SuperKamiokandeにおける超新星爆発モニターについて

M.Ikeda
(U Tokyo, ICRR)

For Super-Kamioiande Collaboration
@木曽シュミットシンポジウム2024

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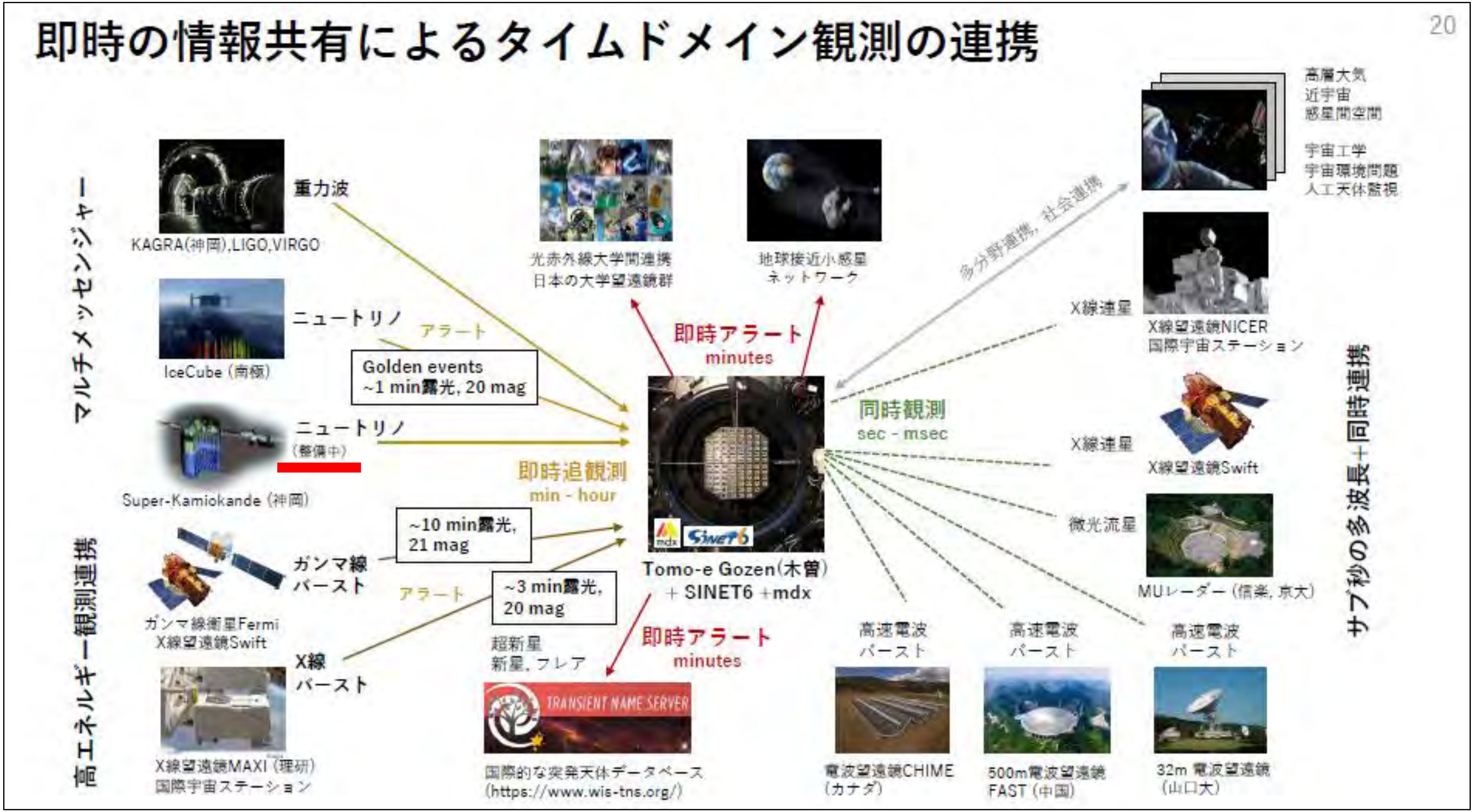
  - Super-Kamiokande
  - SK Gd status
- Improvements of SN burst detection
  - SN direction fitter improvement
  - Supernova monitor at SK
  - Pre-SN alarm
- Summary

Google map

酒向さんのＪＳＰでのスライド



Super-K experiment

1000m underground = 2600 m.w.e

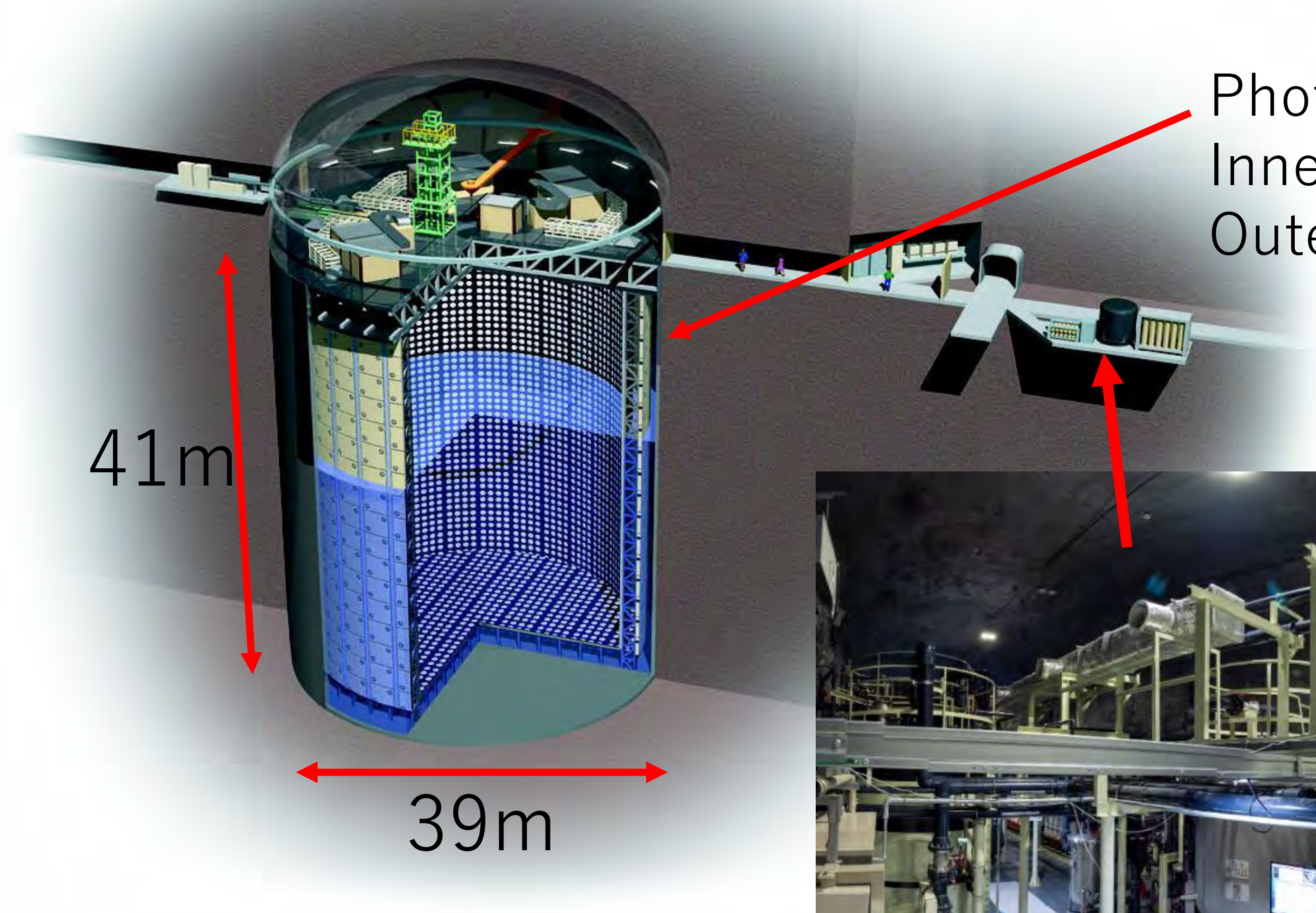
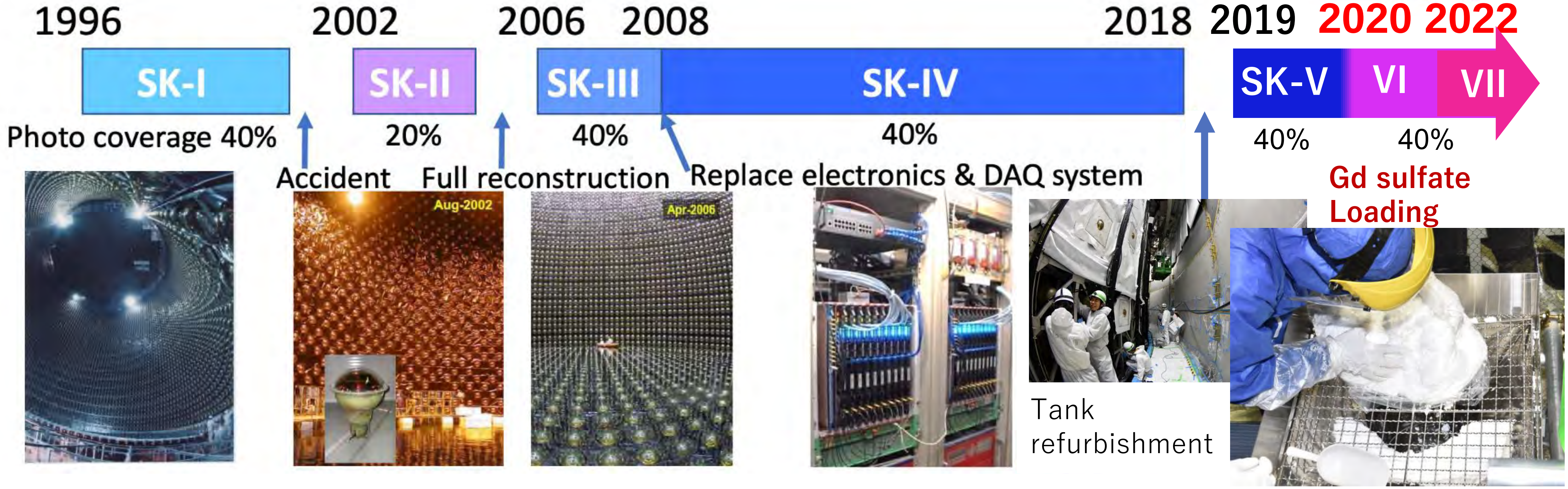


Photo sensors :
Inner detector: 11129 20inch PMTs
Outer detector: 1885 8inch PMTs

Gd water system room

History of Super-Kamiokande



- 1996 Start observation
- 1998 Discovery of the neutrino oscillation by atmospheric neutrino observation
- 2001 Discovery of the solar neutrino oscillation (together with SNO result)
- 2011 Discovery of electron neutrino appearance (T2K)
- 2015 Nobel prize
- 2016 Breakthrough prize
- 2020 Constraint on neutrino CP phase (T2K)

SK-Gd project

Dissolving Gd to enhance detection capability of neutrons from ν interactions

Phys.Rev.Lett. 93 (2004) 171101

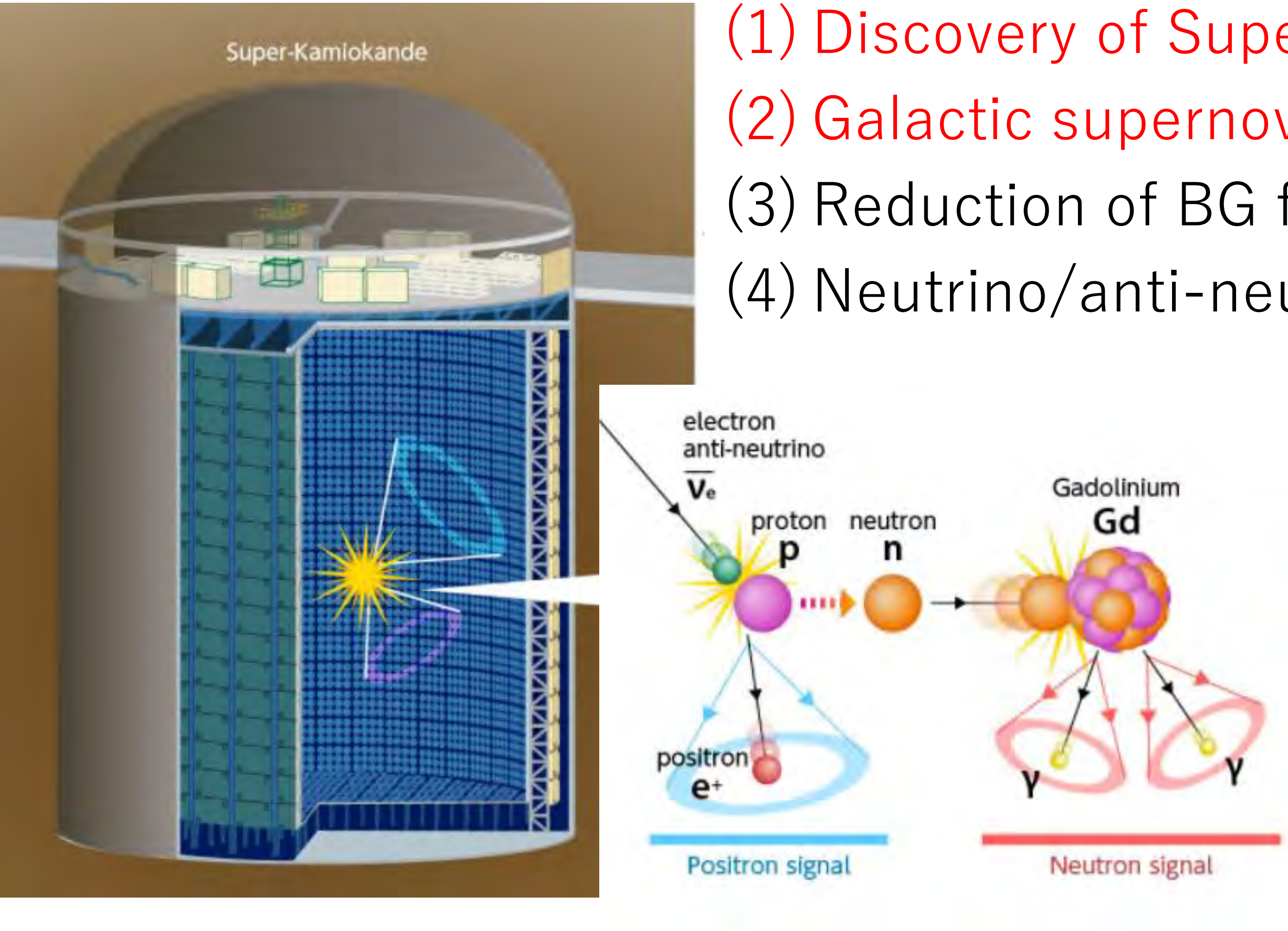
<u>Physics targets:</u>

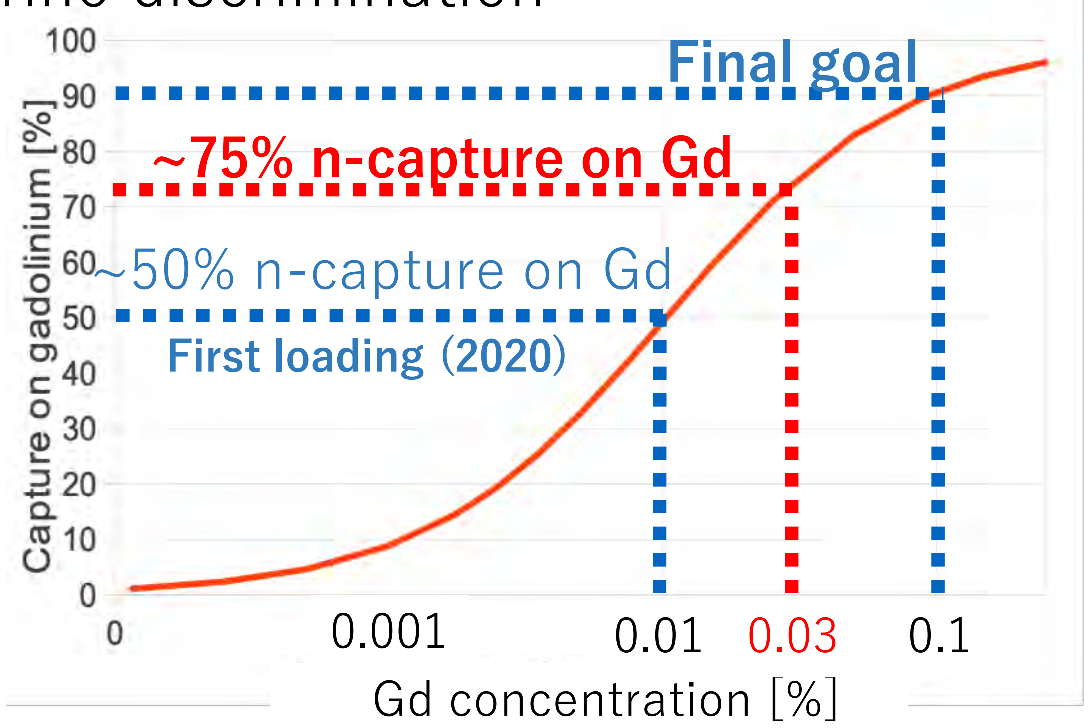
(1) Discovery of Supernova relic neutrino (or DSNB)

(2) Galactic supernovae (pointing accuracy, and pre-SN ν)

(3) Reduction of BG for proton decay, solar ν, or reactor ν

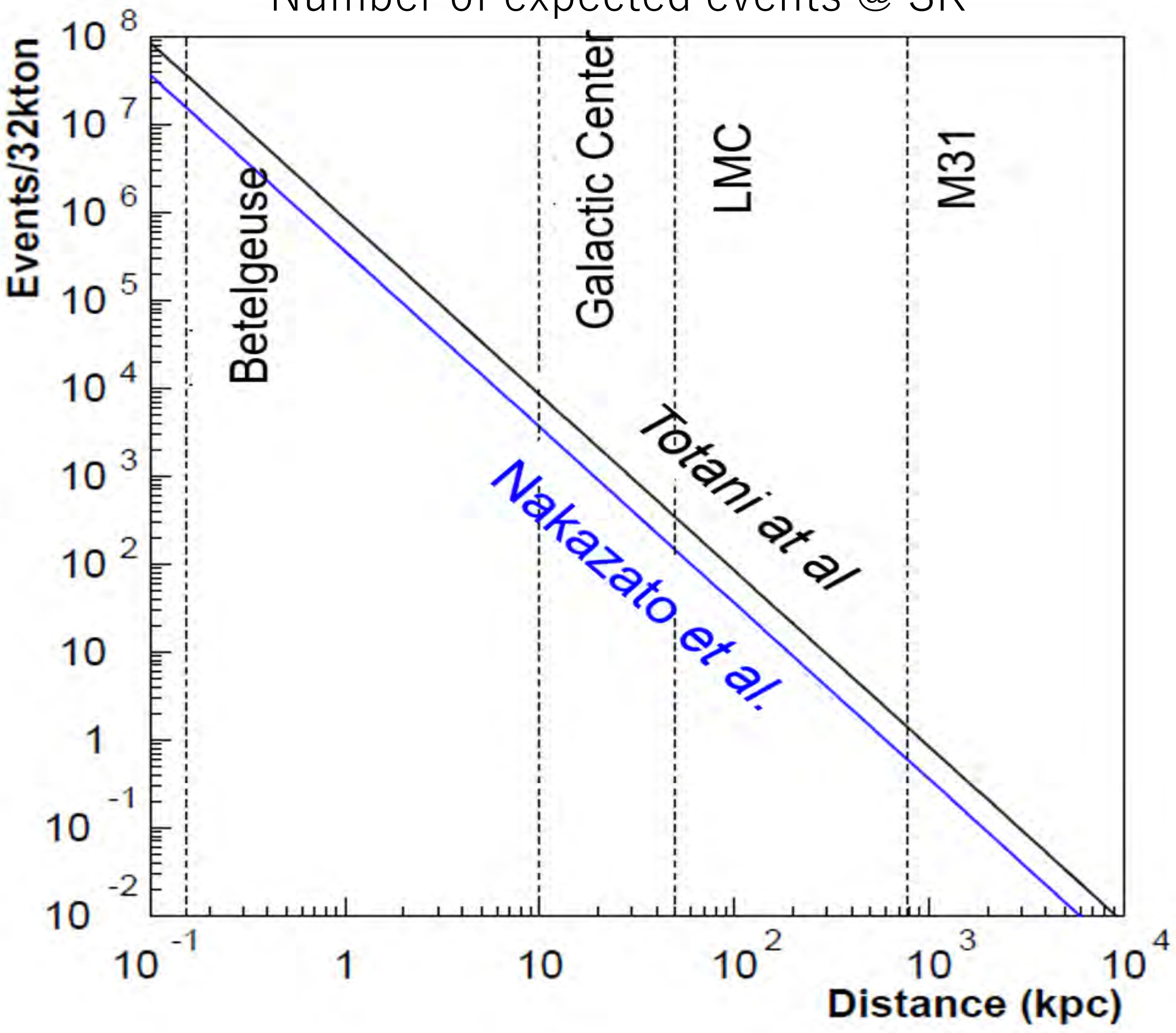
(4) Neutrino/anti-neutrino discrimination



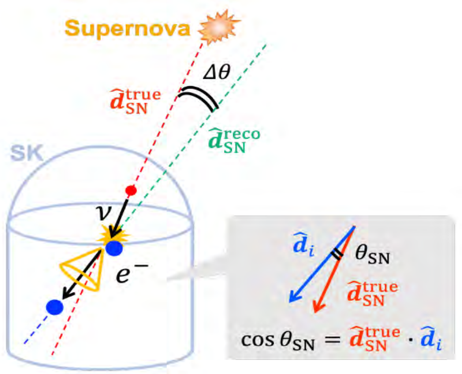


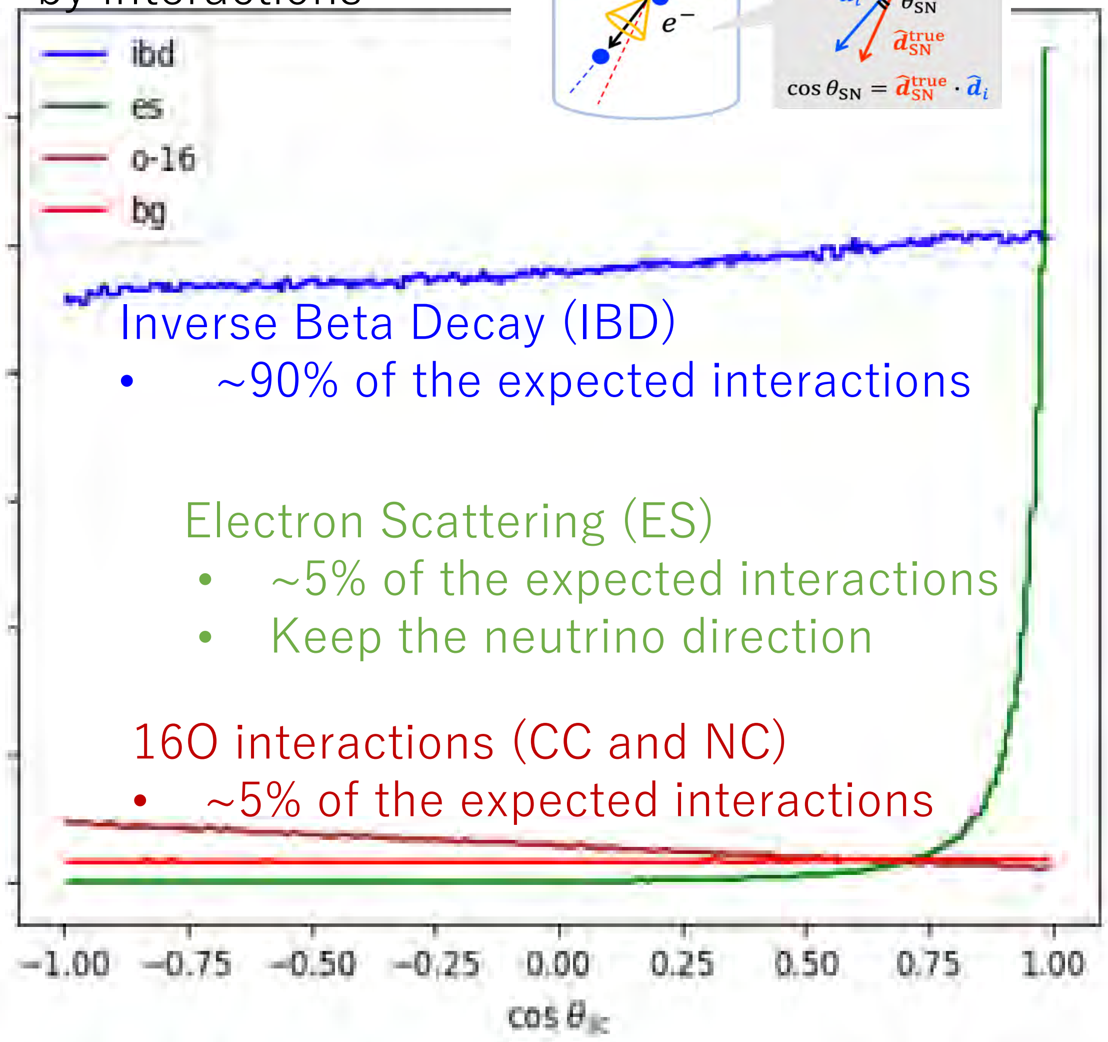
Detection of SN burst neutrinos

Number of expected events @ SK



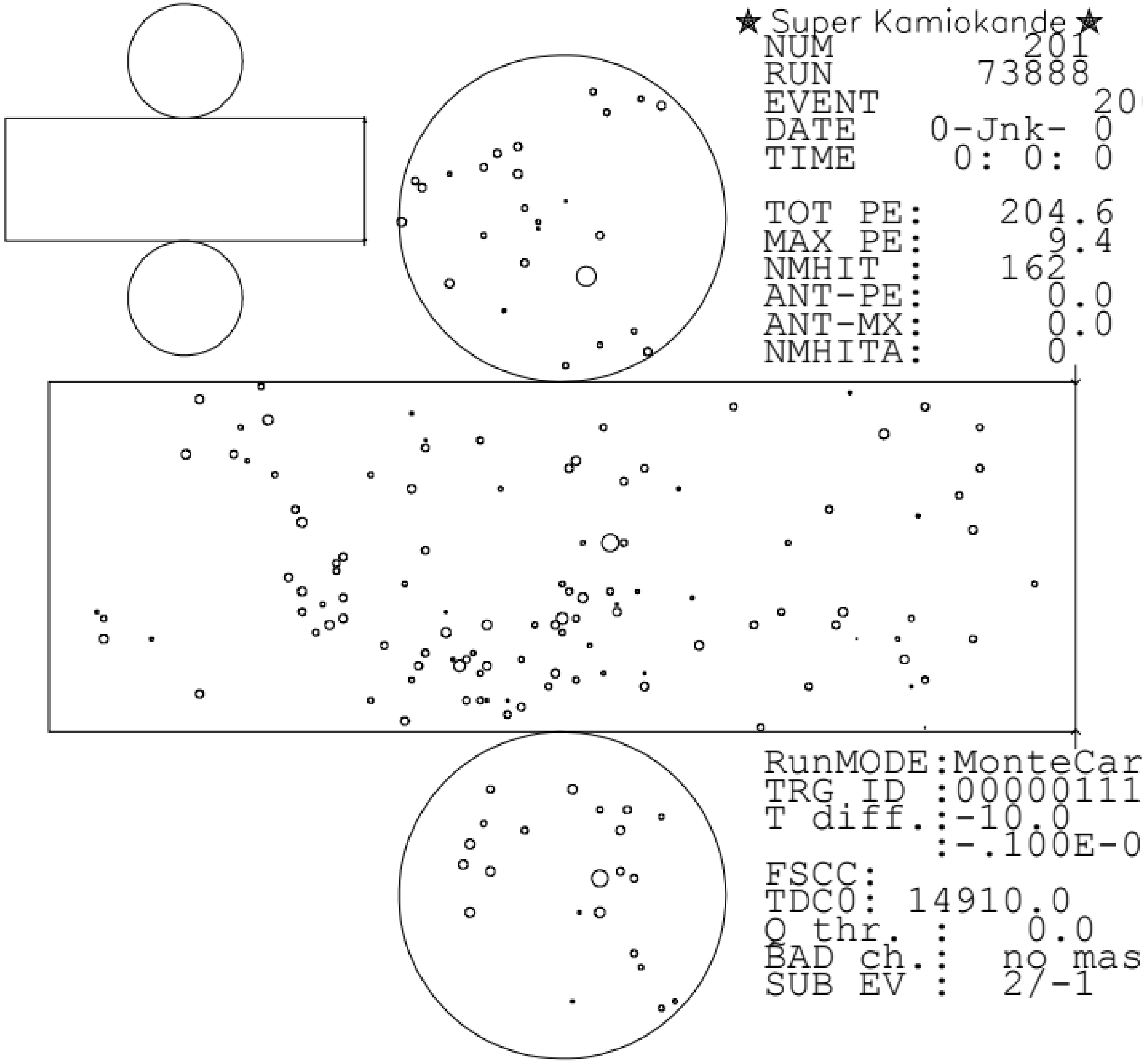
Angular response by interactions





Supernova event (smulation) in SK

- Number of PMT hits in SN events : ~100 hits
  - ~6 PMT hits / MeV in SK
  - Typical SN event ~20MeV
- Event gate : 1.3 μ sec
  - > ~1MHz, pile up events
  - Galactic supernova case
    - 10kpc : maximum few kHz



Supernova

- Number of PM
  ~100 hits
  - ~6 PMT hits
  - Typical SN e
- Event gate : 1.3
  - ＞~1MHz, p
  - Galactic sup
    - 10kpc : ma

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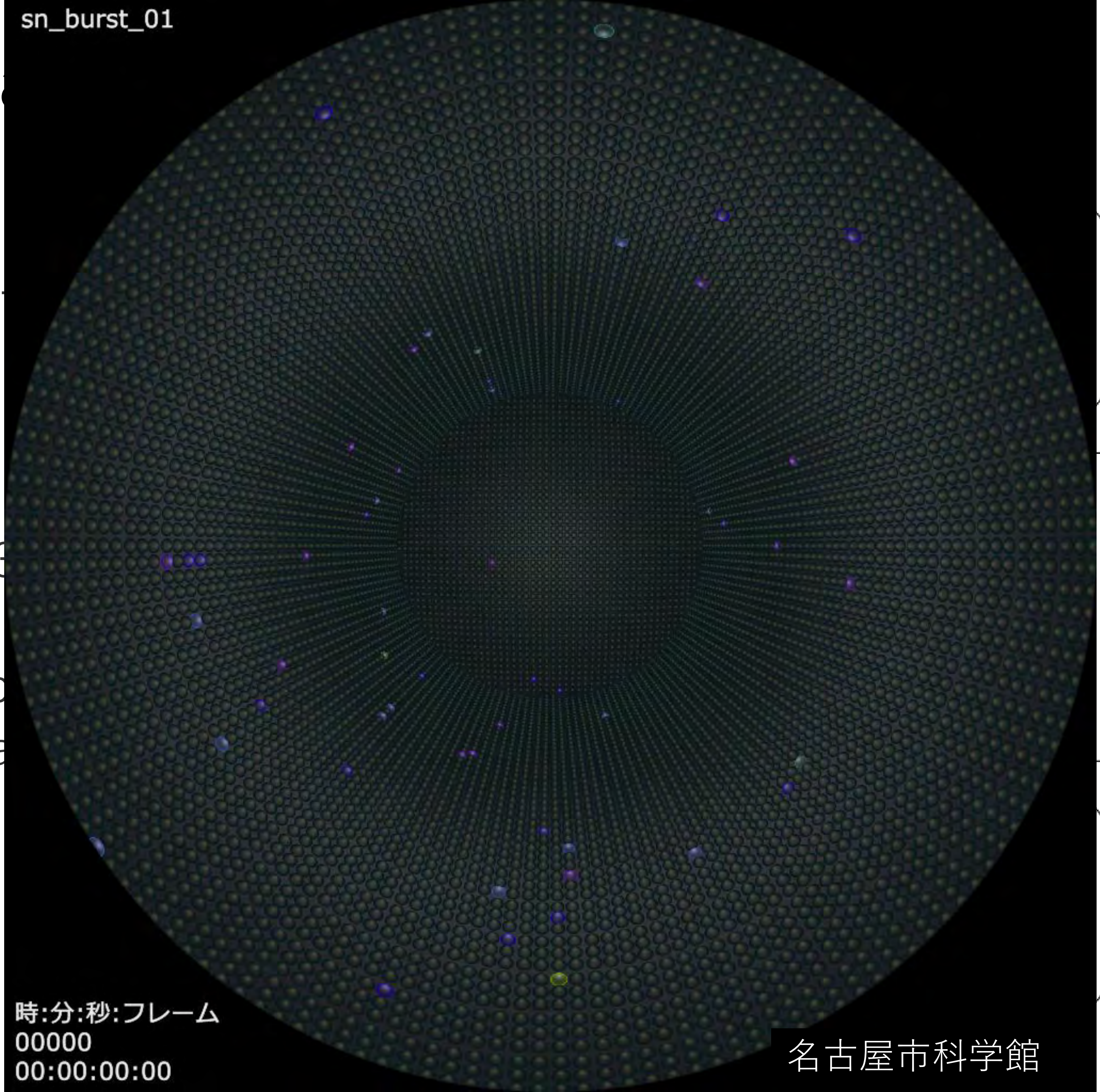
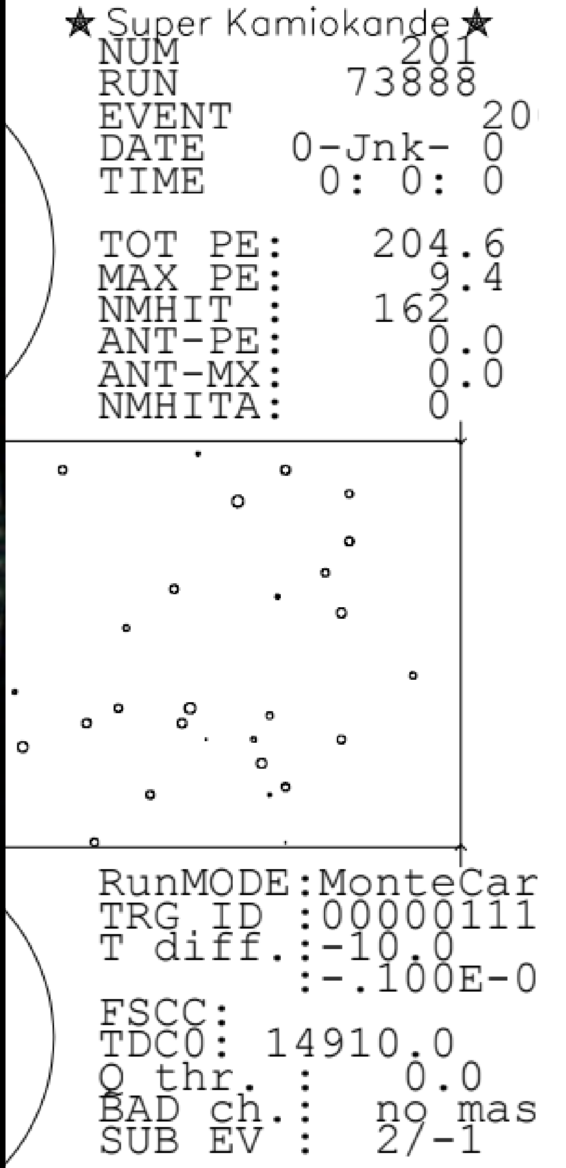
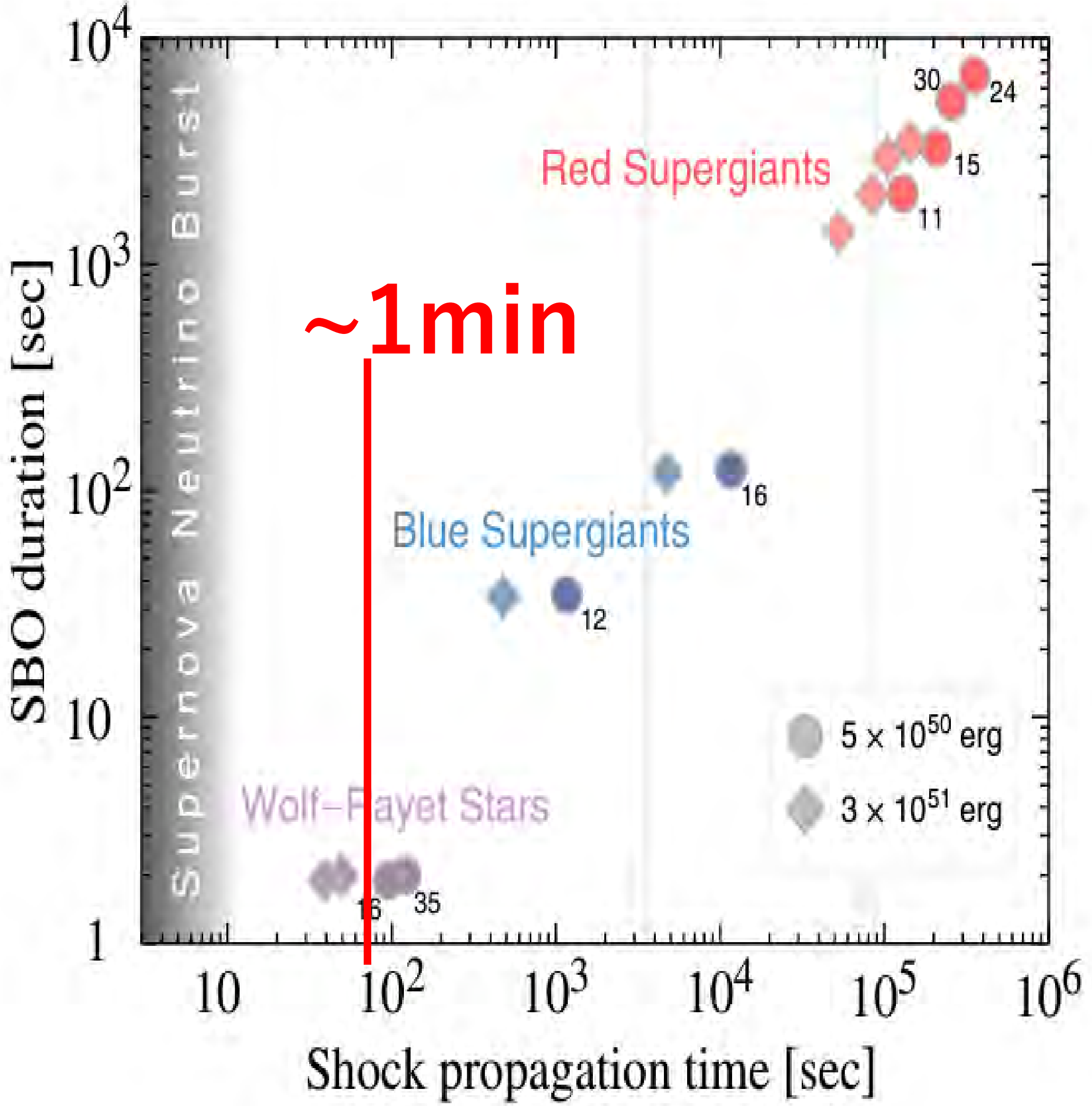
ありがとうございました！



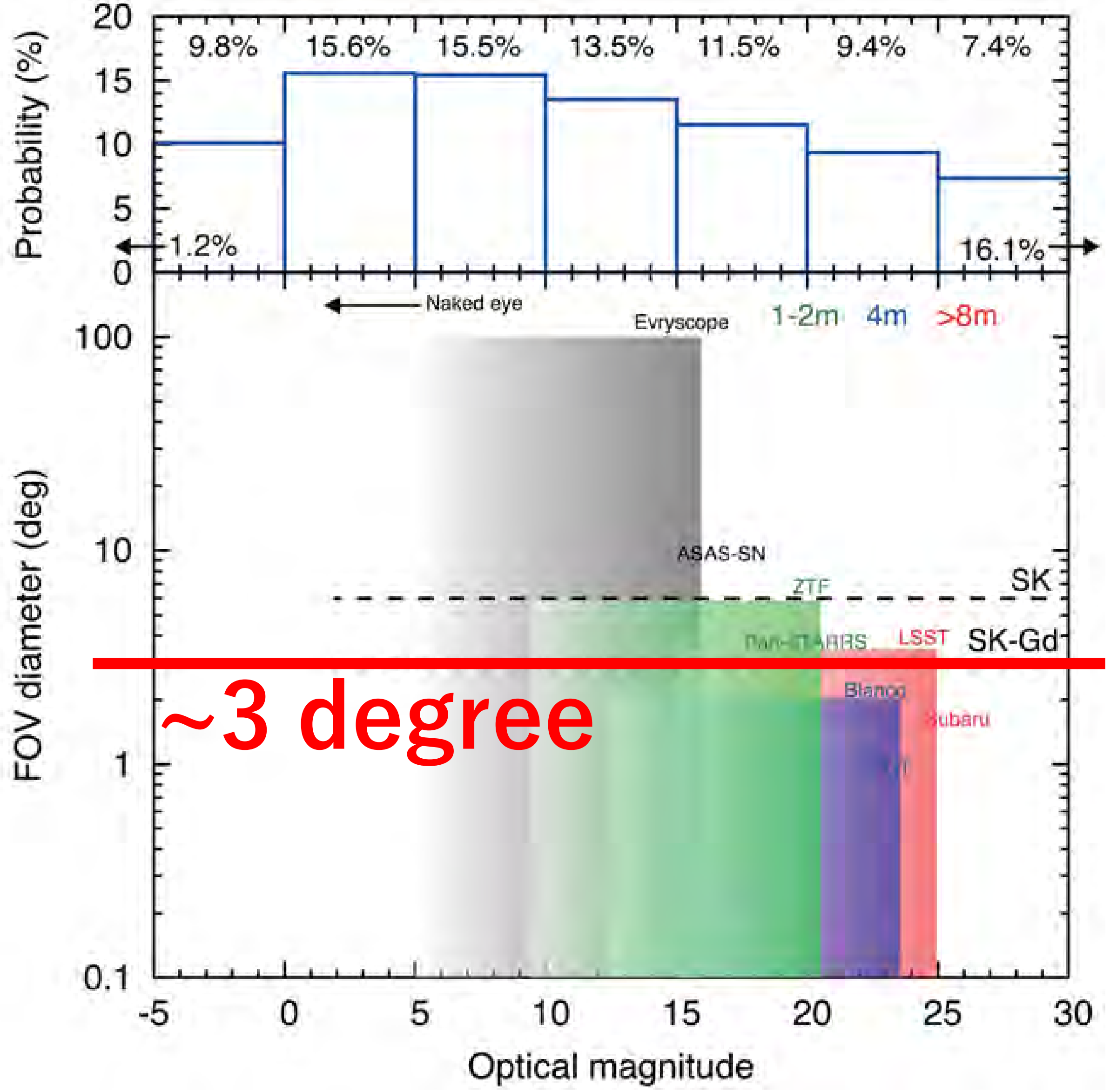


Our requirement

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

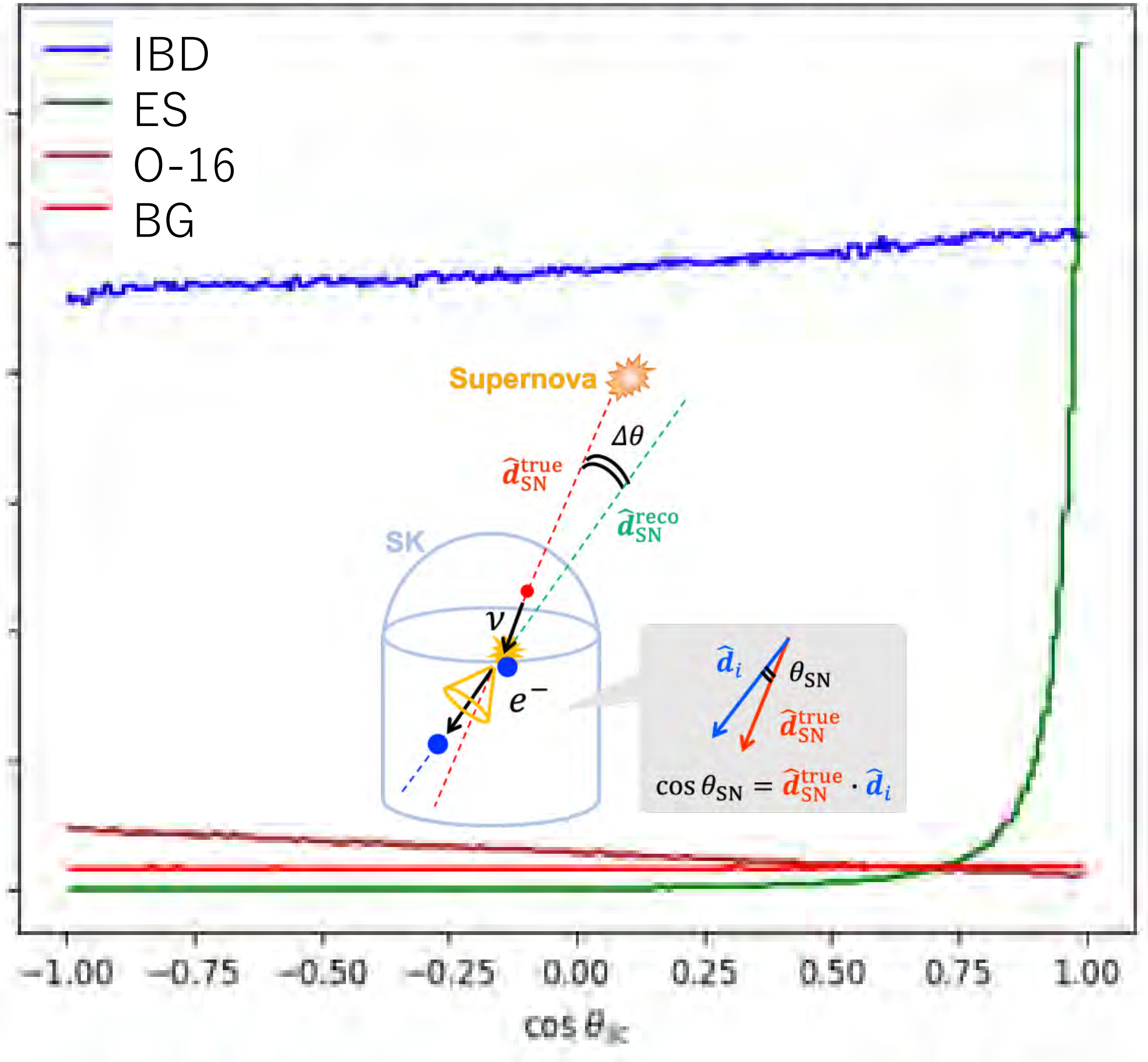


K.Nakamura et al. MNRAS461,3296–3313(2016)



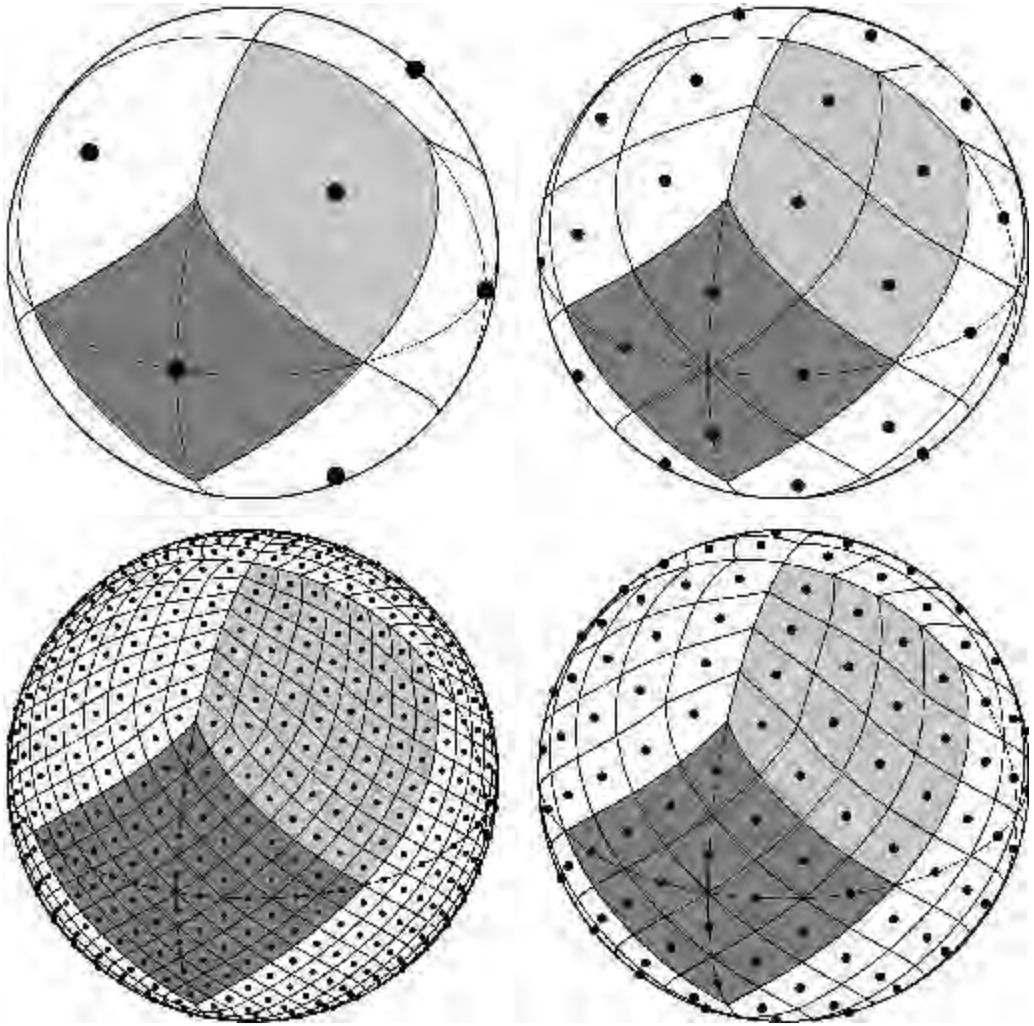
Direction fitter using Gd signals

- Now, SK can tag IBD event with Gd
  - N-tag eff:
    - N-Capture eff × Tagging eff ~ 50%
    - Trying to improve more
- >10kpc, the statistics is very important.
- We should not just treat IBD events as background of ES
  - IBD also has slight directionality
- Solution:
  - If IBD like (= tagged by Gd signal)
    - Use IBD pdf (Blue)
  - If ES like
    - Set weight for IBD pdf as N-tag eff



Faster and more accurate!

- Original fitter has 2 steps;
  - Initial grid search
  - Maximum Likelihood fit
- In both steps, we needed many loops which runs all burst events to get difference between a trial SN direction and each event direction.
  - Takes ~ 5min for 10kpc burst
- New fitter
  - Grid search -> HEALPix spheres
  - Event loops -> put them in to vectors
  - To implement them, Phython is used since it has many useful packages

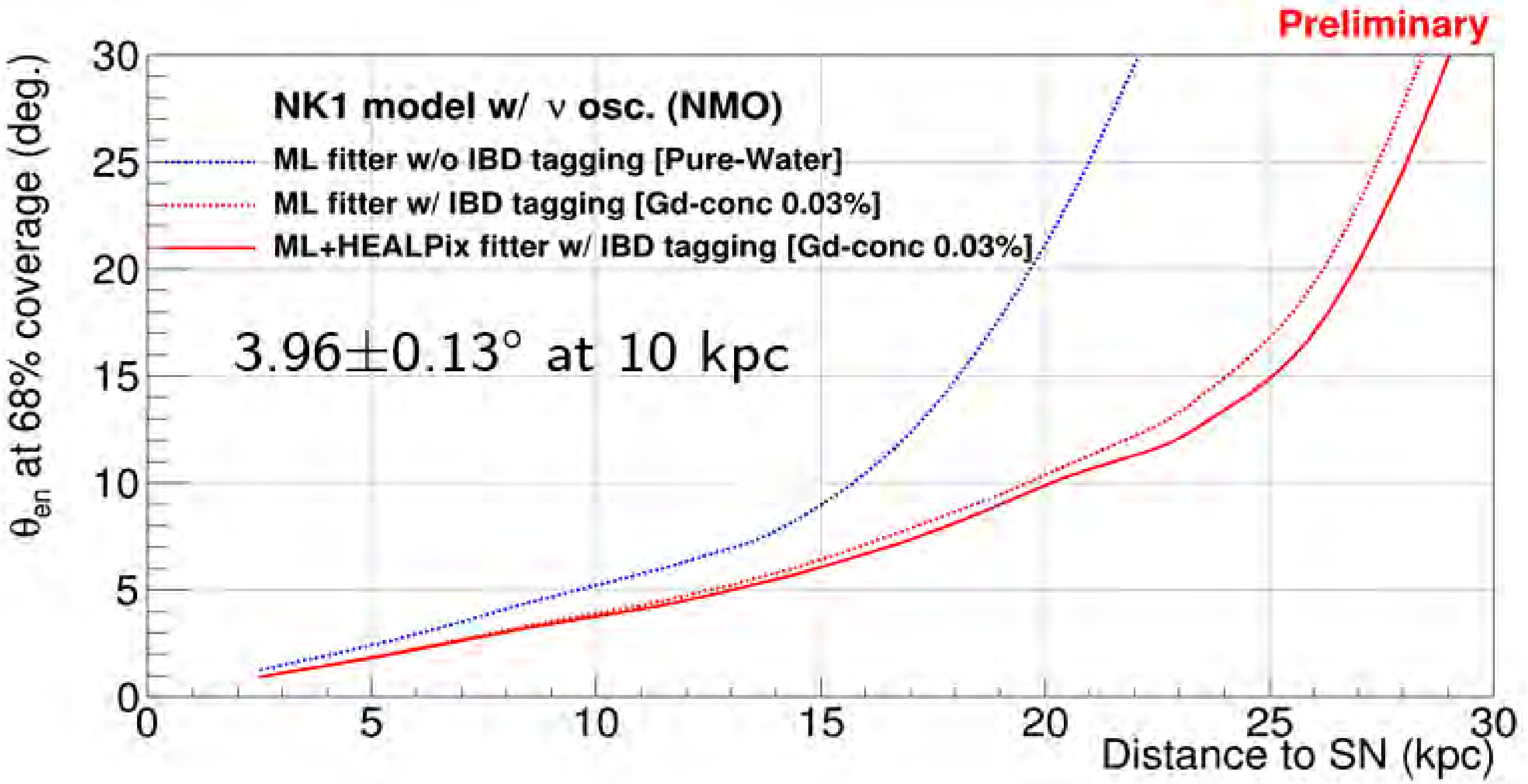


https://healpix.sourceforge.io/

Great improve!

Paper in preparation

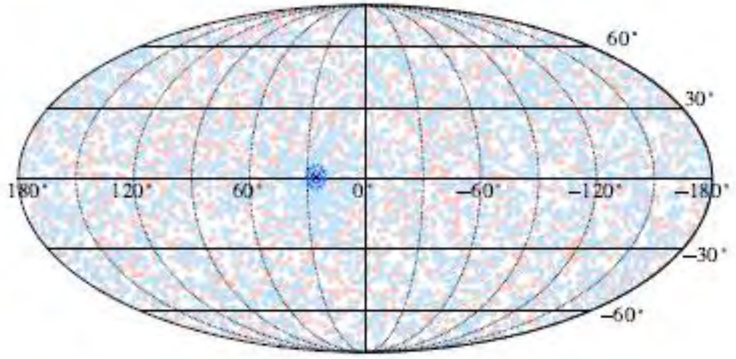
- With new fitter the direction can be obtain in a second!
    - Previously it was taking few min..
- Including data processing and reconstruction,
- we can send the auto alarm within ~few min



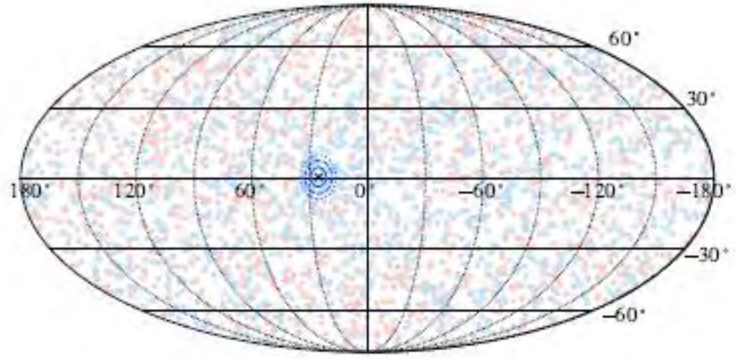
Pointing accuracy for different models

https://arxiv.org/abs/2403.06760

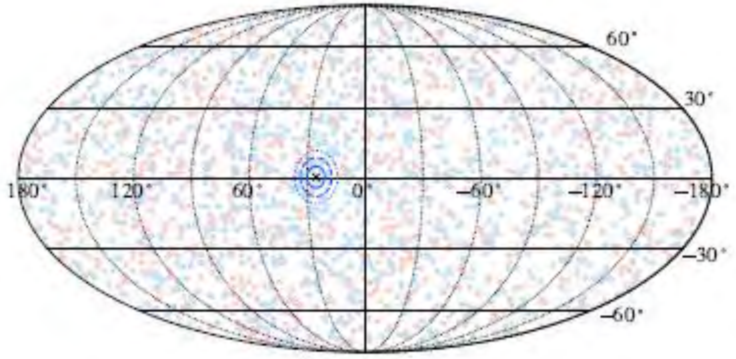
Blue : ES like, Red: IBD like



(a) the Wilson model

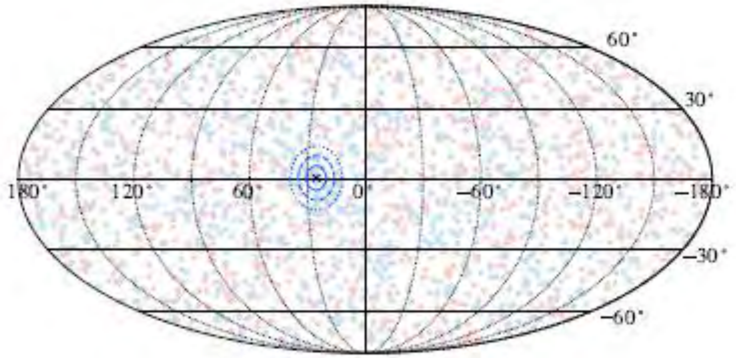


(b) the Nakazato model

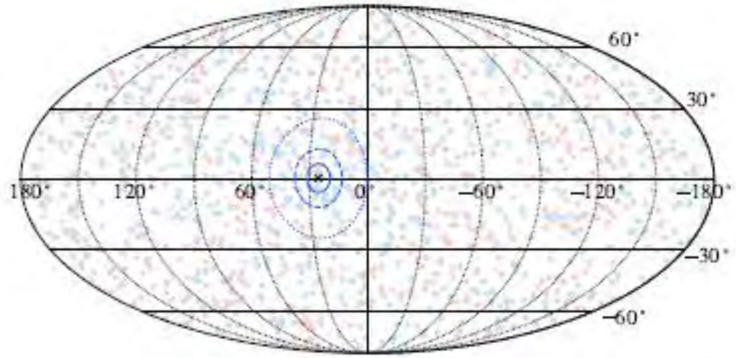


(c) the Mori model

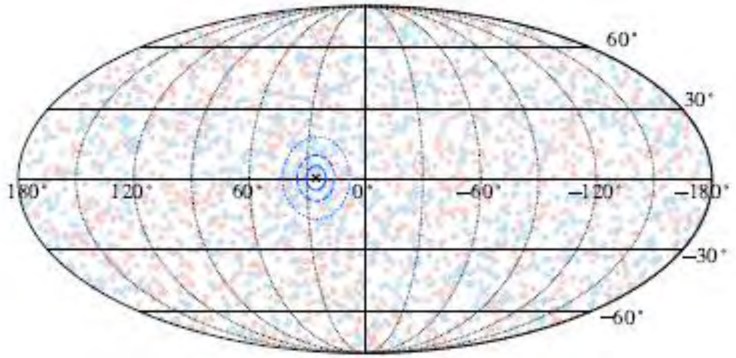
3~6-degree resolution at 10kpc SN



(d) the Hüdepohl model



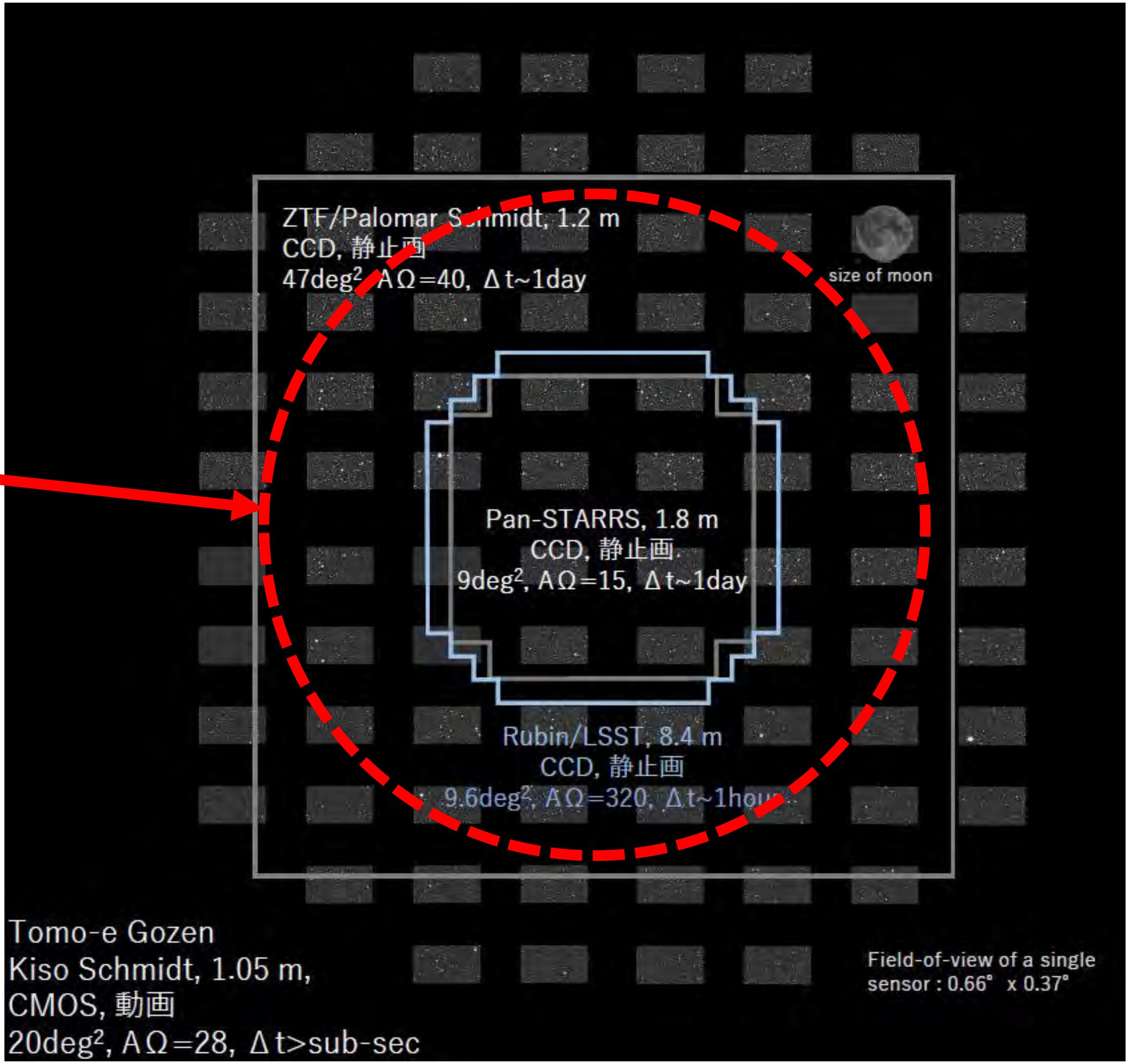
(e) the Fischer model



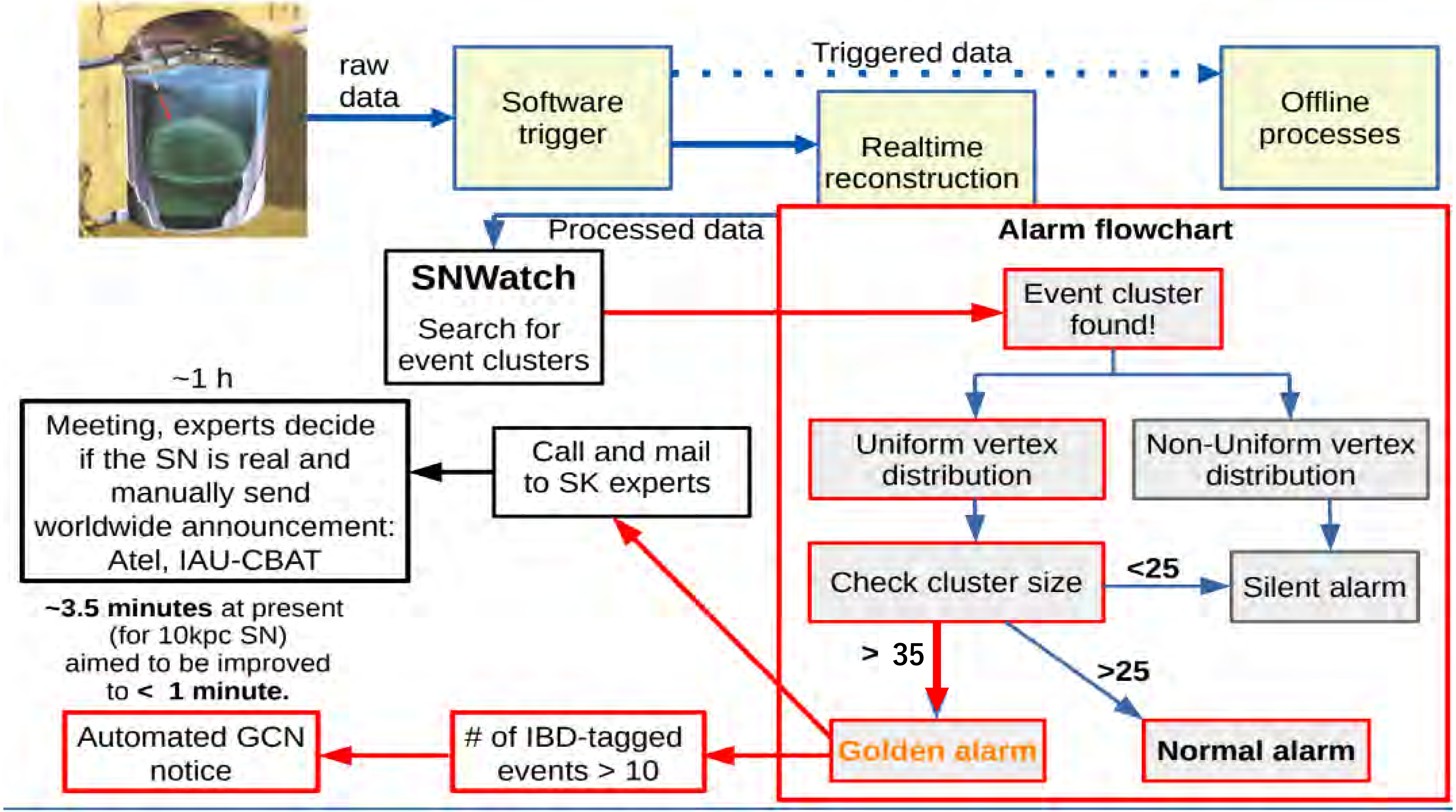
(f) the Tamborra model

Comparison with Tomo-e FOV

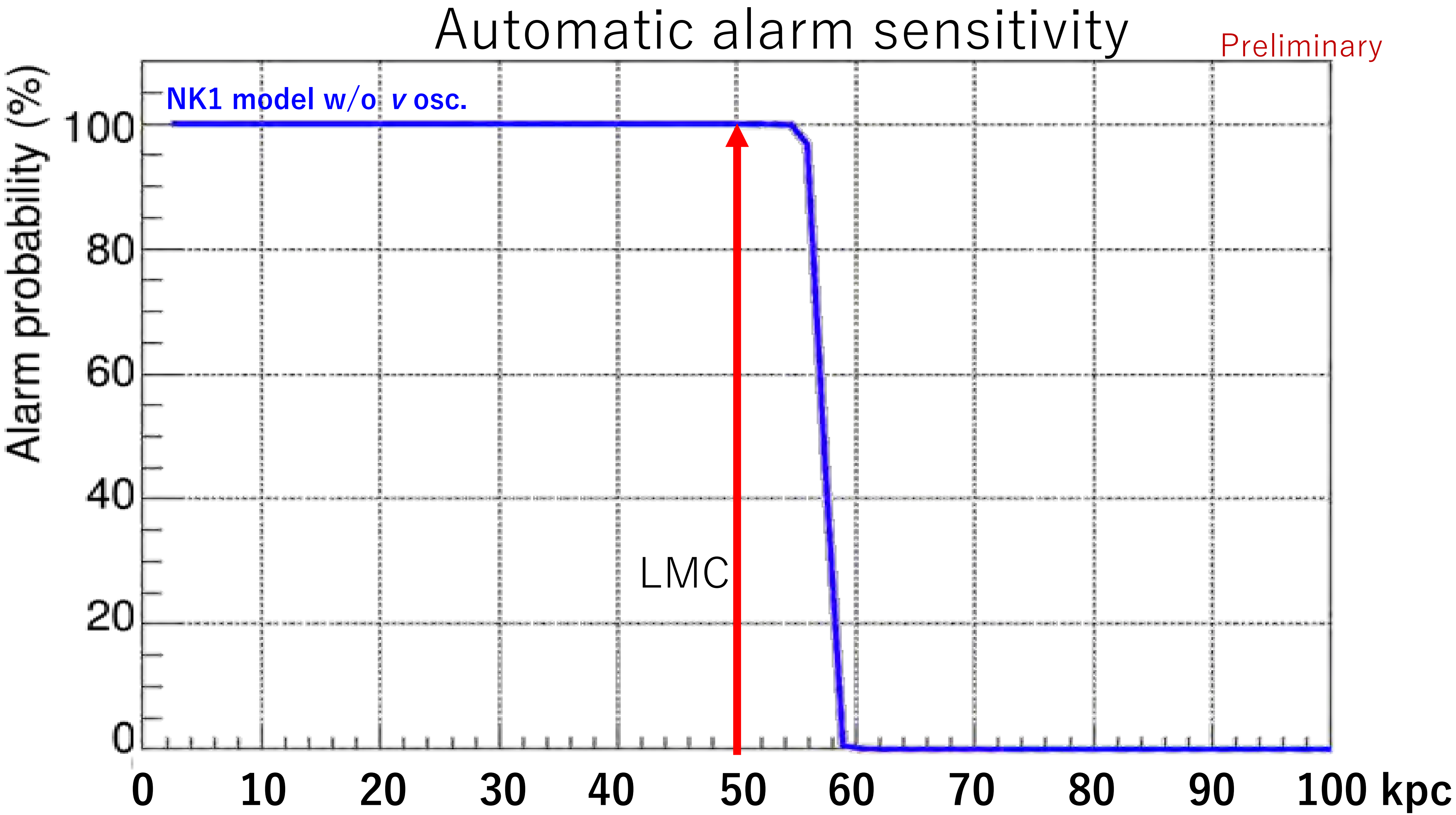
SN angular resolution
of SK for 10kpc SN



Automatic alert to GCN notice



Detection efficiency vs. distance

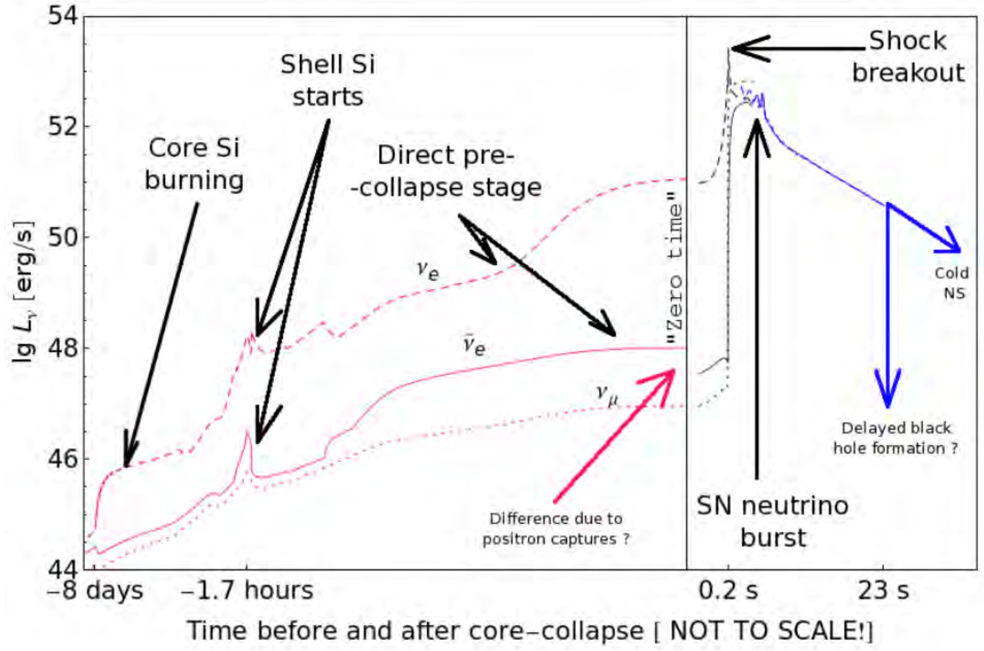


Pre-SN neutrinos

- Neutrinos emitted by a progenitor can give early warnings of very close supernova (~up to 500pc).
    - Pre-supernova (pre-SN) neutrinos
    - About 20 candidate stars
- For a core-collapse supernova, before the burst, neutrinos of all flavors are increasingly emitted by the pre-SN star, potentially detectable.

- Pre-SN alarms established at Super-Kamiokande and KamLAND.
    - KamLAND pre-SN monitor online in 2015. [K. Asakura et al. *Astrophys. J.* 818 (2016)]
    - Super-K also set a pre-SN monitor in 2021, [L.N. Machado et al. *Astrophys. J.* 935 (2022)].
        - Thanks to great BG reduction in SK-Gd
- A **combined pre-SN monitor** with Super-K and KamLAND
    - https://arxiv.org/html/2404.09920v1
    - Improve sensitivity to pre-SN neutrino signal
    - **Online and open to external users!**

Odrzywolek & Heger, *Acta Phys. Pol. B*, 41 (2010)



https://www.lowbg.org/presnalarm/

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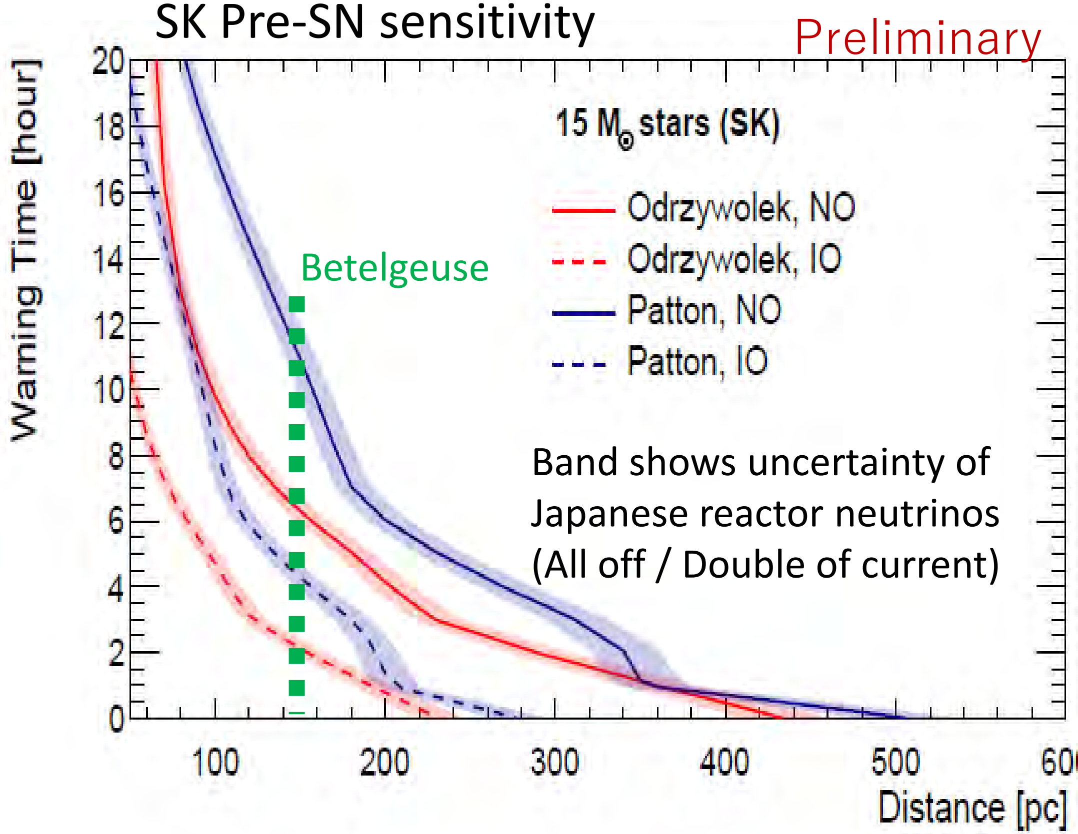
SK Pre-SN sensitivity



https://www.lowbg.org/presnalarm/

Summary

- SK Gd status:
  - Start observation with 0.03% Gd since 2022
- Many improvements of SN burst detection
  - SN direction fitter improvement
    - HP fitter and new ML fitter enable to send auto alarm within few min.
    - Angular Resolution : ~ 3 degree in our Galaxy
  - Automatic GCN Notice has been installed after SK-Gd
- Pre-SN neutrinos
  - Sensitive up to ~500pc (~ 20 candidate starts)
  - In case of Betelgeuse, we can issue an alarm 5-10 hours before the core collapse.