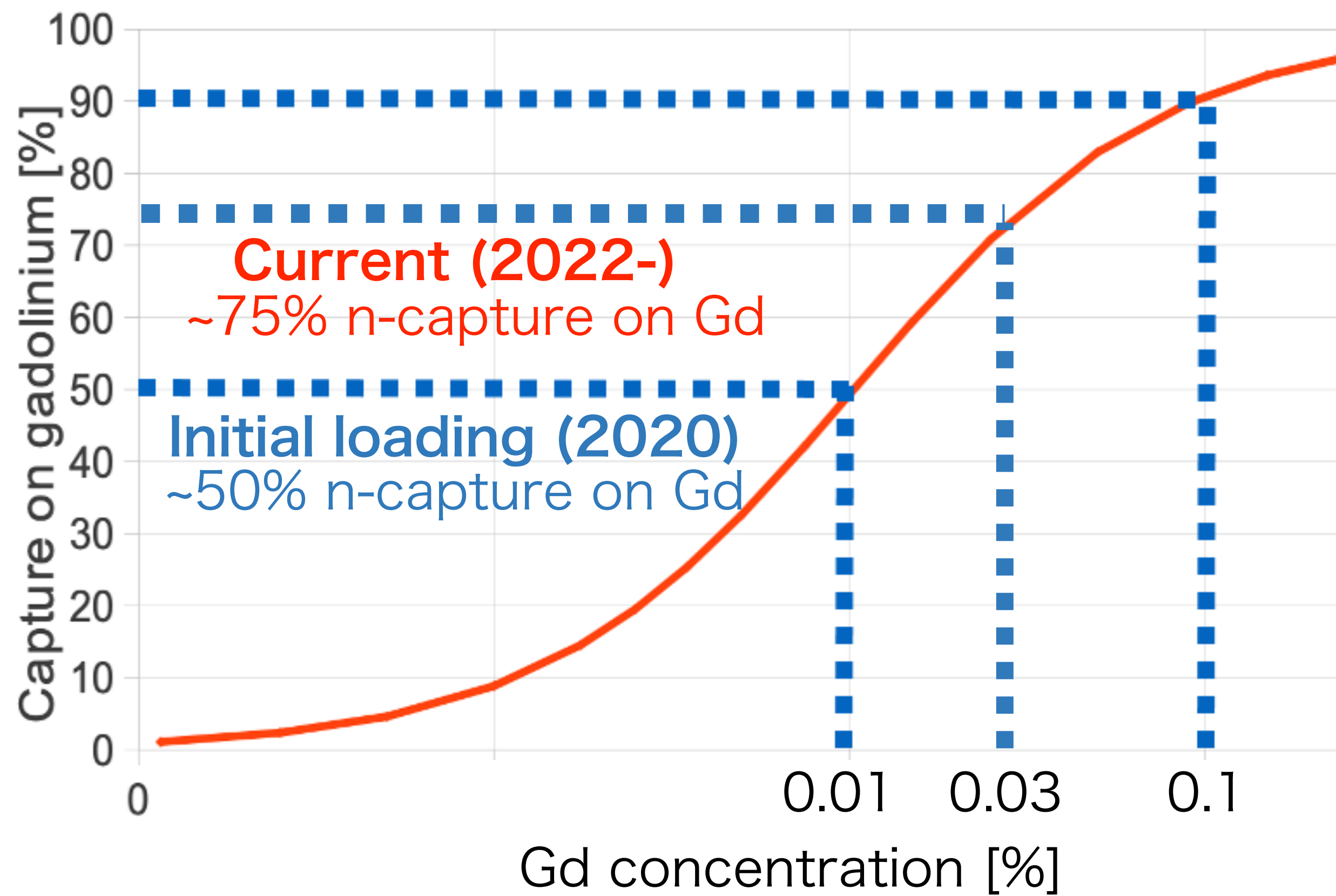


Remove the neutron tagged events
in the direction calculation

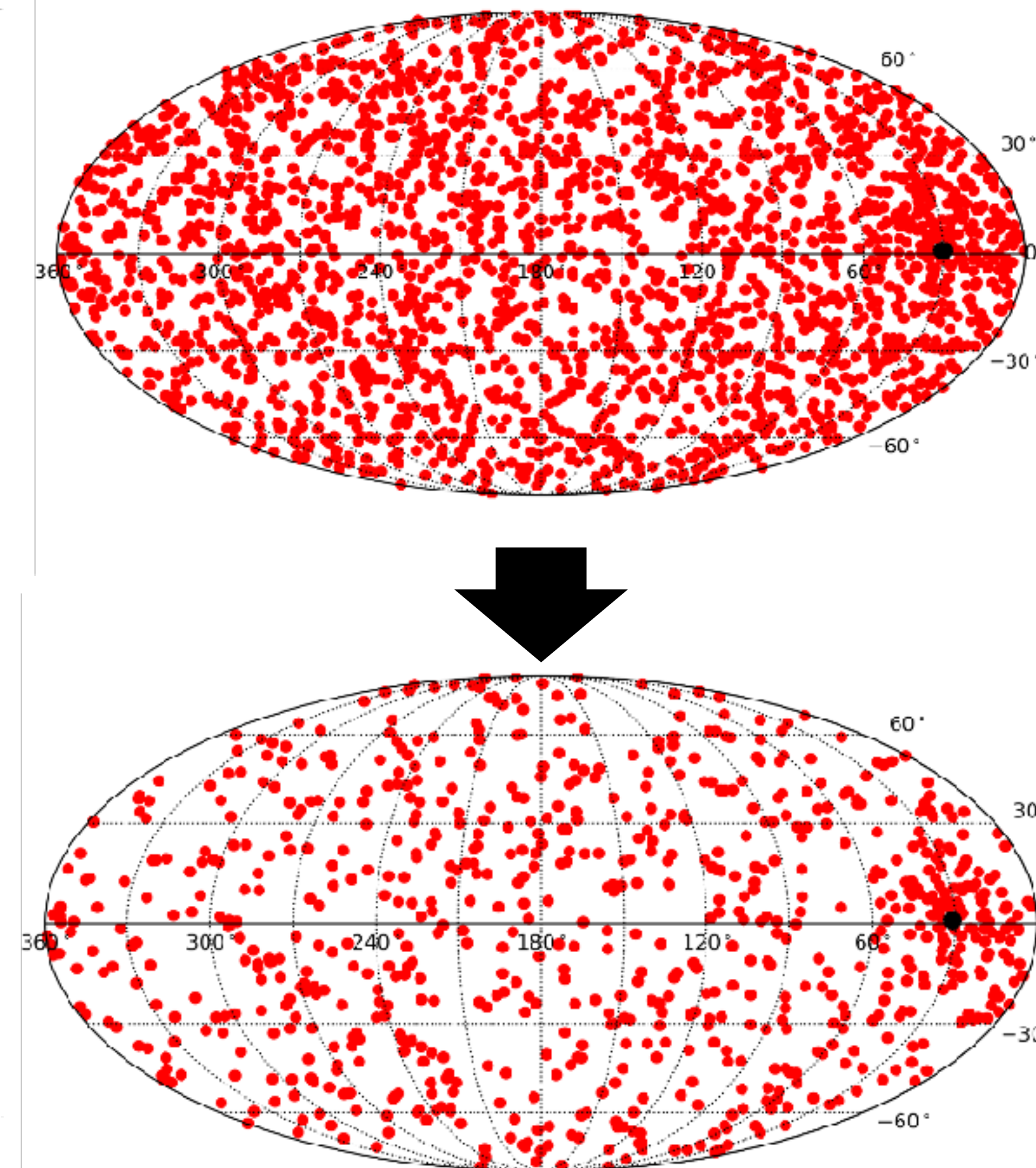
Supernova burst neutrino

Improve the pointing accuracy in SK-Gd

Neutron capture efficiency on Gd



SN simulation at 10kpc



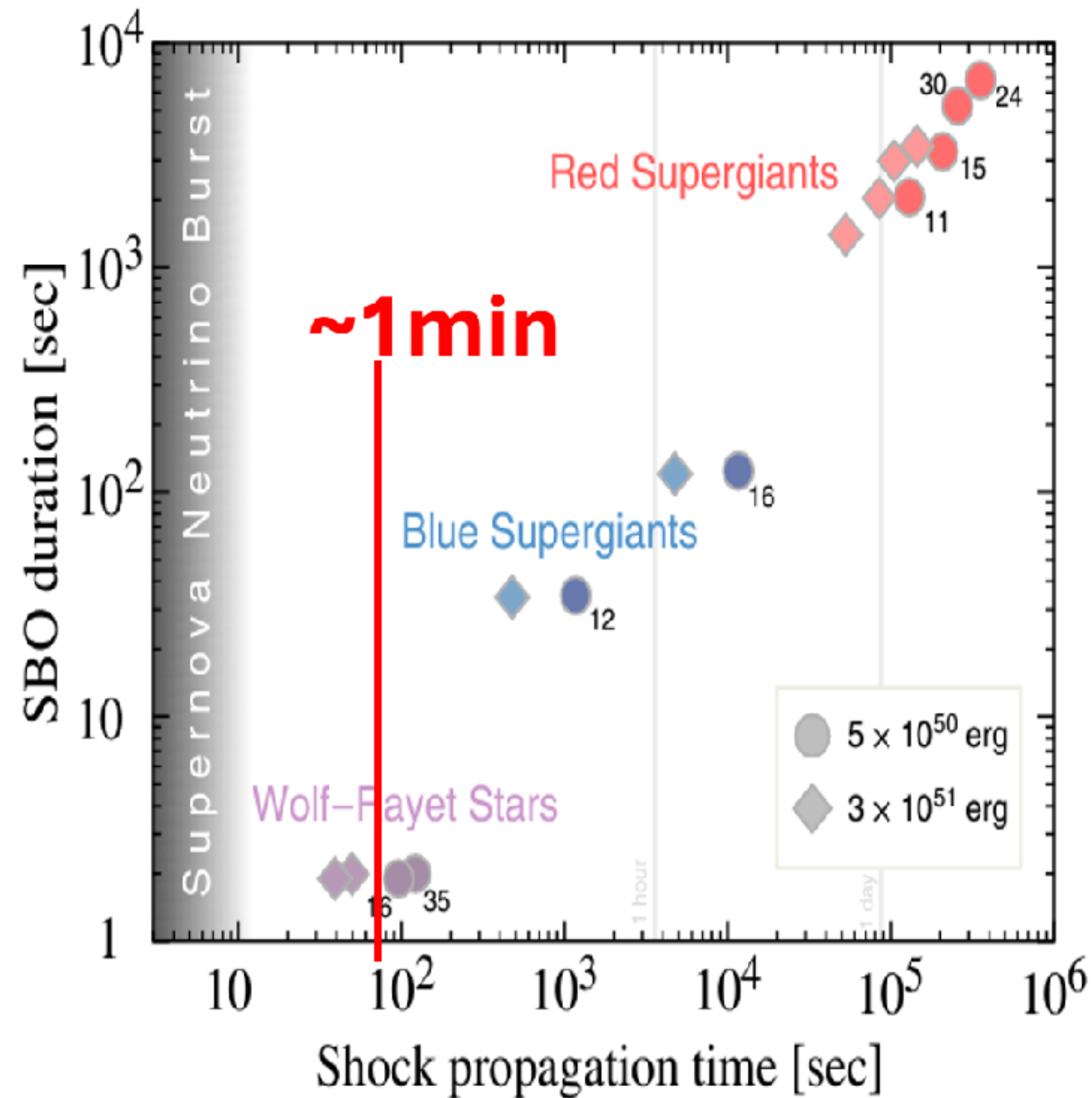
without IBD
tagging

72% of IBD tag
and removed

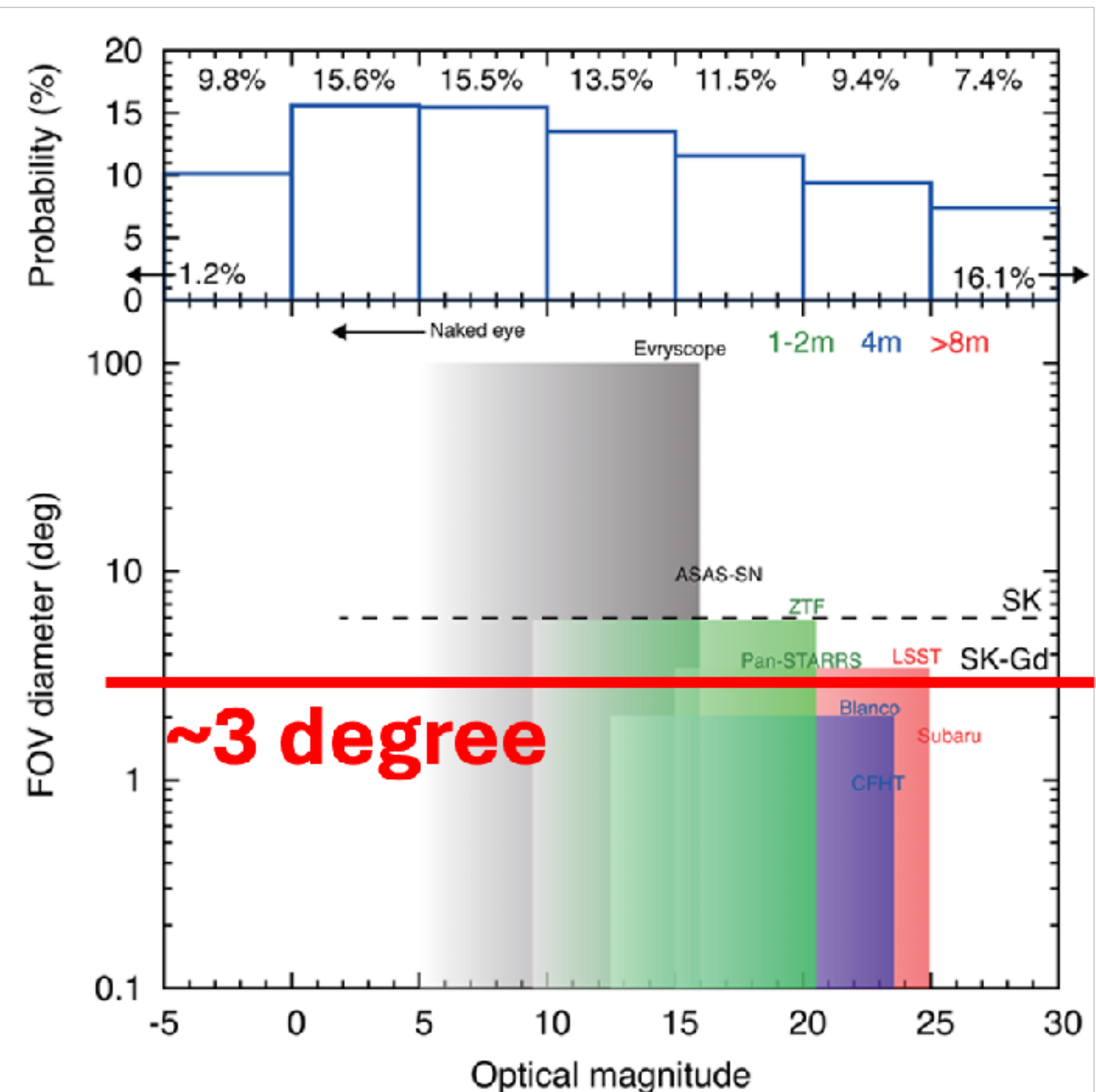
Realtime supernova monitor

Requirement and goal

Kistler, M., Haxton, W., & Yuksel, H. 2013, *Astrophys. J.* 778:81, 9pp

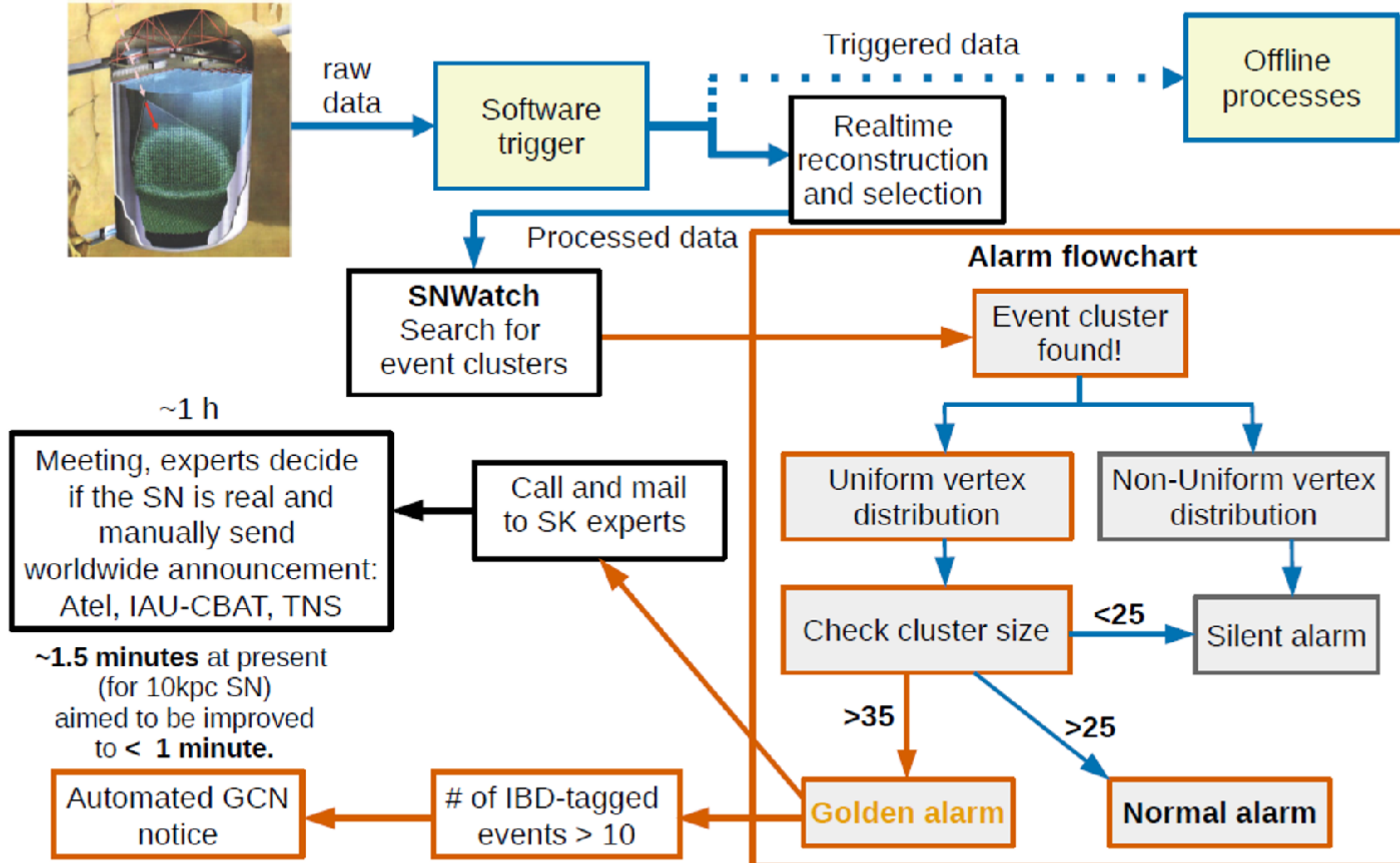


K.Nakamura et al. *MNRAS*461,3296–3313(2016)



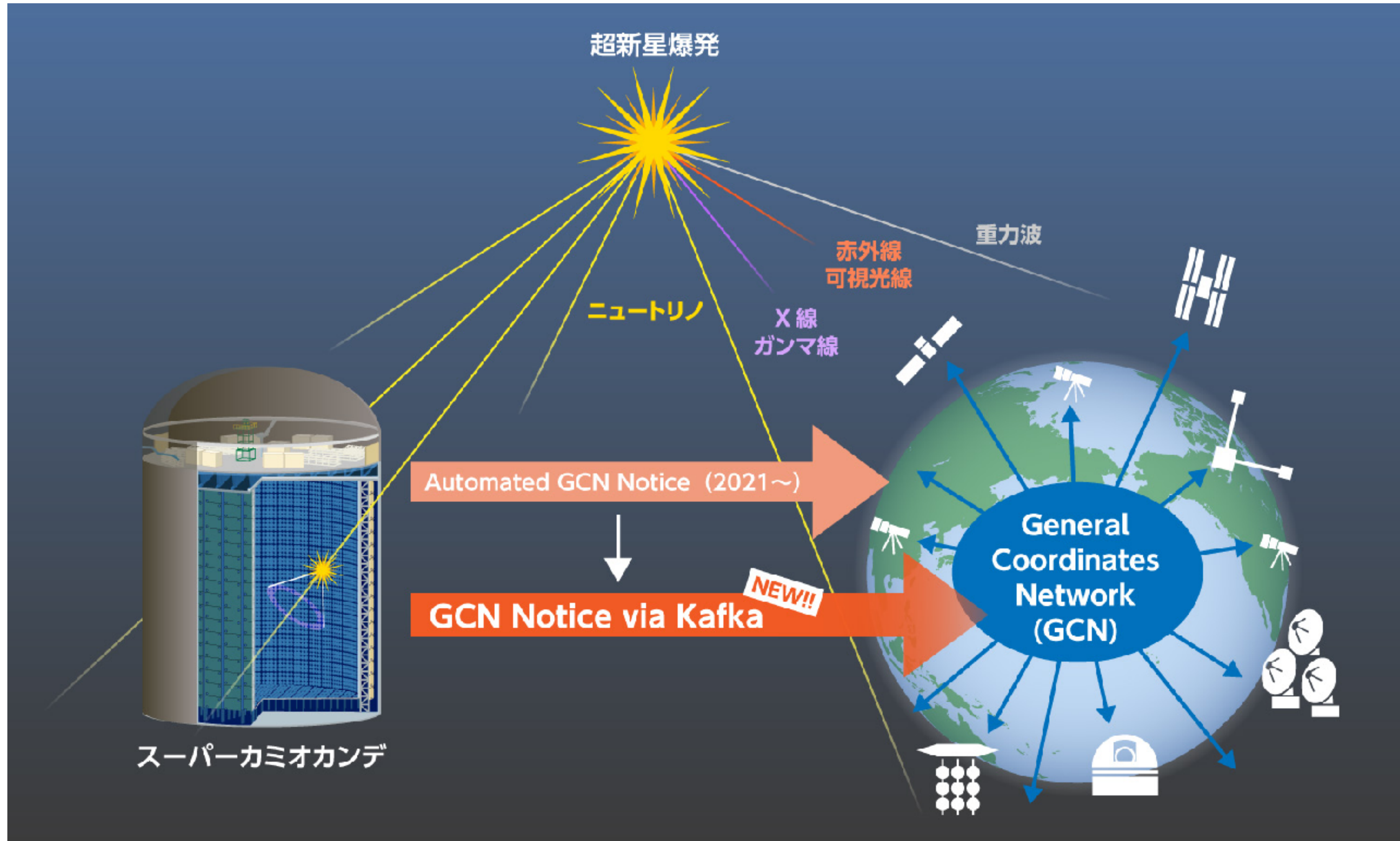
Realtime supernova monitor

Flow



Realtime supernova monitor

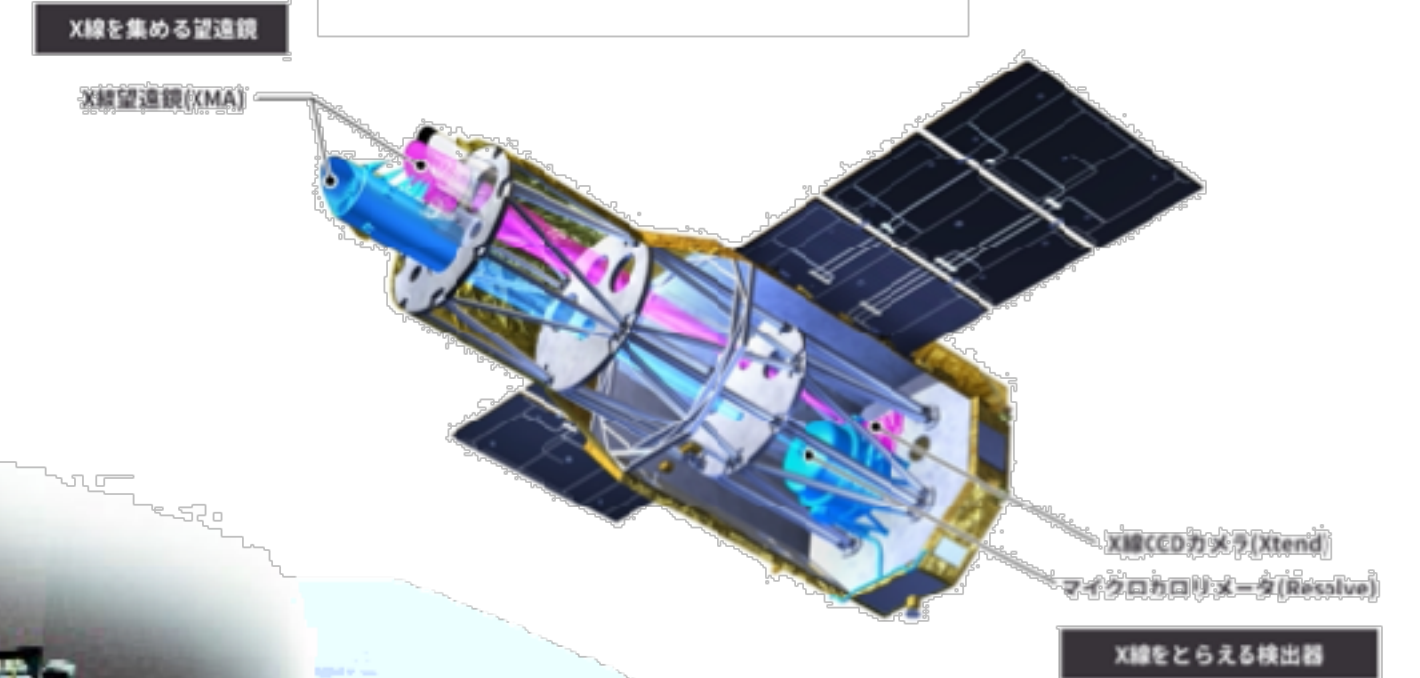
Automated GCN notice via Kafka



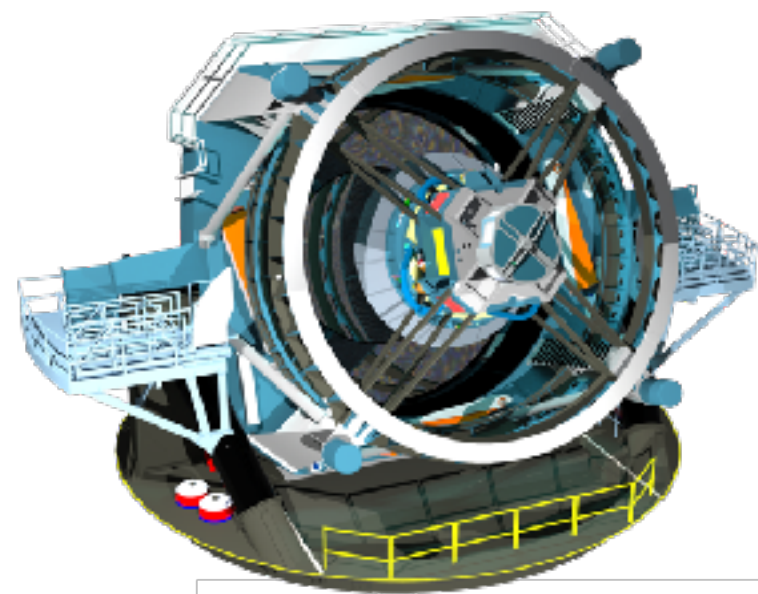
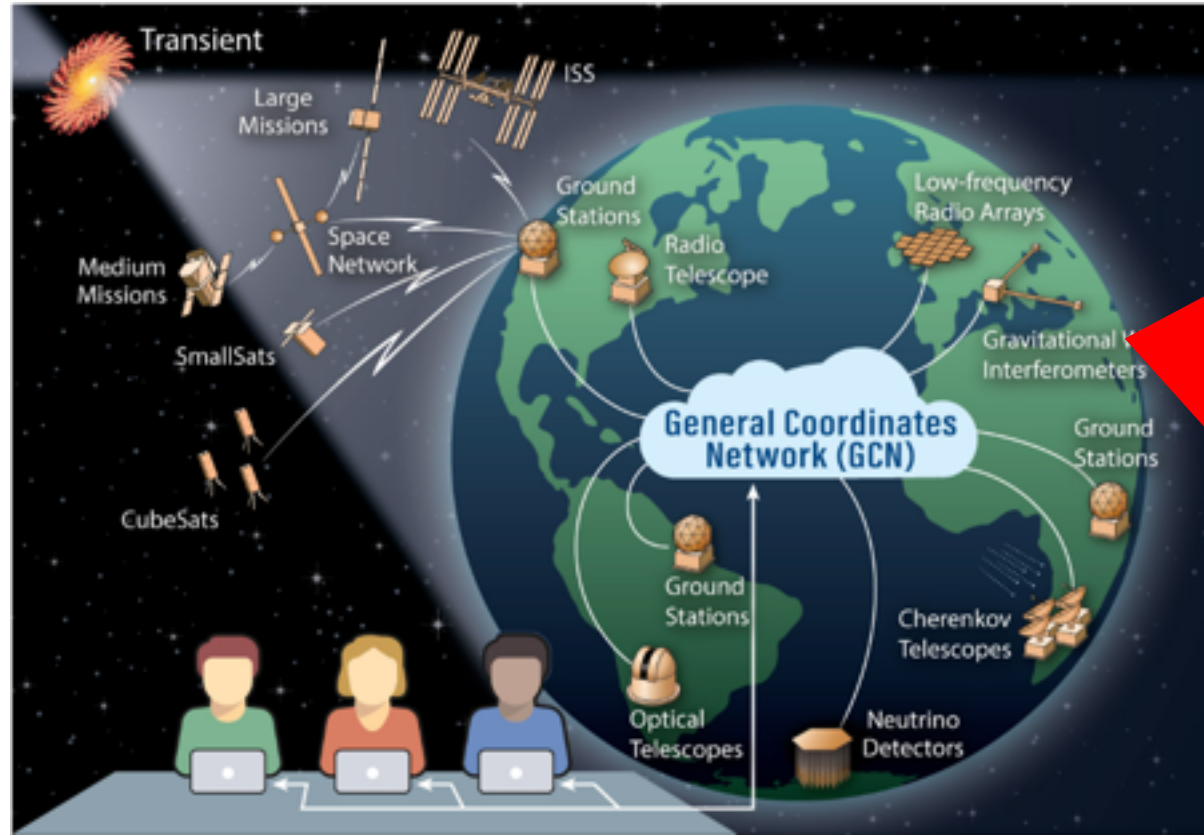
Cooperation with telescopes expanding cooperation

内田さん発表

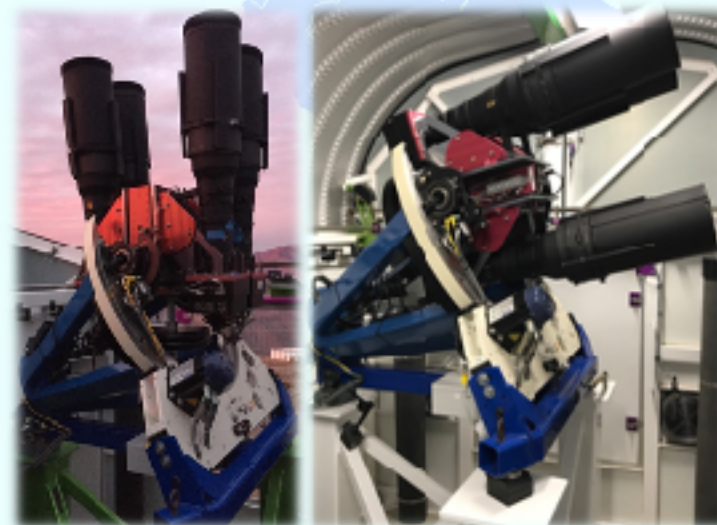
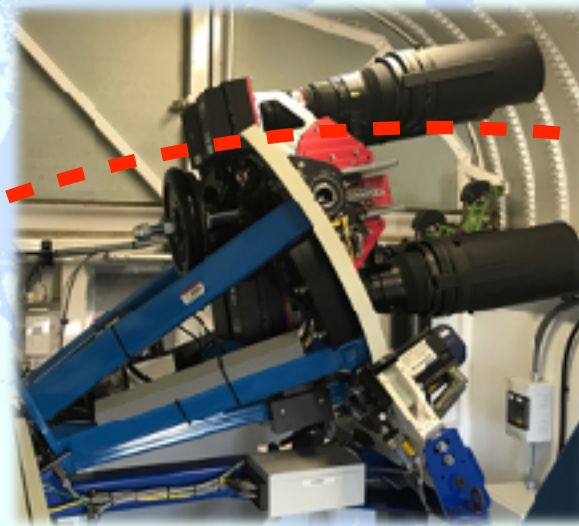
XRISM ~2024



Automated GCN notice



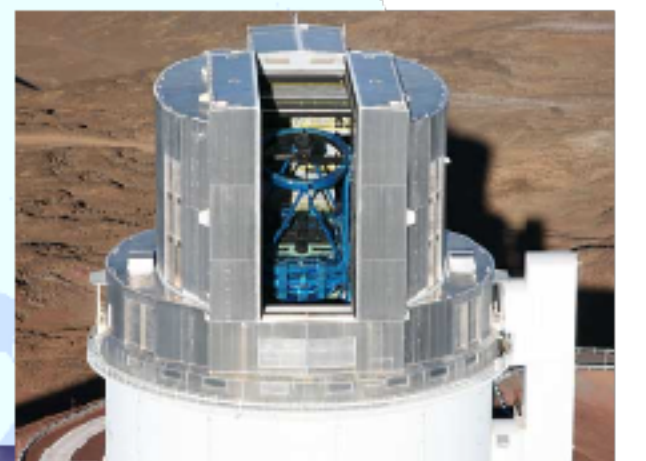
Rubin ~2025



ASAS-SN~2023 MoU



Tomo-e ~2024 MoU 新納さん発表



Subaru ~2024

Realtime supernova monitor

Latency improvement

Observation (in case of 10kpc SN)



Data transfer ~1 min

Length of subrun is ~1 min



Event reconstruction ~1 min

Obtain energy, vertex position, and direction for each event



SN direction fitter ~10 min



New method

Better resolution

Faster! ~few sec



Have a meeting among experts and confirm signals ~30 min



Auto GCN Notice ~ sec



SN Golden alert (Originally ~1 h)

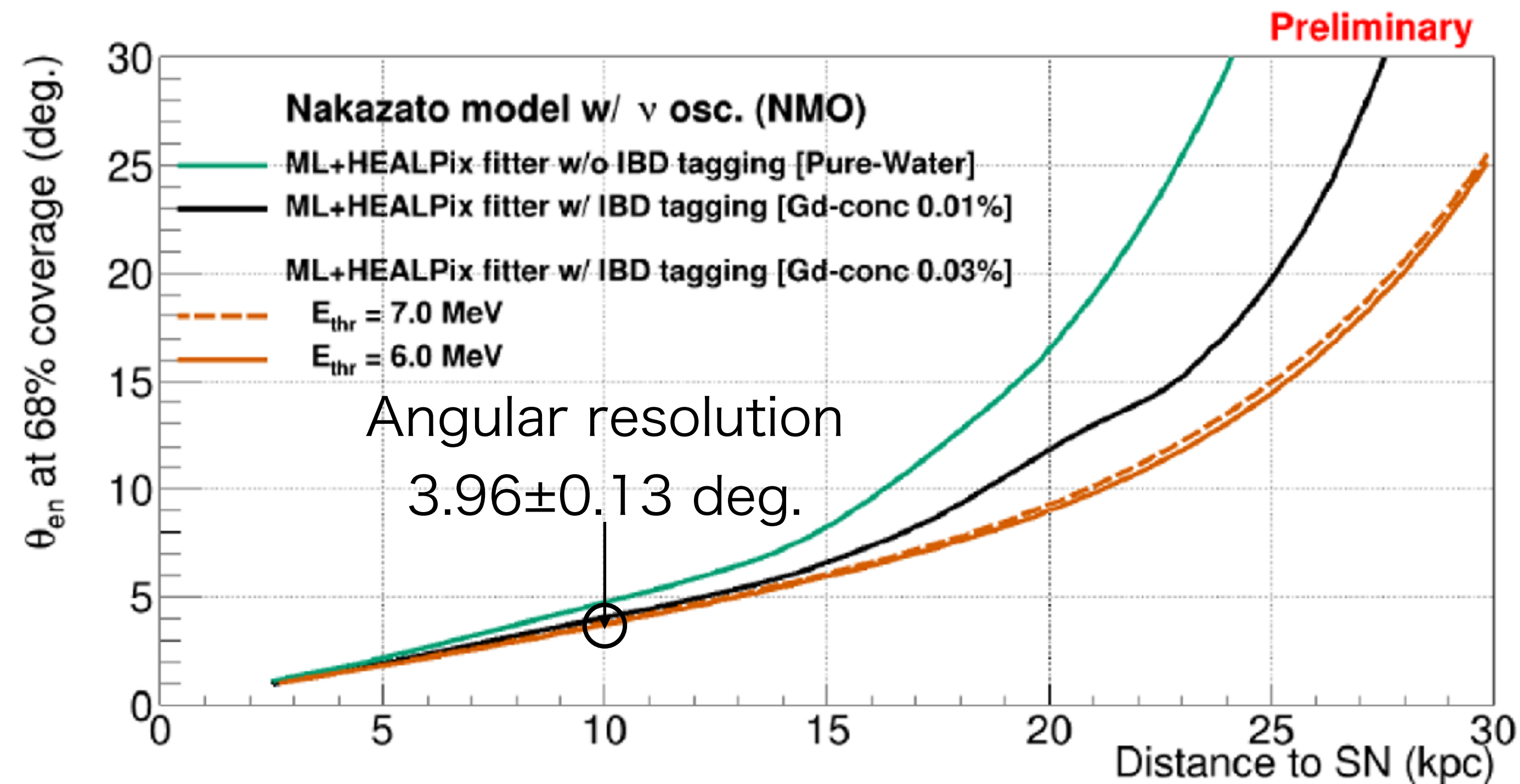


Current latency : ~ few min

Realtime supernova monitor

Pointing accuracy

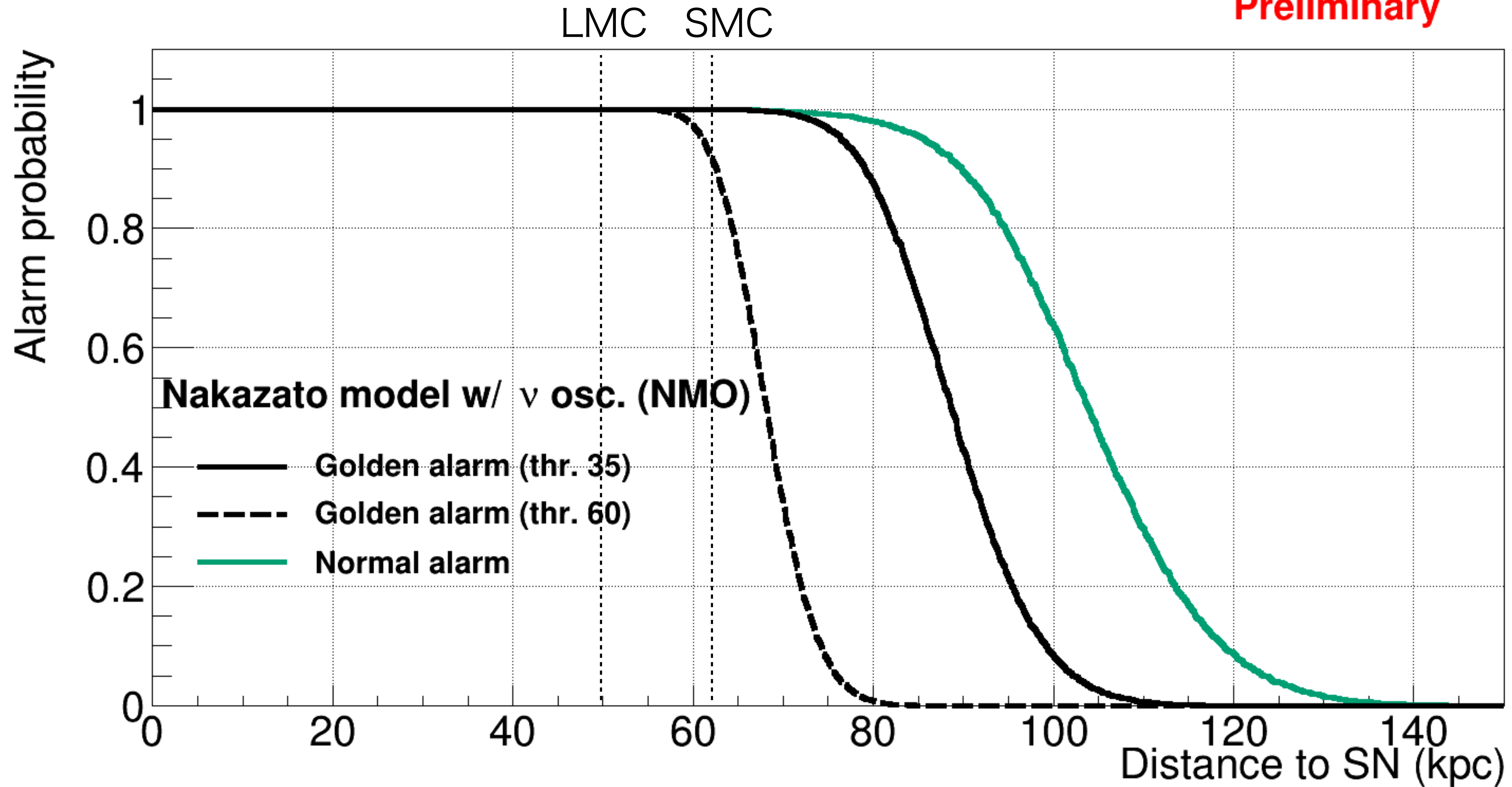
- Recently, we developed a new fitter (Maximum Likelihood+HEALPix) for the direction. It takes less than 10 seconds to calculate.
- The pointing accuracy is 3-7 degrees at 10 kpc in several SN models.



Realtime supernova monitor

Detection efficiency

Preliminary



Realtime supernova monitor

Recent update -> LLA

- Since December 13th 2021, an automated GCN notice will be sent.
 - Golden alarm (isotropic distribution and more than 60 good events) and the number of IBD tagged events is >10 .
-> ~100% for SMC, while 0% above 80 kpc..
 - **Low Level Alarm (LLA)**, which has weaker conditions and is sensitive to even further SN, is prepared for Tomo-e, not open to public.
 - We don't want to miss any chance for them even if the possibility is small.
 - Most triggered events are background via cosmic ray muon spallation.

Realtime supernova monitor

Galaxies between SMC and M31 (from ChatGPT)

Boötes I (Boo I) — 64–66 kpc (ultra-compact, very sparse dSph)

Draco — ~76 kpc (dSph)

Ursa Minor — ~76 kpc (dSph)

Sculptor — ~86 kpc (old stellar-dominated dSph)

Sextans — ~86 kpc (dSph)

Carina — ~105 kpc (dSph)

Fornax — ~147 kpc (dSph, with past star formation history)

Leo II — 200–230 kpc (dSph)

Leo I — 250 kpc (dSph).

Leo T — 410–420 kpc (transitional, small but young star clusters observed)

Phoenix dwarf — 415–440 kpc (transitional, with past to recent low-level star formation)

NGC 6822 (Barnard's Galaxy) — ~500 kpc (active star-forming region in the irregular Local Group.

Separate RSG catalog available)

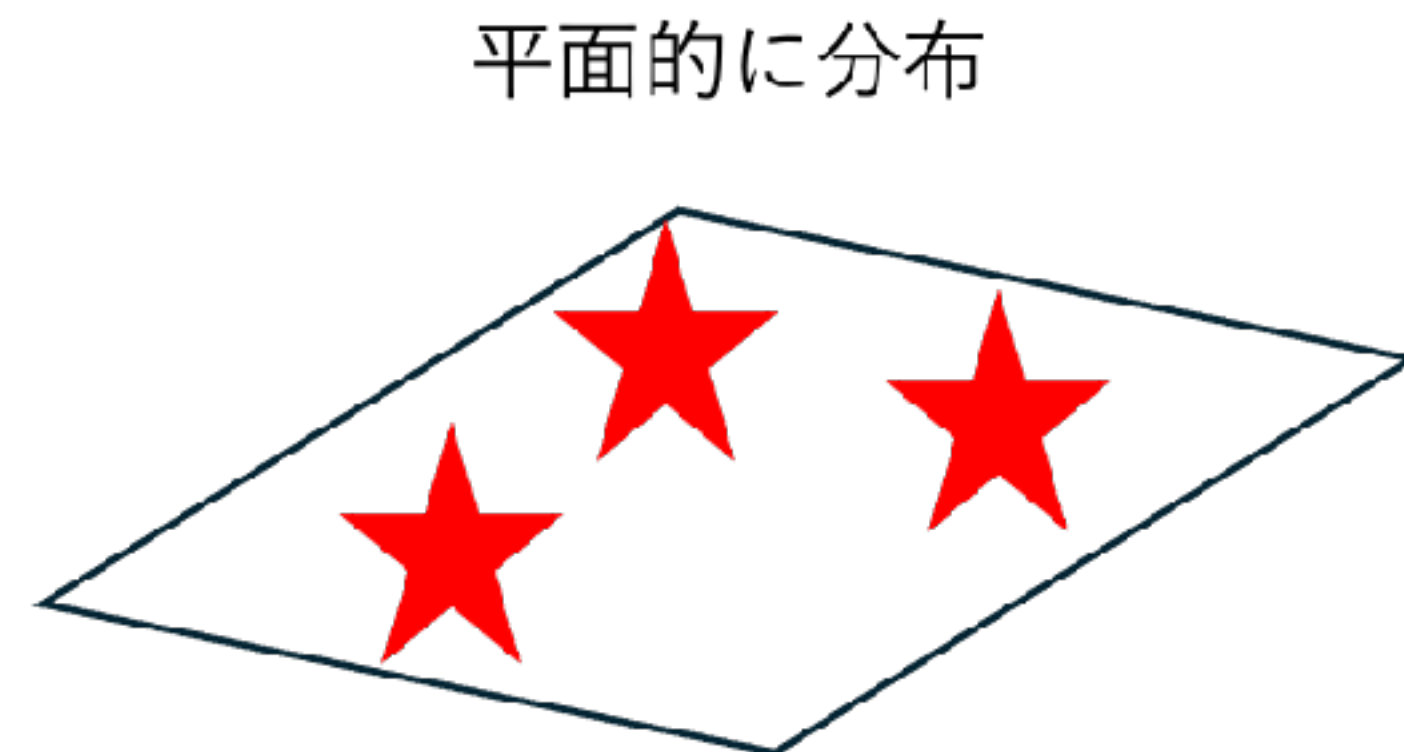
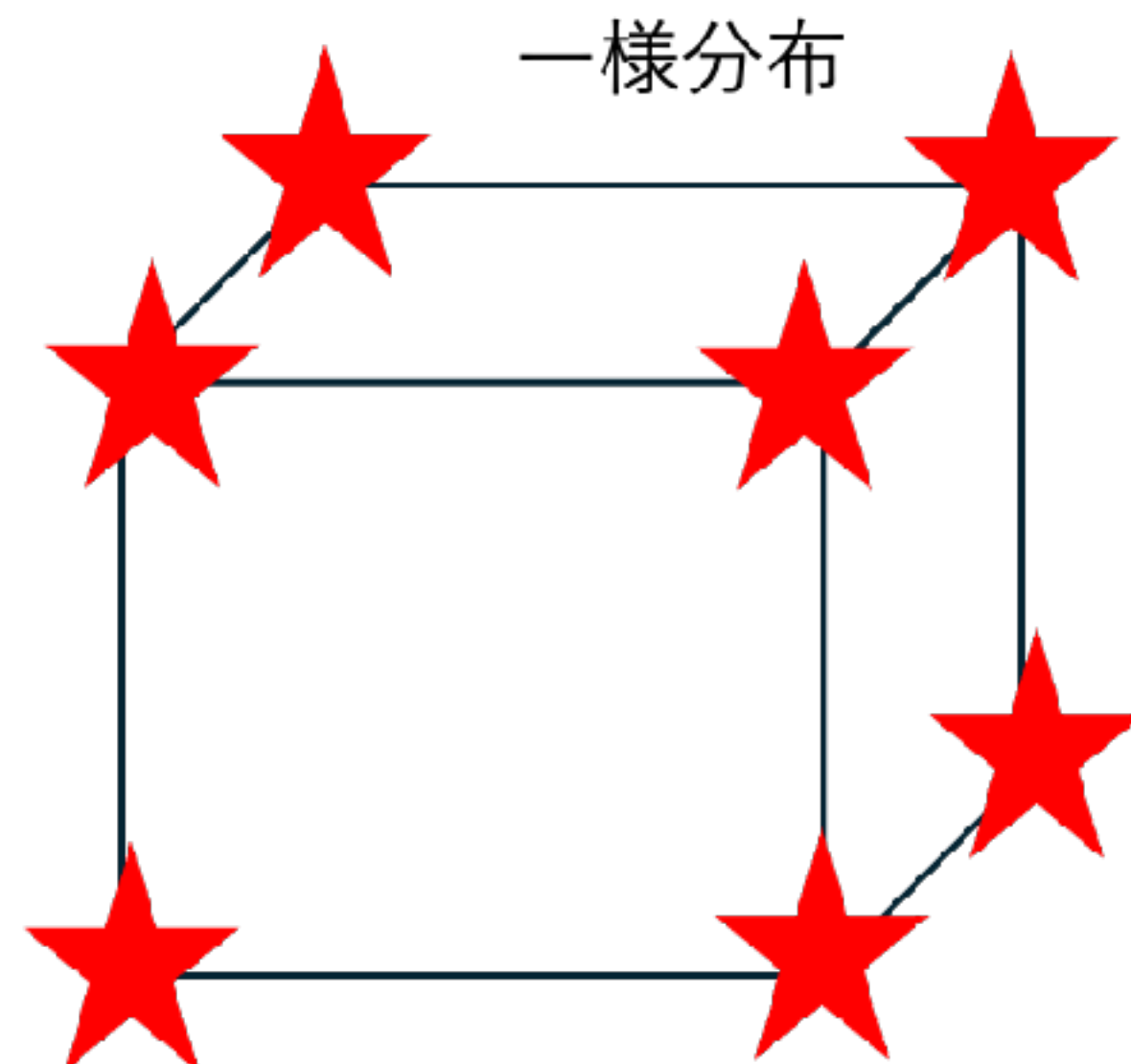
NGC 185 — 620–640 kpc (companion galaxy of M31, mainly old stars, low SFR)

NGC 147 — TRGB observations indicate ~680 kpc (?) (companion galaxy of M31, mainly old stars)

Realtime supernova monitor

Golden vs Low Level Alarm

	Golden	Low level
事象発生点が検出器内で一様か	一様分布	一様分布 または、平面的に分布
事象数	35	10 (調整中)
IBD tag された事象数	10	4 (調整中)

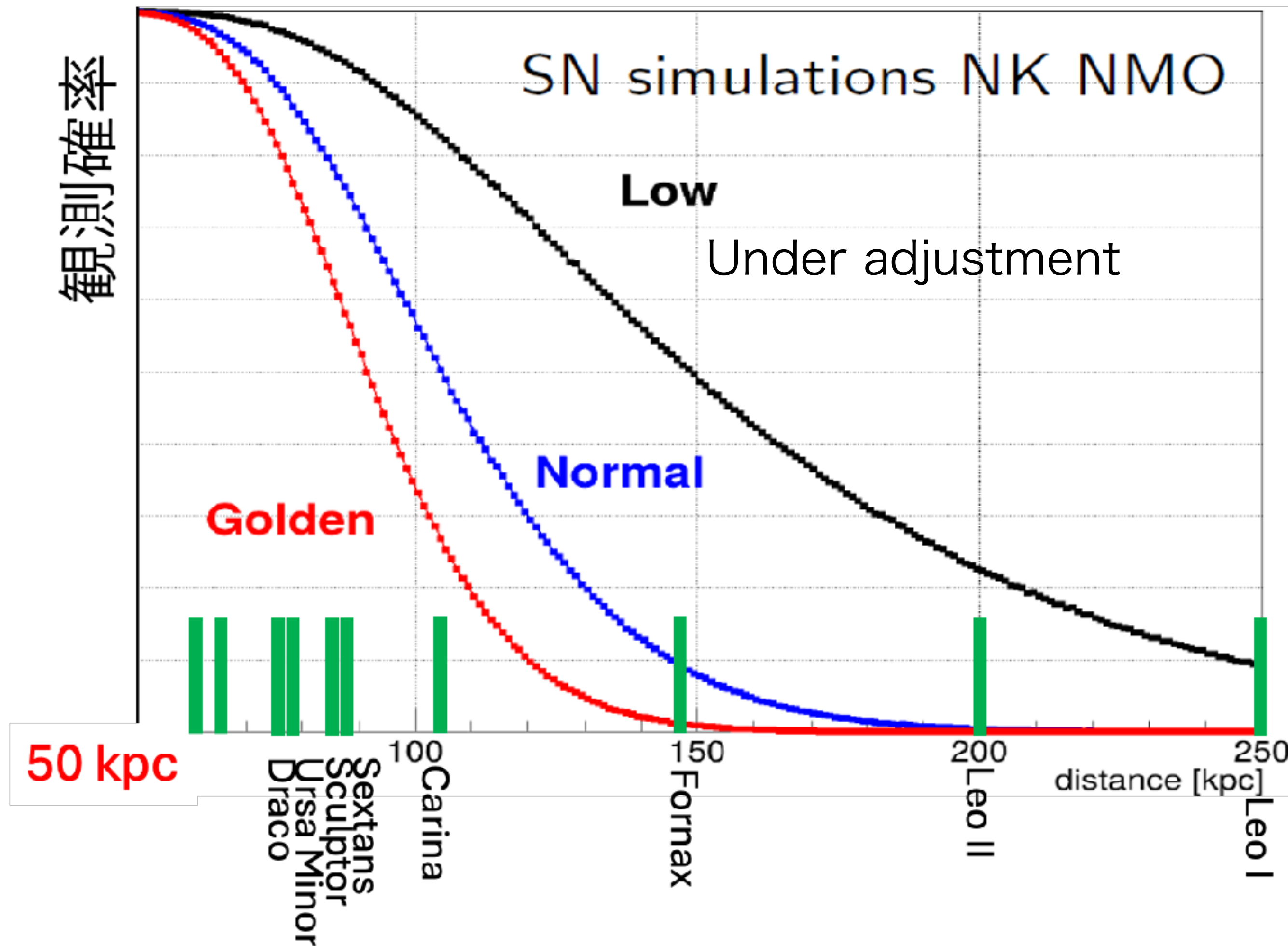


事象数が少ないと、SNの場合でも平面的に分布していると判断されることが多い

Realtime supernova monitor

Observation probability as a function of distance

preliminary



Under the criteria of the number of events, the observation probability is over 10% up to ~250 kpc. => can we go up to Leo I ?

Cooperation with OISTER

multi-messenger of supernova explosion

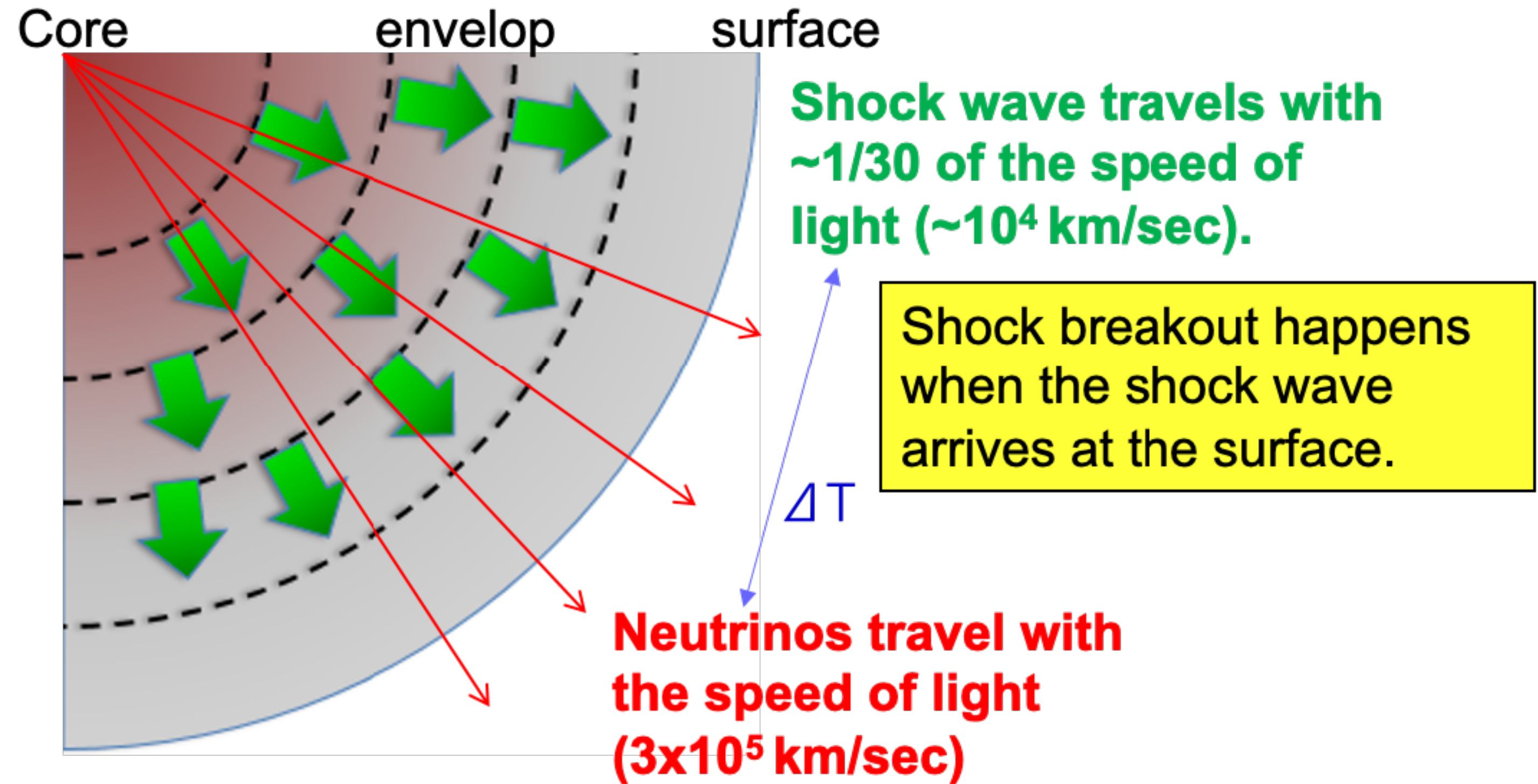
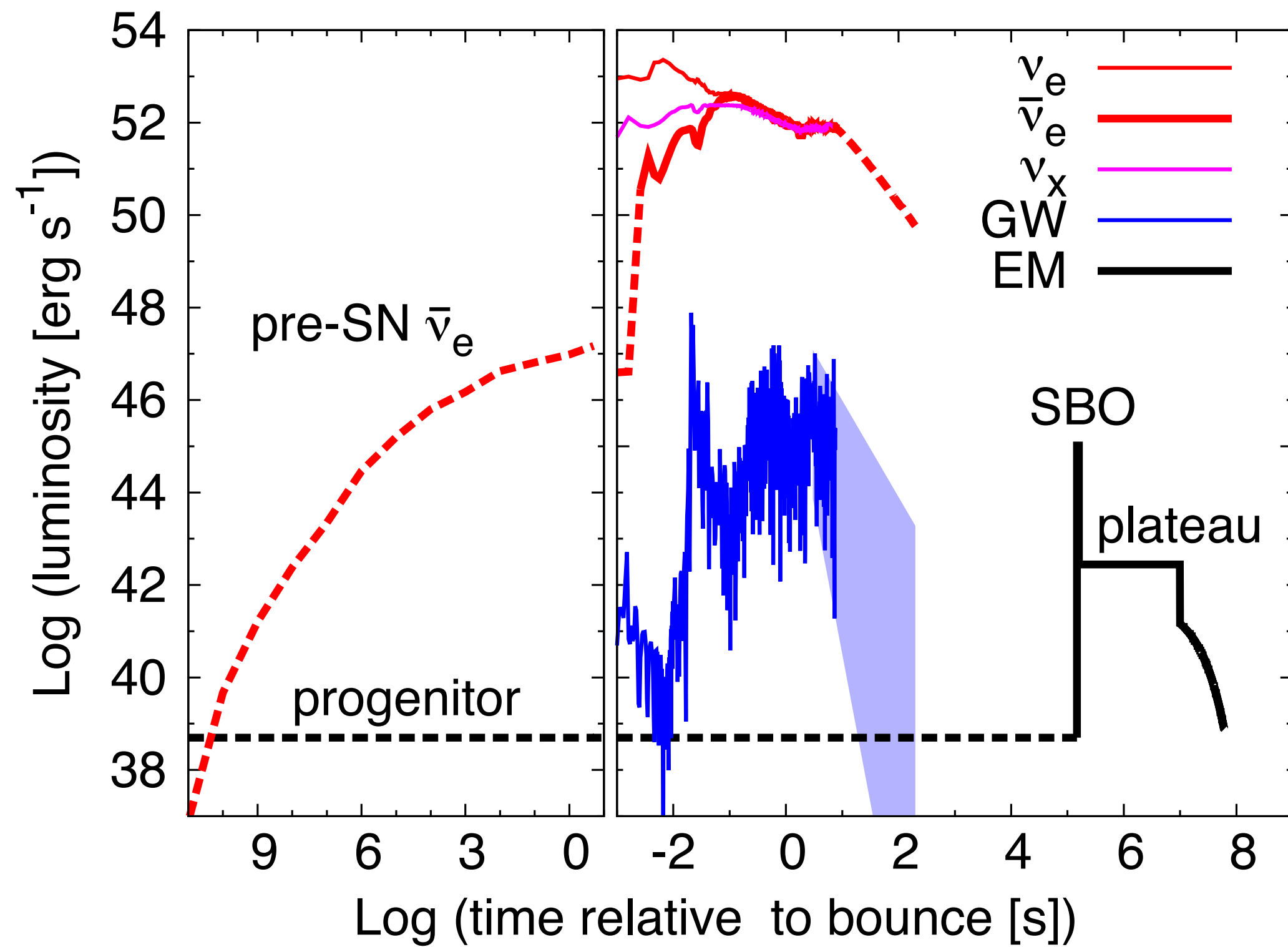


So far, we are making effort to make partnership between SK and each telescope

Now we need more cooperation between telescopes to share information during SN observation

Example of a target

Can we see the shock breakout?



Super-Kamiokande
Refurbishment Work
2018 Summer



ご協力をよろしく申し上げます

Thank you for your attention