SK-Gd and Supernova detection

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2021.1.7 SN workshop

Contents

- Introductions
- First Gd to SK
- Detector status
- Supernova neutrino detection

The Super-Kamiokande Collaboration

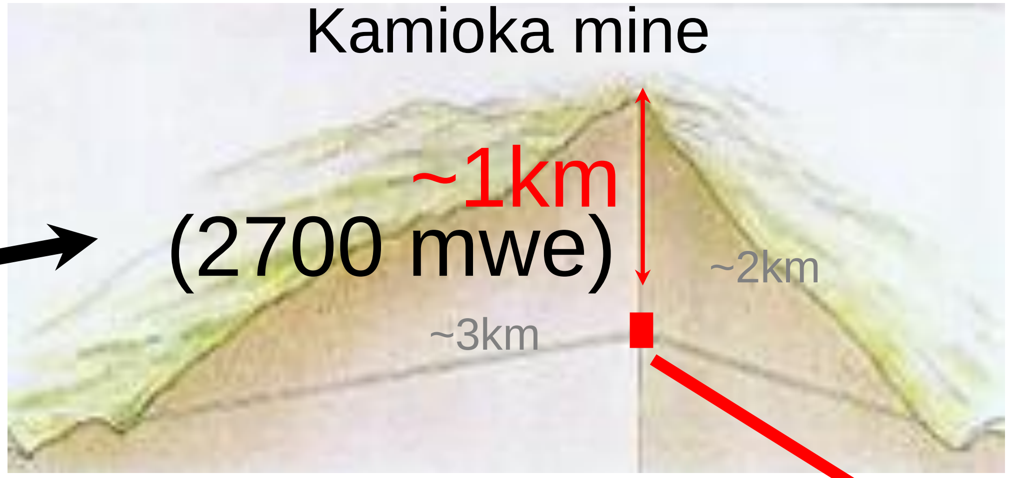
~190 collaborators from 49 institutes in 10 countries

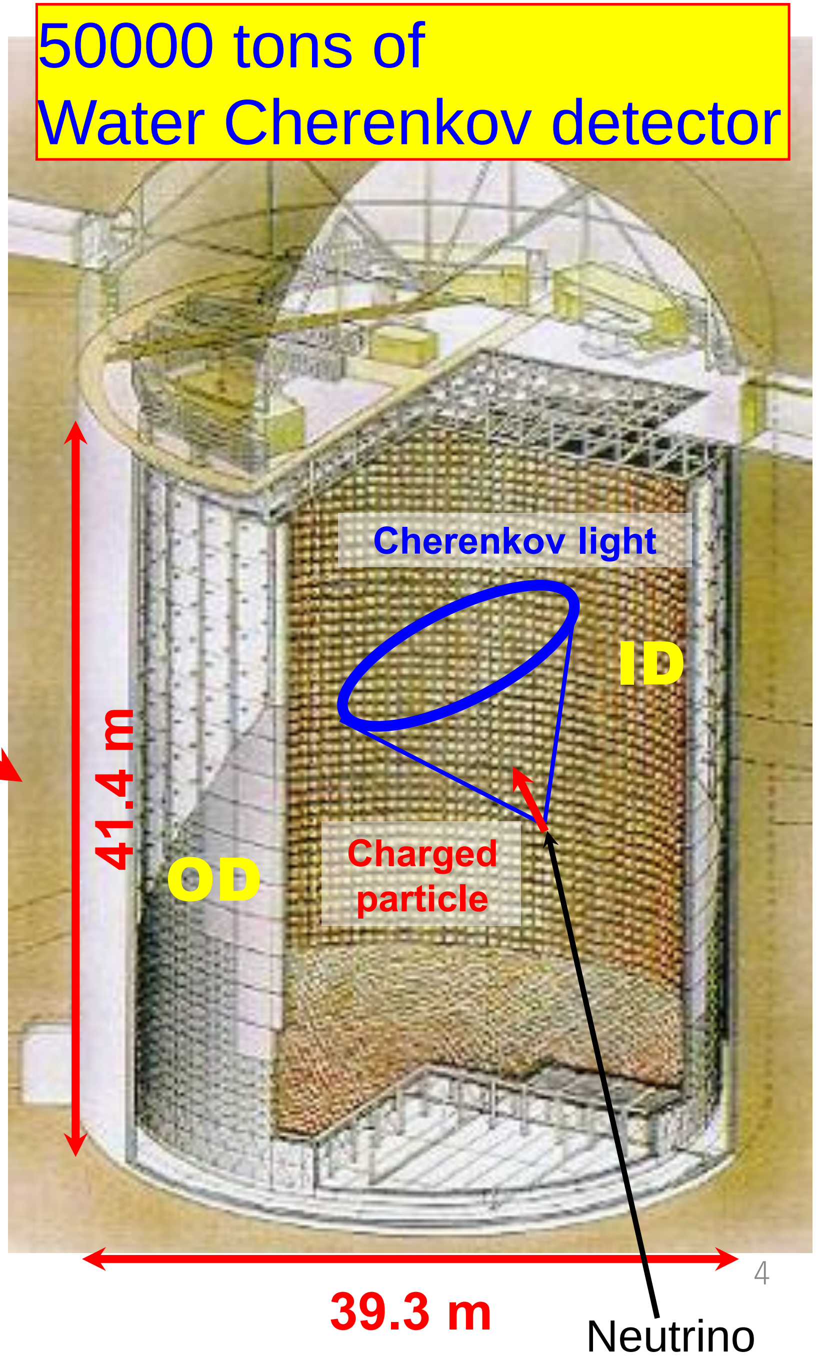
Kamioka Observatory, ICRR, Univ. of Tokyo, Japan
RCCN, ICRR, Univ. of Tokyo, Japan
University Autonoma Madrid, Spain
BC Institute of Technology, Canada
Boston University, USA
University of California, Irvine, USA
California State University, USA
Chonnam National University, Korea
Duke University, USA
Fukuoka Institute of Technology, Japan
Gifu University, Japan
GIST, Korea
University of Hawaii, USA
Imperial College London, UK
INFN Bari, Italy
INFN Napoli, Italy

INFN Roma, Italy
Kavli IPMU, The Univ. of Tokyo, Japan
Keio University, Japan
KEK, Japan
King's College London, UK
Kobe University, Japan
Kyoto University, Japan
University of Liverpool, UK
LLR, Ecole polytechnique, France
Miyagi University of Education, Japan
ISEE, Nagoya University, Japan
NCBJ, Poland
Okayama University, Japan
University of Oxford, UK
Queen Mary University of London, UK
Rutherford Appleton Laboratory, UK

University of Sheffield, UK
Shizuoka University of Welfare, Japan
Sungkyunkwan University, Korea
Stony Brook University, USA
Tokai University, Japan
The University of Tokyo, Japan
Tokyo Institute of Technology, Japan
Tokyo University of Science, japan
University of Toronto, Canada
TRIUMF, Canada
Tsinghua University, Korea
University of Warsaw, Poland
Warwick University, UK
The University of Winnipeg, Canada
Yokohama National University, Japan

Super-Kamiokande





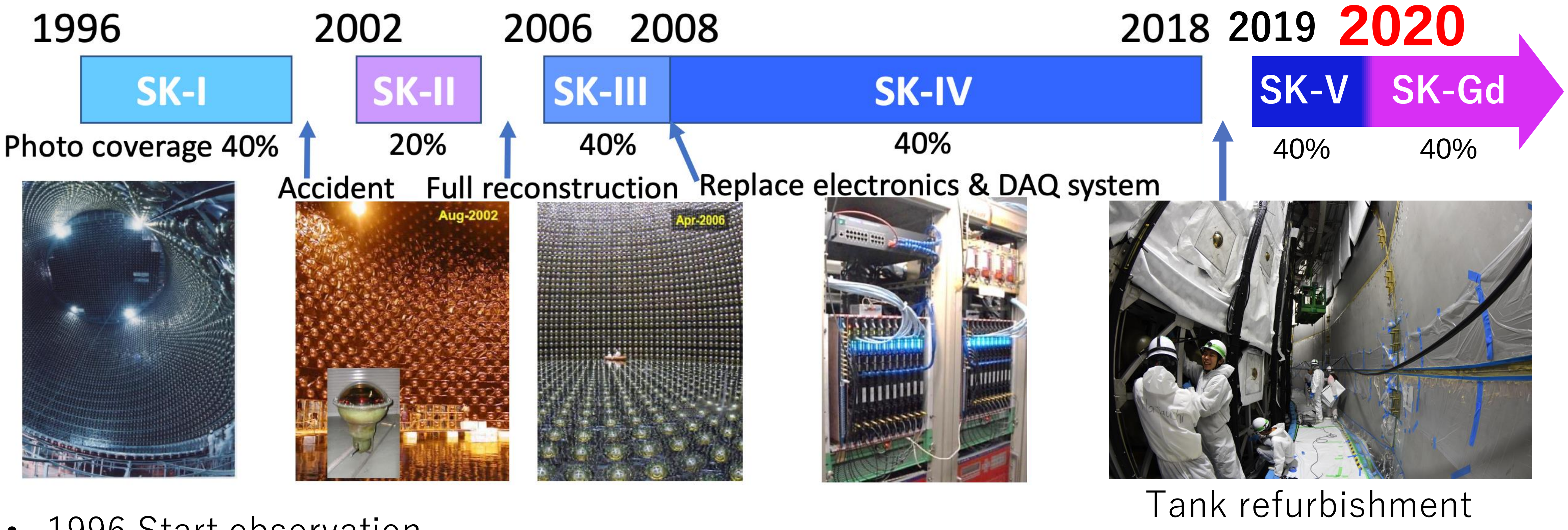
Physics target

~ MeV

- Solar neutrinos
- Supernova neutrinos
- Atmospheric/Accelerator neutrinos
- Nucleon decay

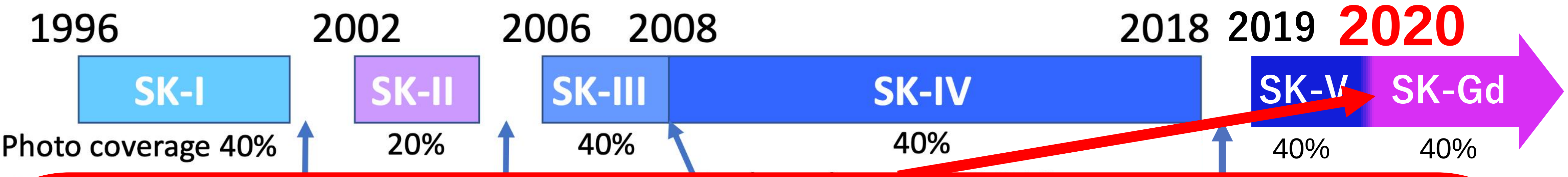
~ GeV

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)

History of Super-Kamiokande



13 ton of $Gd_2(SO_4)_3 \cdot 8H_2O$

First Gd loading to SK in last summer!

SK-Gd project

Dissolving Gd to enhance detection capability of neutrons from ν interactions

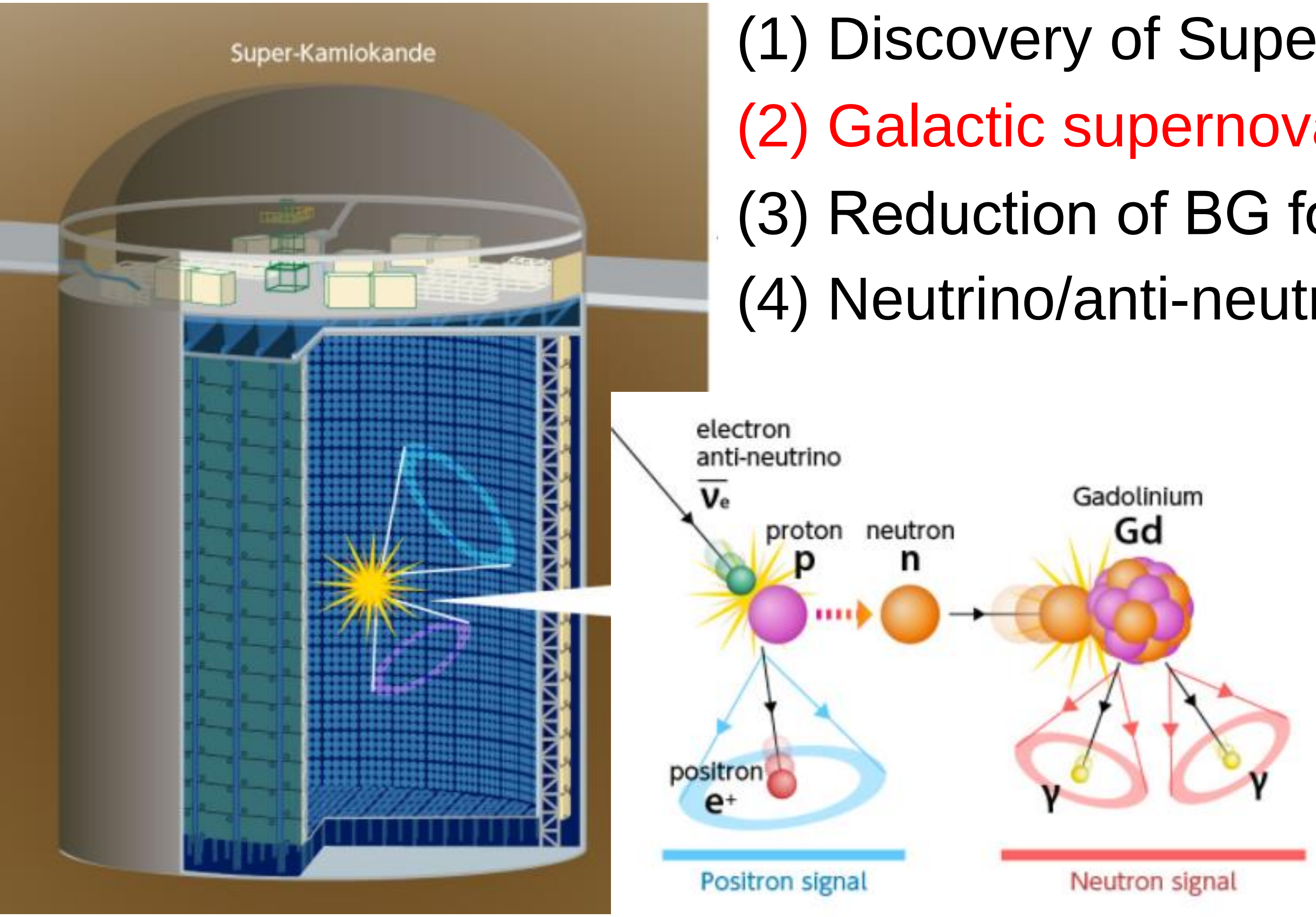
<u>Physics targets:</u>

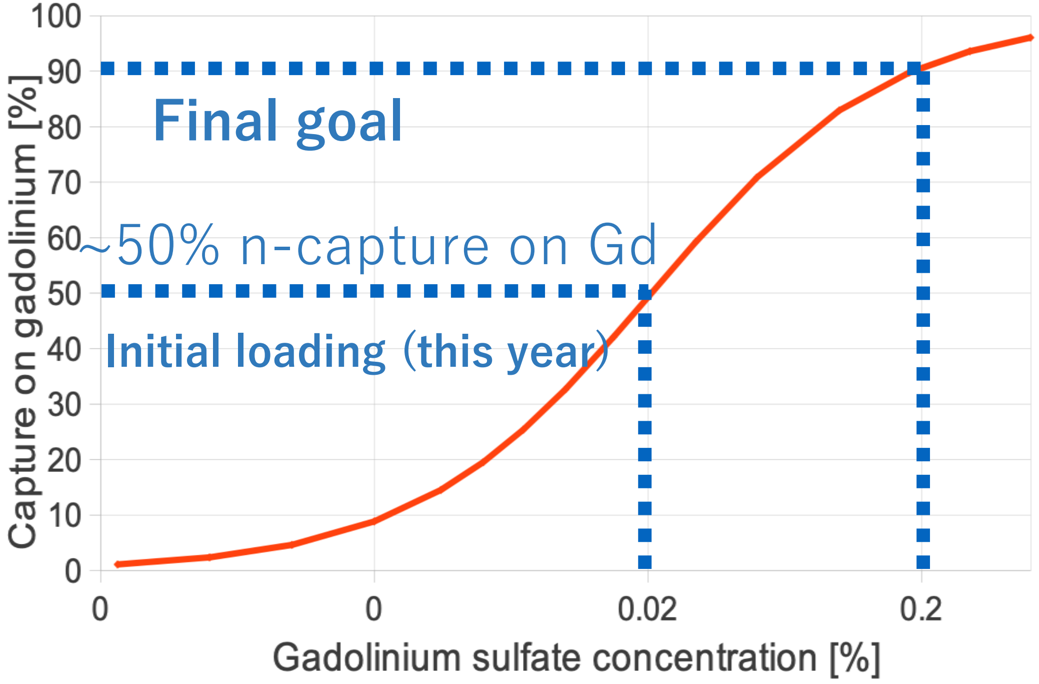
(1) Discovery of Supernova relic neutrino (SRN)⇒芦田さん

(2) Galactic supernovae (pointing accuracy, and Si-burning ν)

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

(4) Neutrino/anti-neutrino discrimination





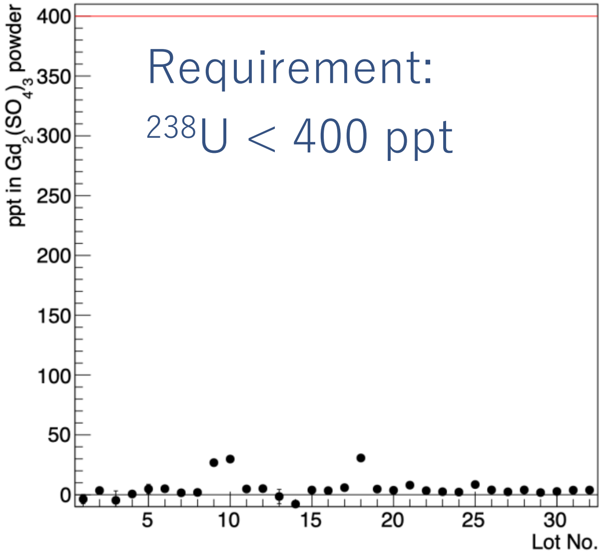
R&D of ultra-pure Gd powder

- Radio impurities in Gd power could introduce additional backgrounds to solar and supernova neutrinos
- Stringent requirement for RI imposed
- Developed methods to evaluate low concentration RI
  PTEP 2017 (2017) 11, 113H01
  PTEP 2018 (2018) 9, 091H01
  arXiv: 2006.09664
- Screened at multiple sites
  - ICP-MS: Kamioka
  - HPGe: Canfranc, Boulby and Kamioka
- Worked with production companies and achieved the required purity

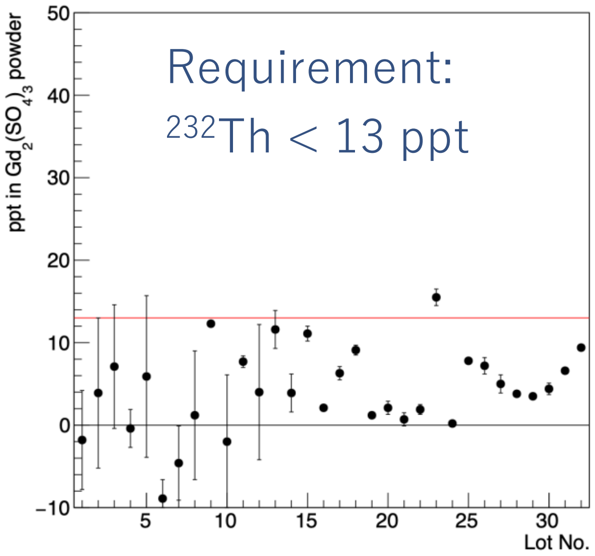
Radioactive impurities for $Gd_2(SO_4)_3$ powder [mBq/kg]

Chain	Isotope	SK-Gd requirements	
		For solar	For DSNB
^{238}U	^{238}U	—	< 5
	^{226}Ra	< 0.5	—
^{232}Th	^{228}Ra	< 0.05	—
	^{228}Th	< 0.05	—
^{235}U	^{235}U	< 30	—
	^{227}Ac/^{227}Th	< 30	—

U contamination (ICP-MS)

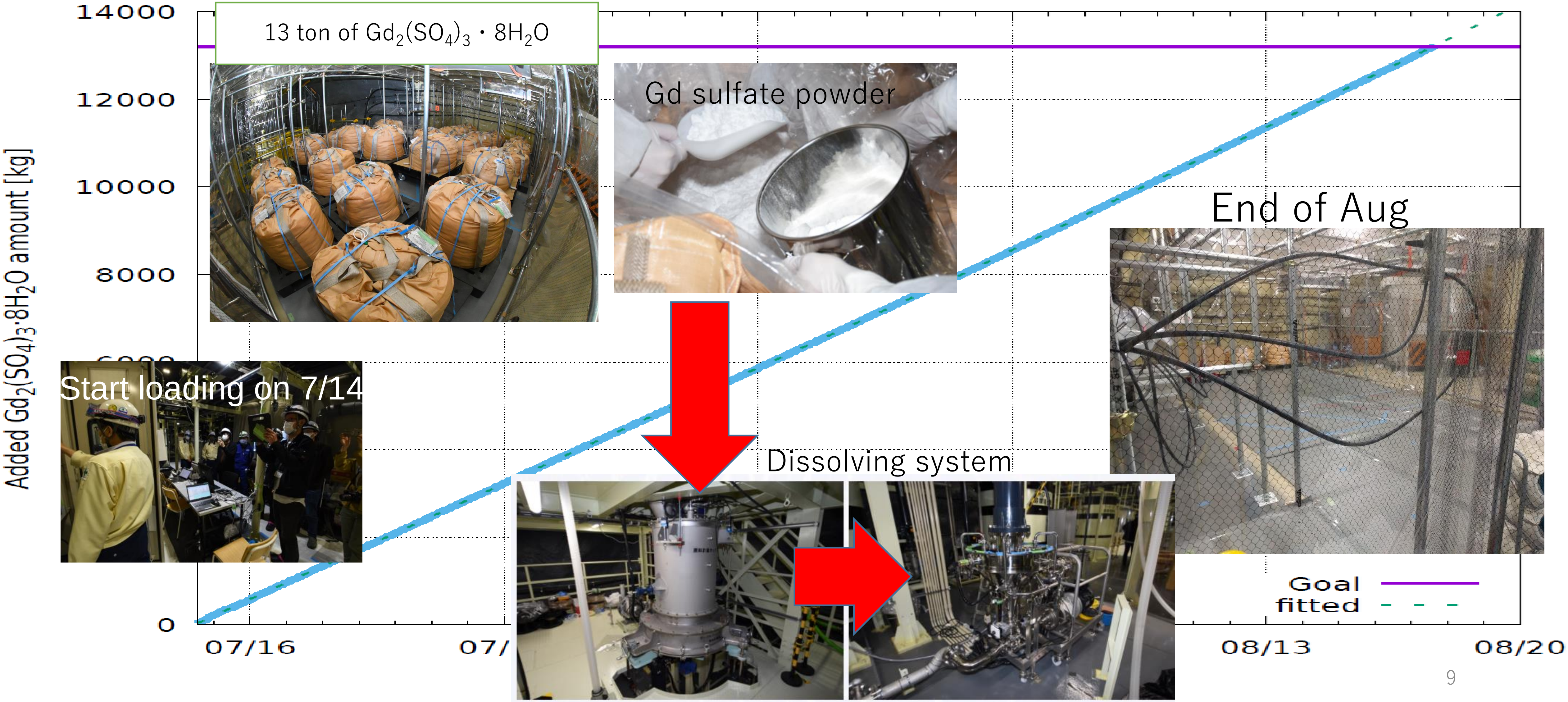


Th contamination (ICP-MS)

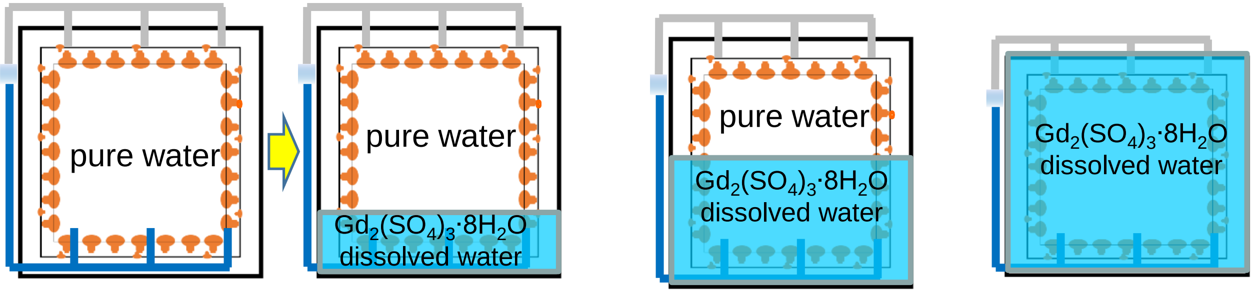


First Gd loading to SK

- 13 ton of $Gd_2(SO_4)_3 \cdot 8H_2O$, (5 ton of Gd) was loaded at Lab-G from 7/14 to 8/17

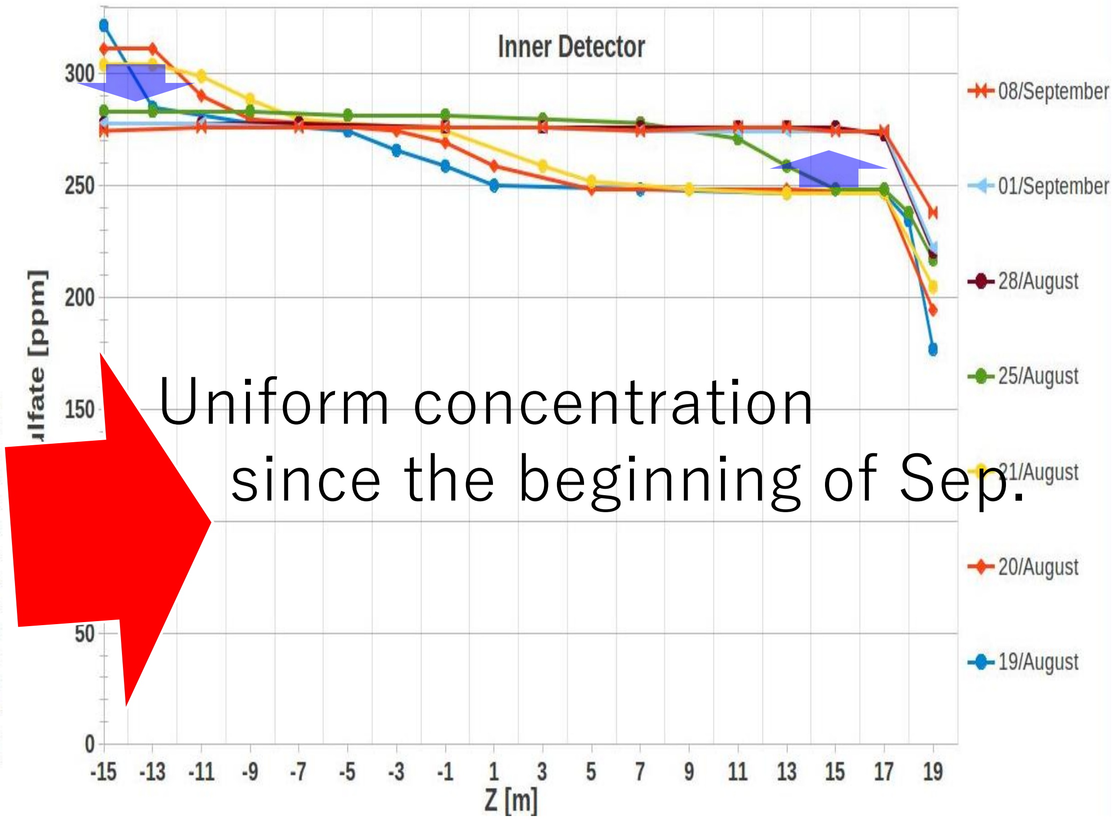


Gd concentration in SK tank



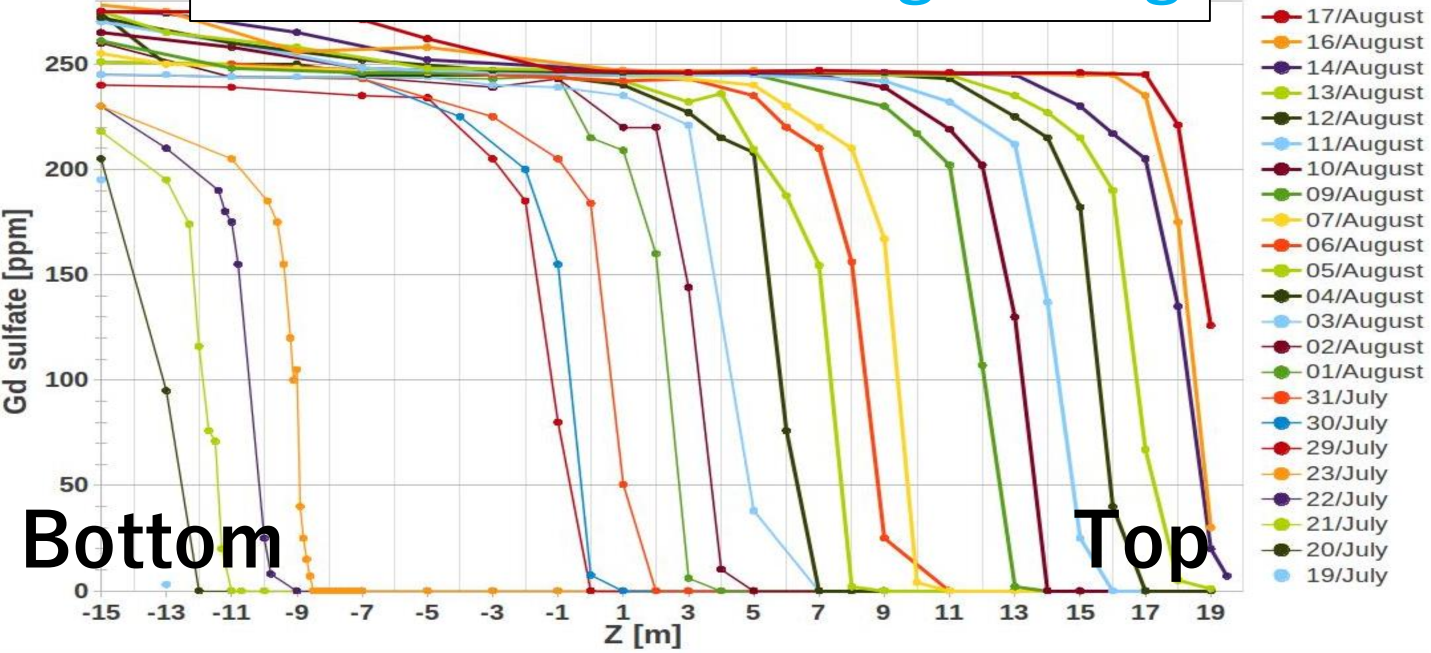
Suck pure water from top, dissolve Gd, and supply cold Gd water from the bottom of SK.

Gd concentration **after loading**



Uniform concentration since the beginning of Sep.

Gd concentration **during loading**



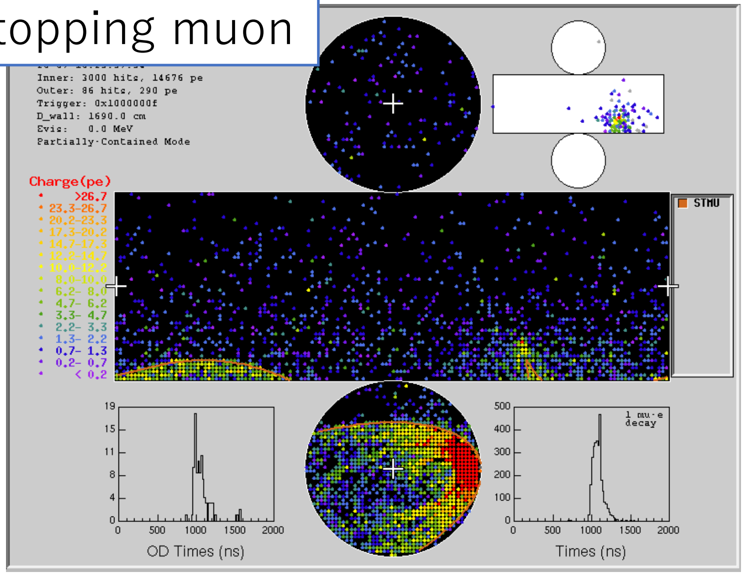
Plots rom Lluis

Neutron events with cosmic muon

- Neutron from stopping muon

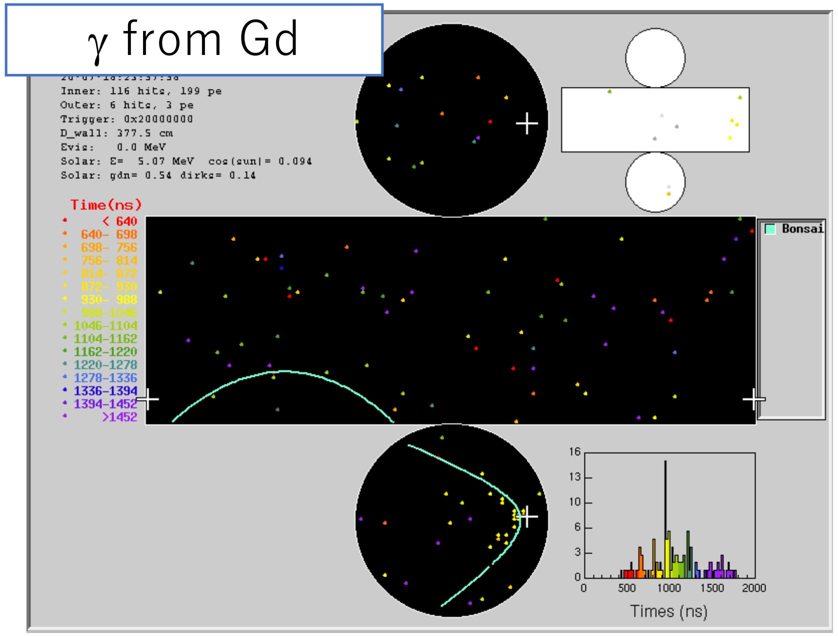
$\mu^- + {}^{16}\mathrm{O} \rightarrow {}^{16}\mathrm{N}^* \rightarrow {}^{15}\mathrm{N} + \mathrm{n}$

stopping muon



$\mathrm{n} + \mathrm{Gd} \rightarrow \mathrm{Gd} + \gamma$

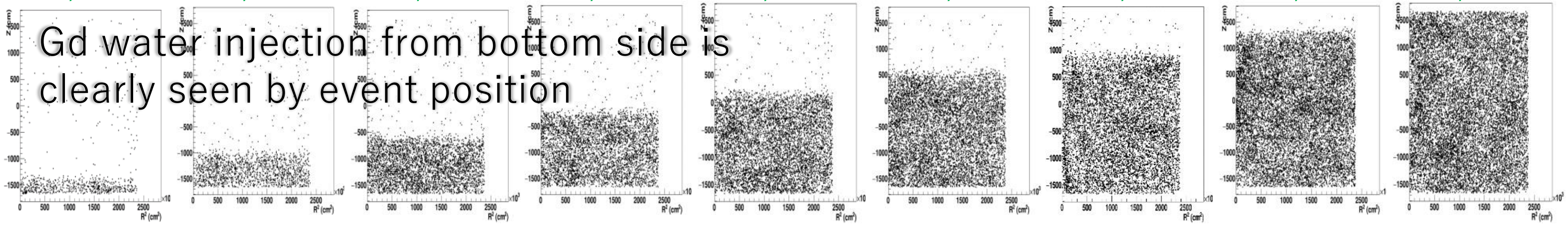
γ from Gd



- Neutron from spallation

O(10^4) ev/day

Date → 7/18 7/21 7/24 7/27 7/30 8/2 8/5 8/8 8/12

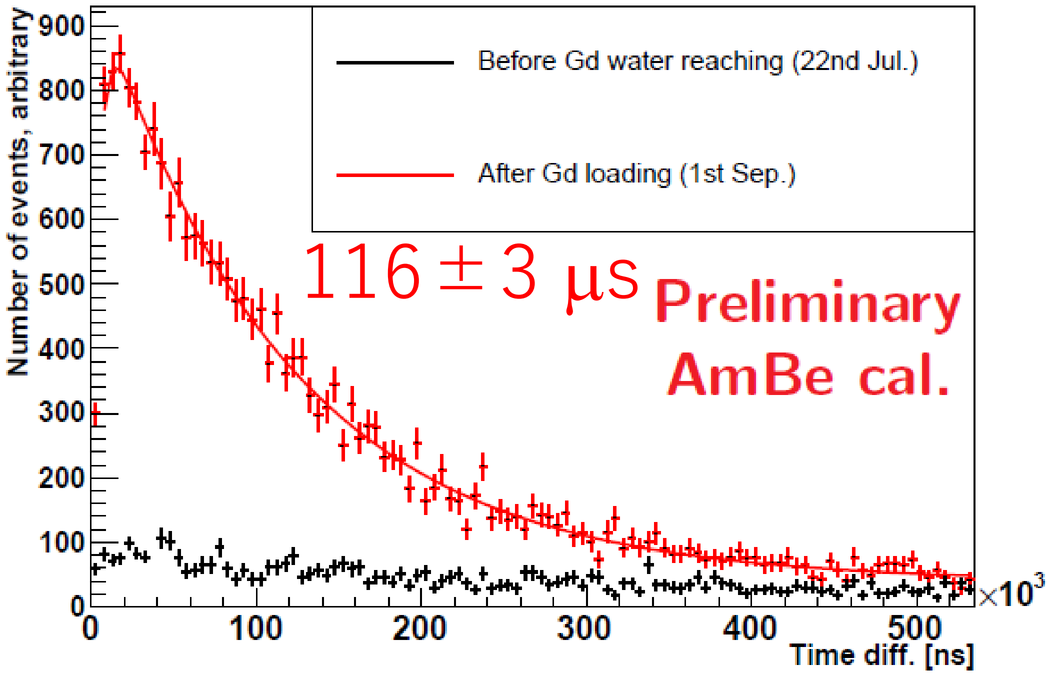


Gd water injection from bottom side is clearly seen by event position

Neutron tagging by AmBe source

- Calibration with Am/Be : neutron + gamma-ray source
- Neutron capture signal after gamma-ray is obtained
- Gd concentration is consistent with what we added

Neutron capture time at detector center



Plot from Yano san

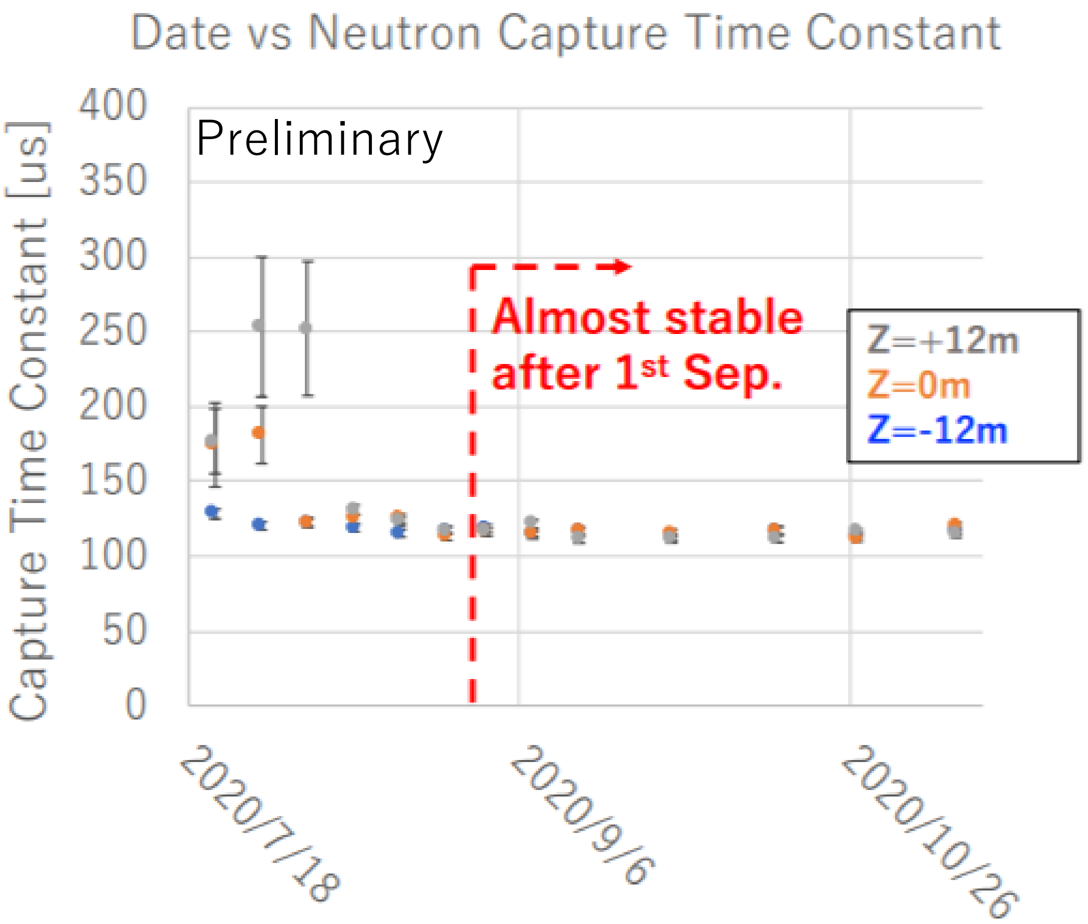
Table from Guillaume san

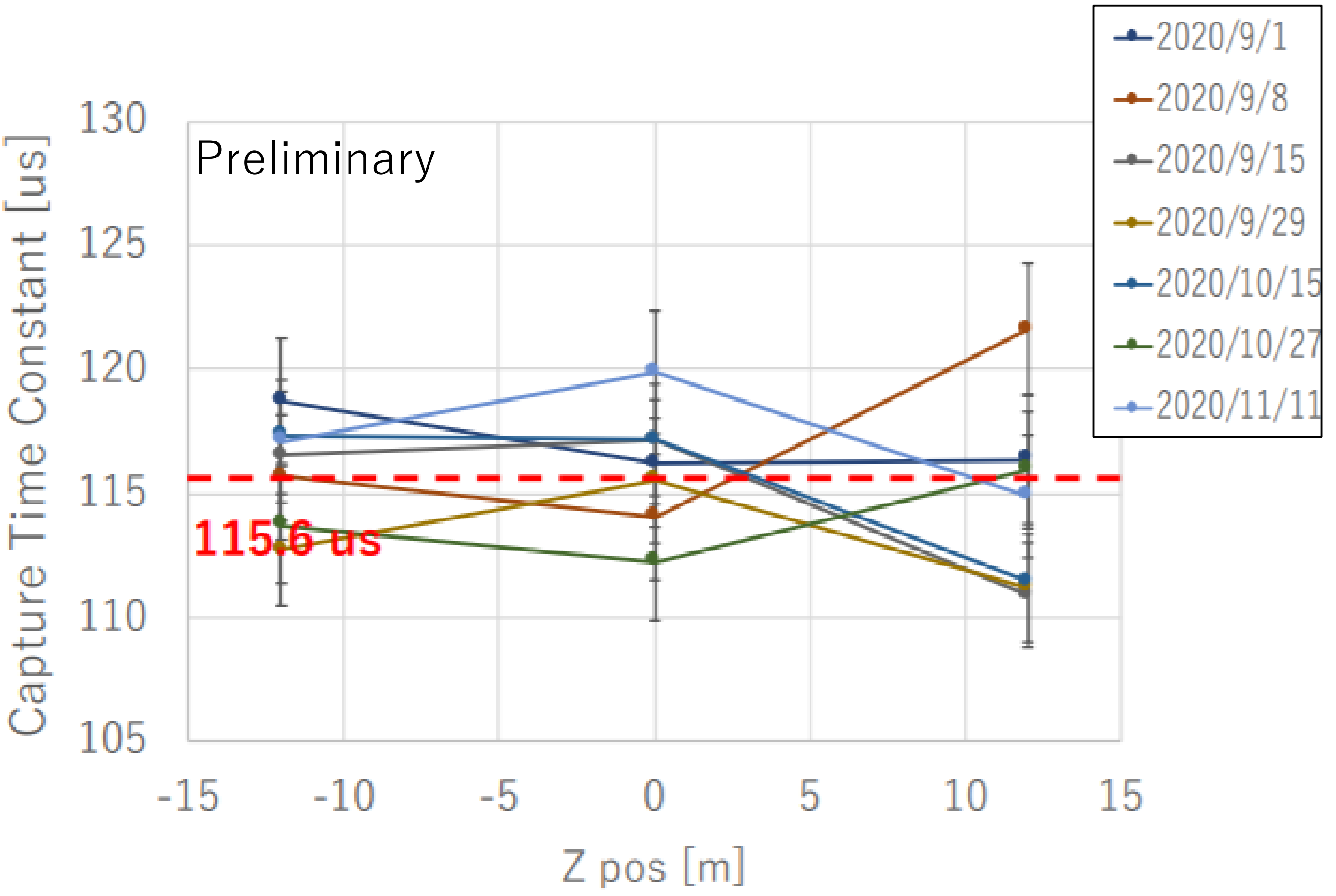
Gd concentration	Gd-n ratio	Capture time [μs]
0.1%	0.880	25
0.05%	0.802	44
0.03%	0.722	63
0.02%	0.642	82
0.01%	0.490	116

Gd-n capture time estimated from Geant4 simulation

Gd uniformity check by AmBe

Plots from Yano san



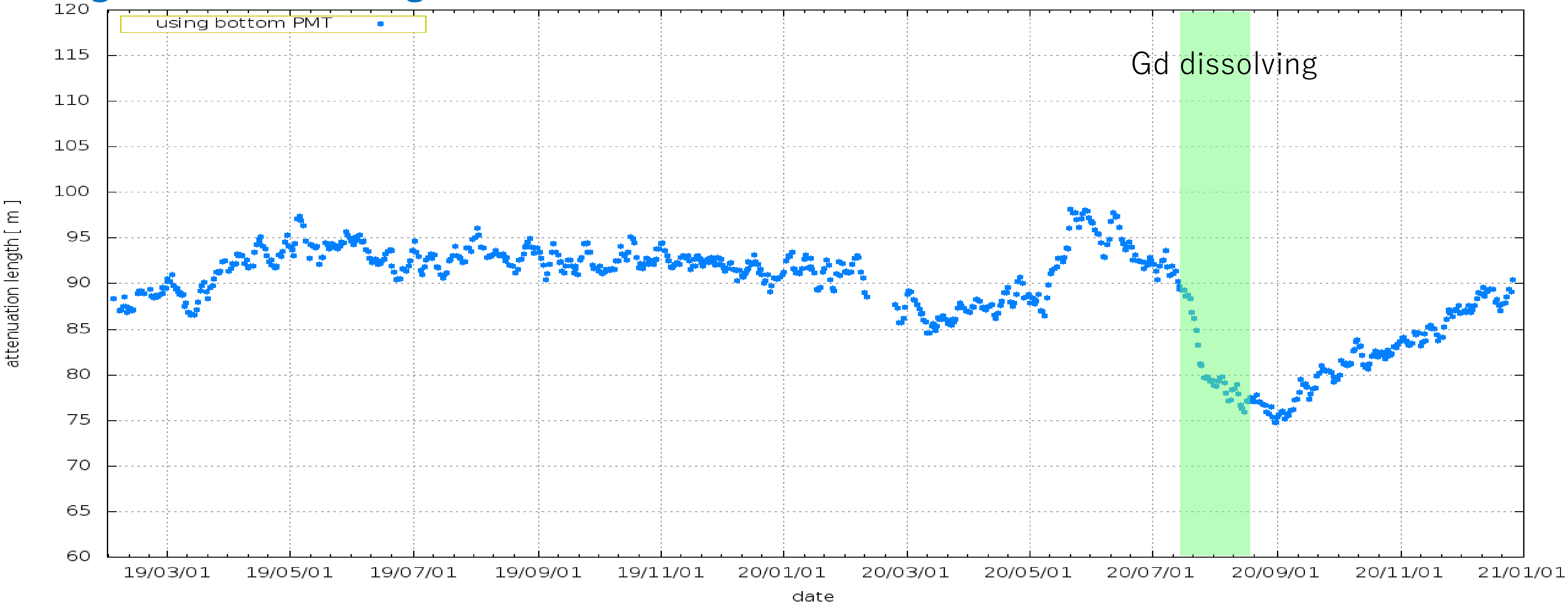


Confirmed uniformity after Sep.

Water transparency

Light attenuation length measured with cosmic muons

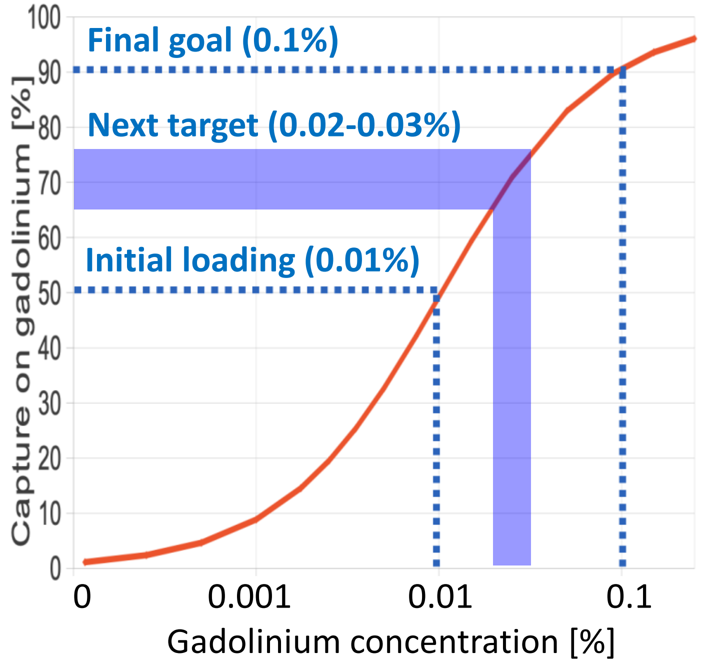
Plot from Sekiya san



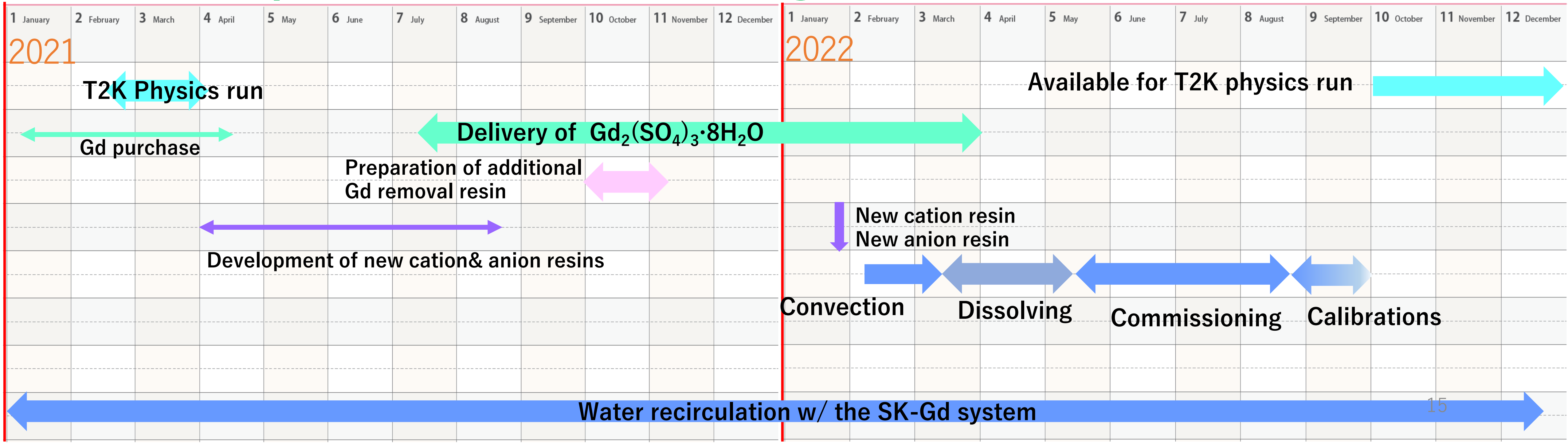
Water transparency is good enough and still recovering after Gd loading

Plans of SK-Gd

- Aiming to dissolve up to ~26 tons of additional $Gd_2(SO_4)_3 \cdot 8H_2O$ in 2021-2022
  - Target Gd concentration: 0.02-0.03% (Currently 0.01%)
  - Gd capture efficiency: 65-75% (Currently 50%)



Possible plan for the next loading



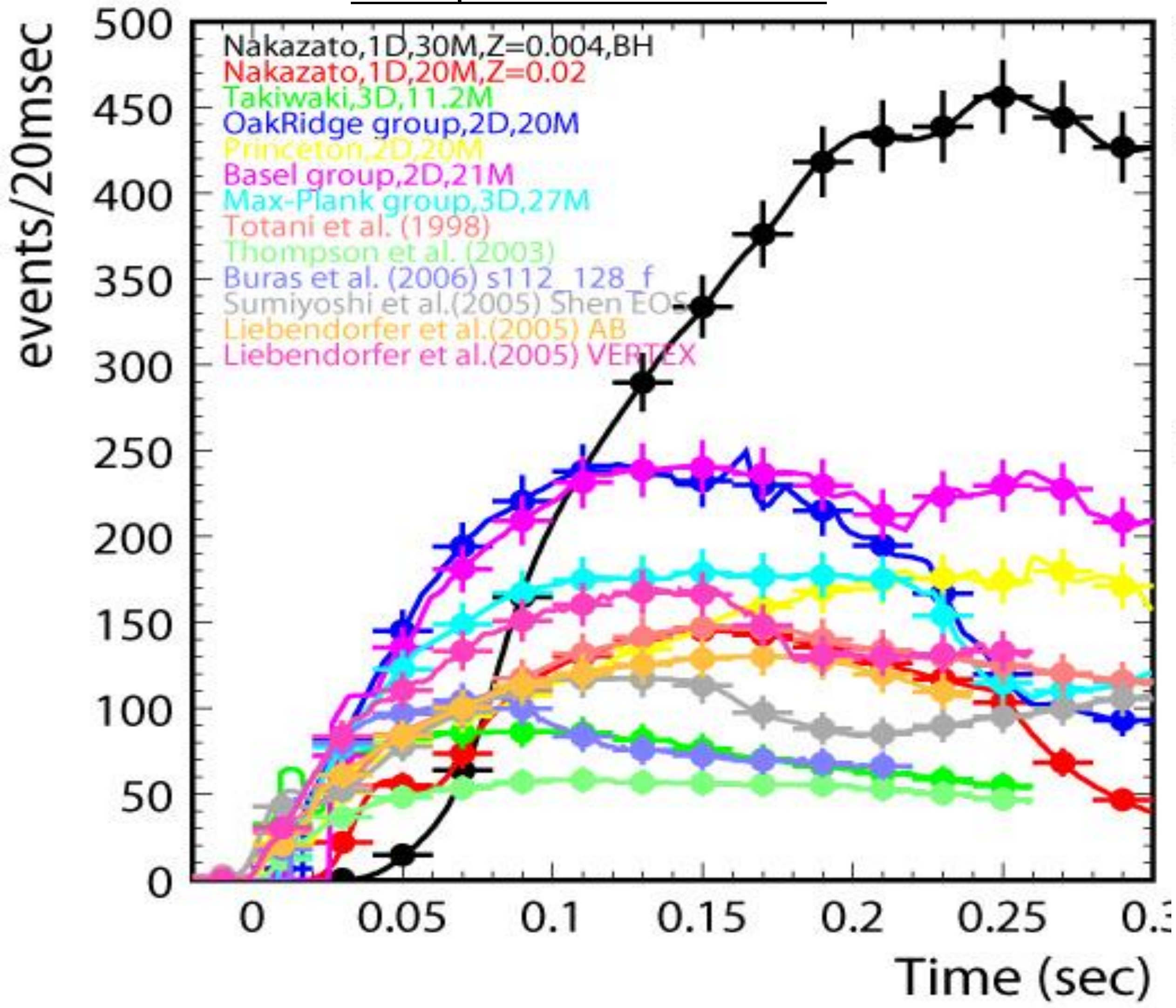
Supernova burst detection at Super-K

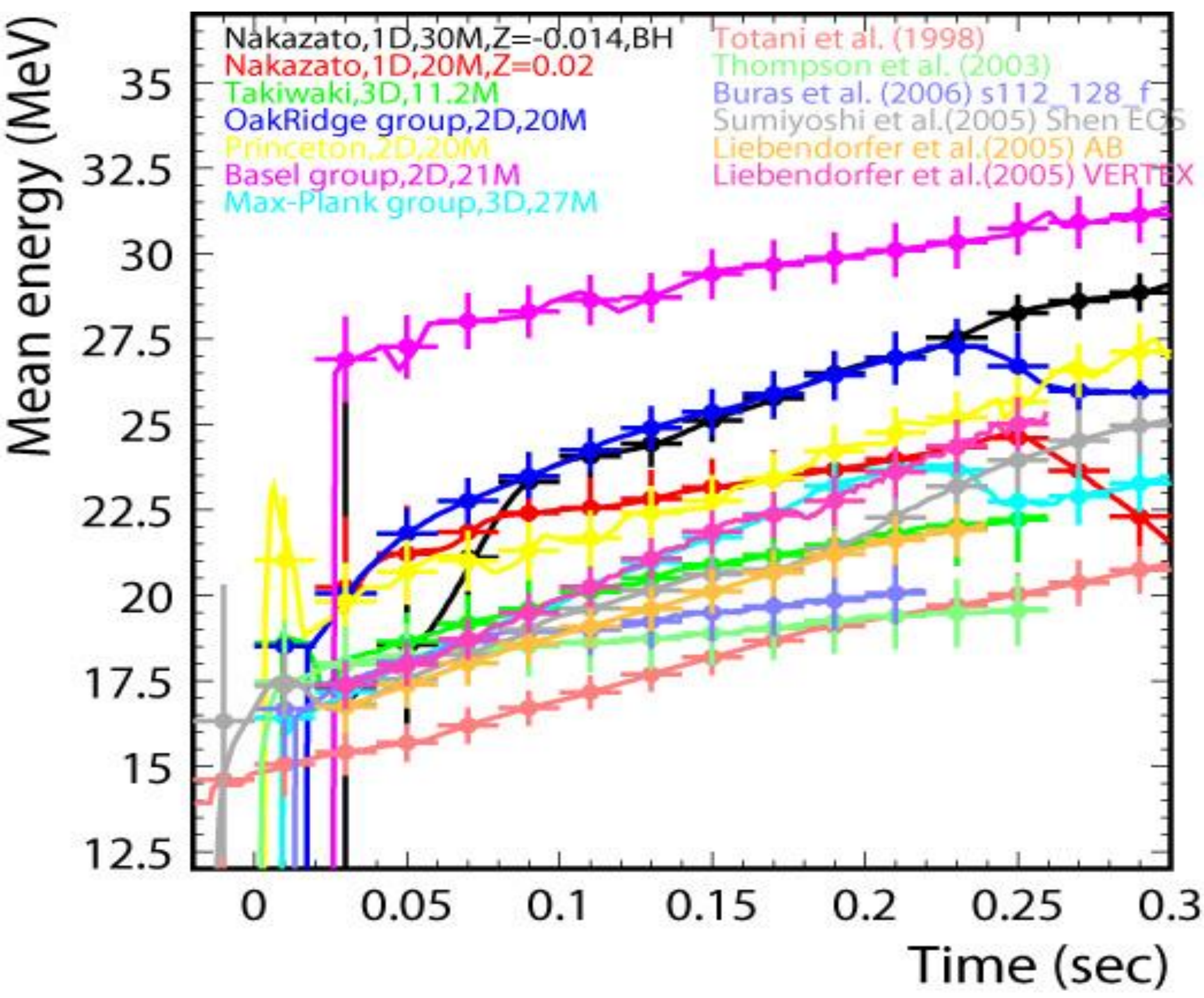
- Time profile of SN burst neutrino signal
- Pointing accuracy
- Pre-SN signal

Model discrimination by Super-K

Plots from Nakahata san
Cooperation: H. Suzuki

10kpc supernova





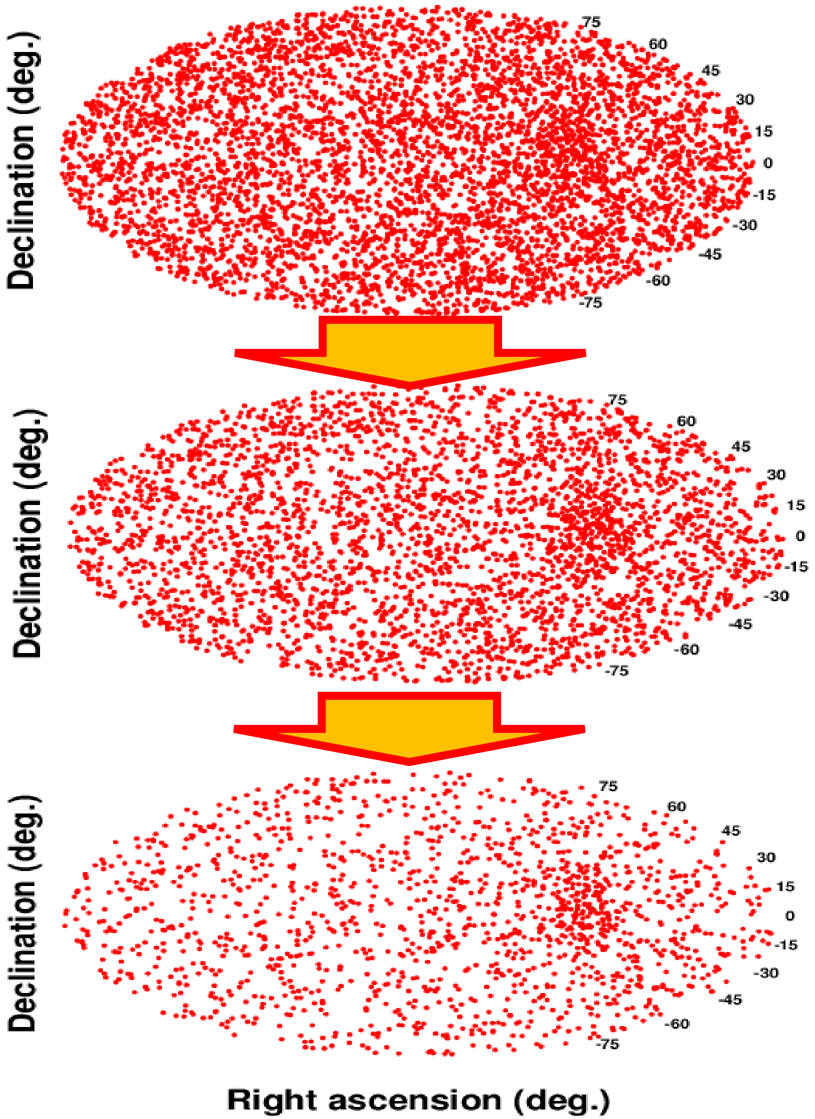
Enough statistics to study SN models

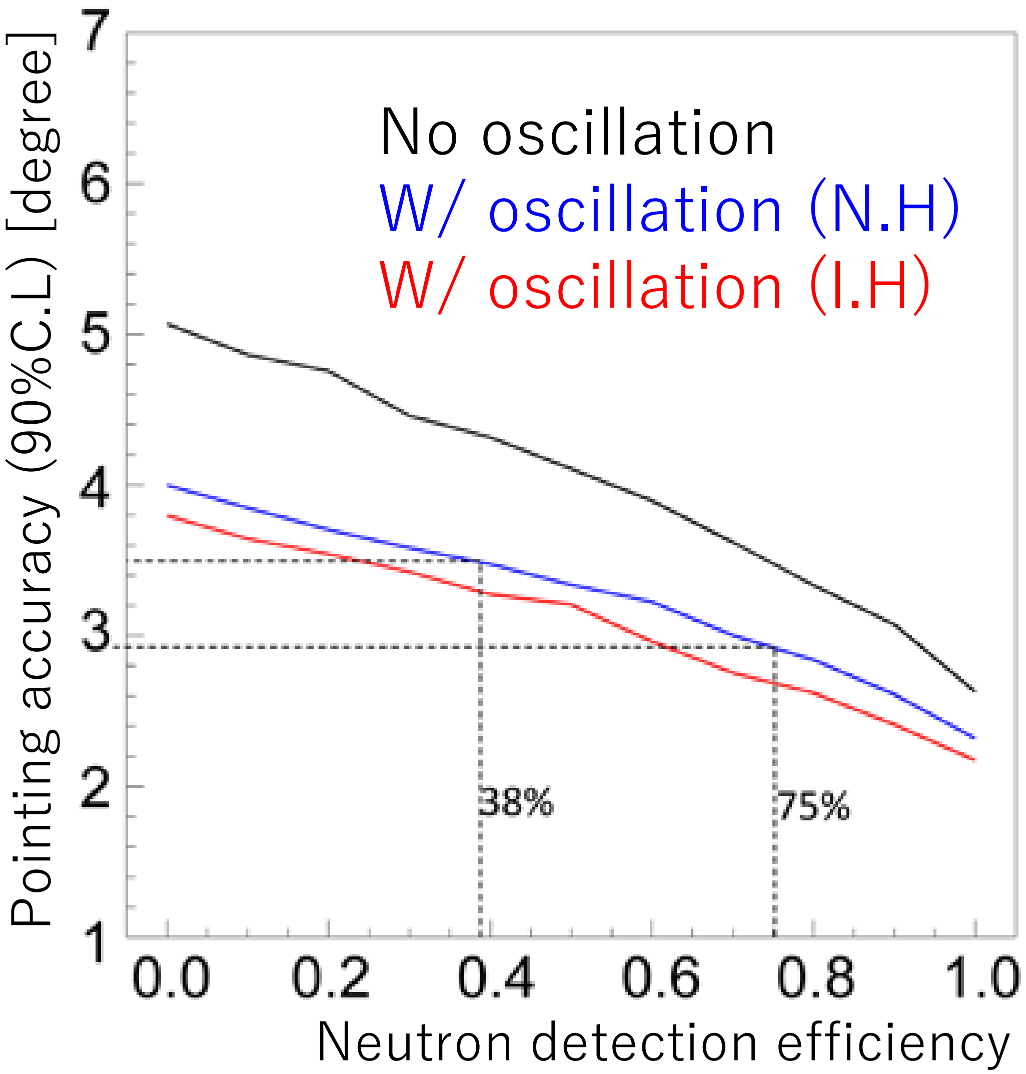
Expected improvement of SN pointing accuracy

No Gd

0.01%Gd
(Current)

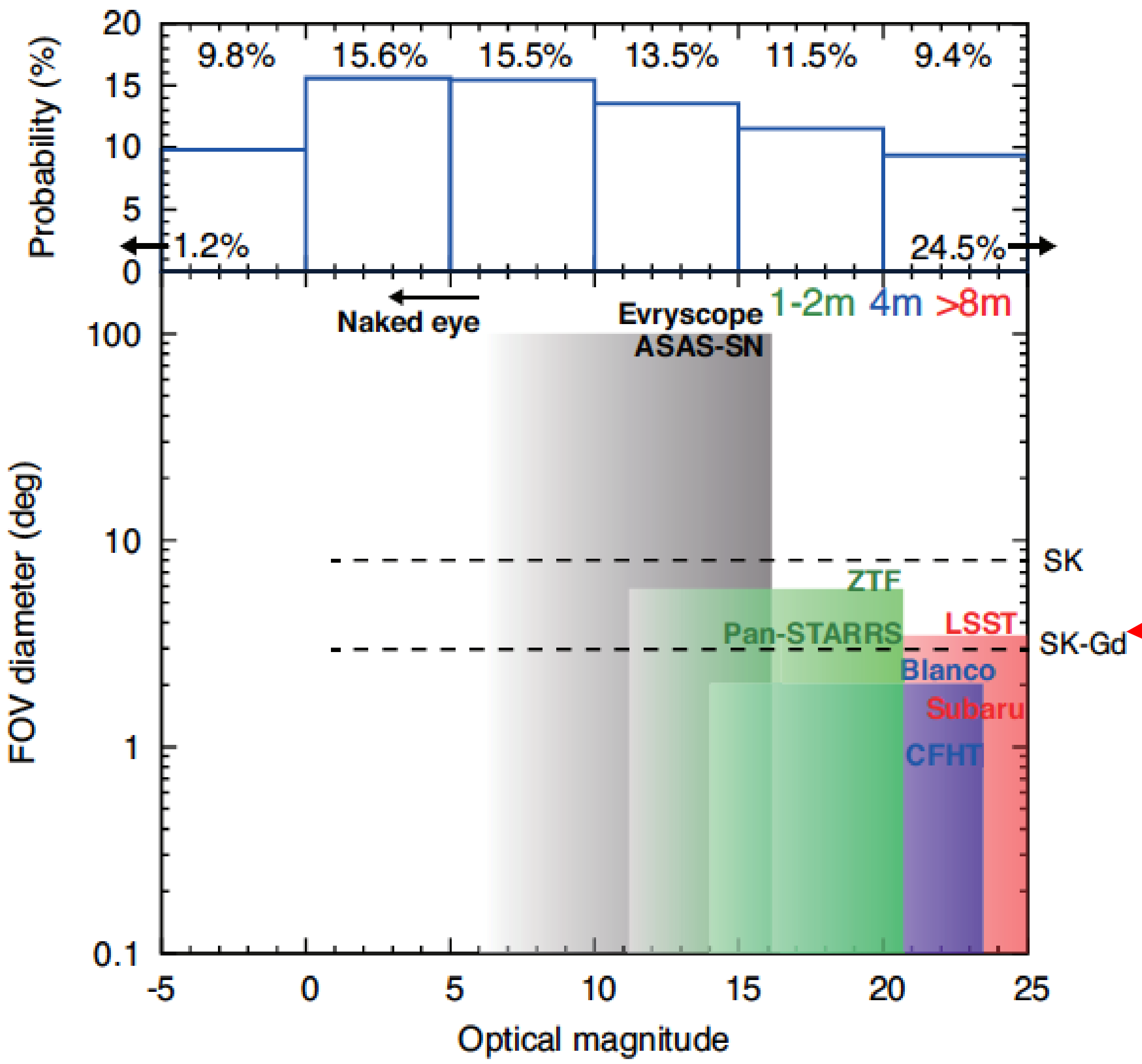
0.03%Gd
(Next)



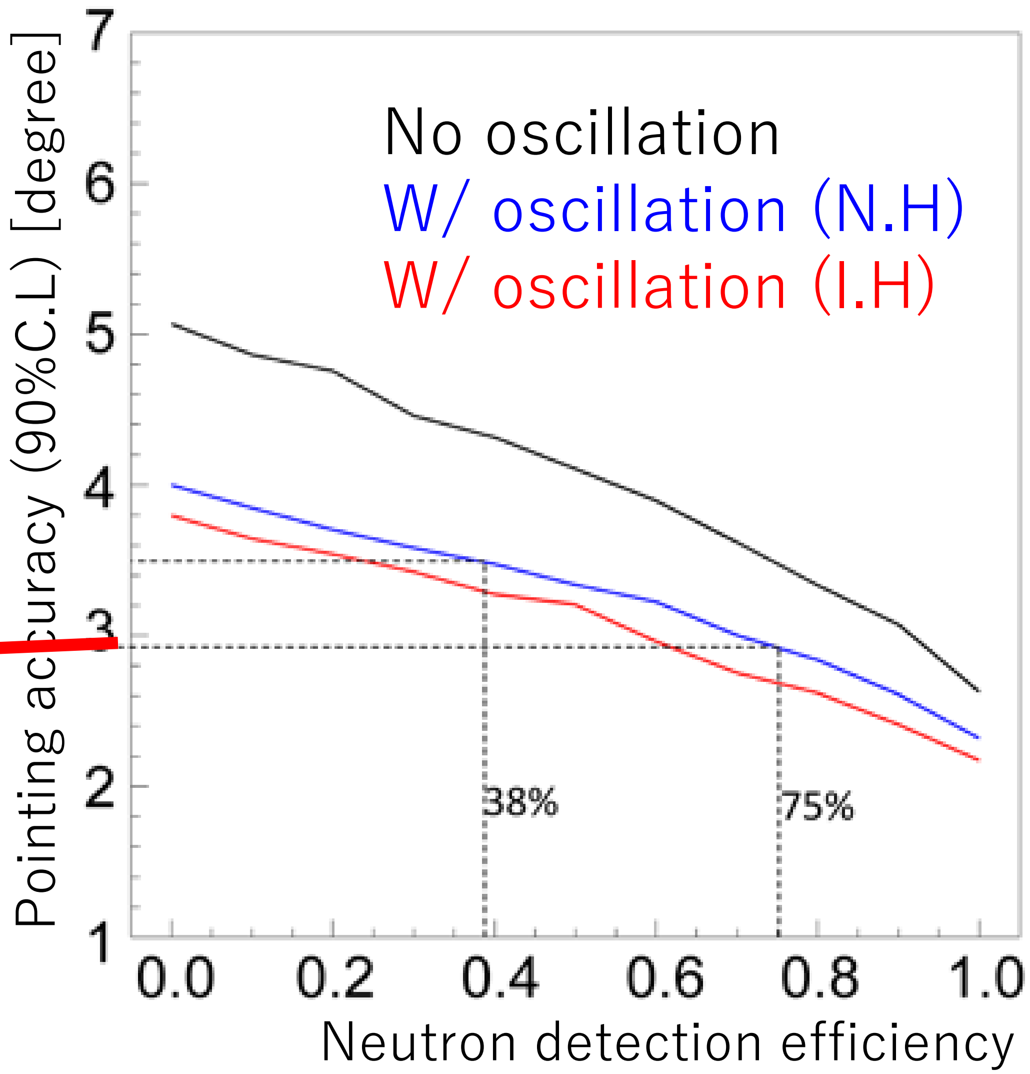


Aiming to reduce the accuracy to < 3 degree after the next loading

Expected improvement of SN pointing accuracy

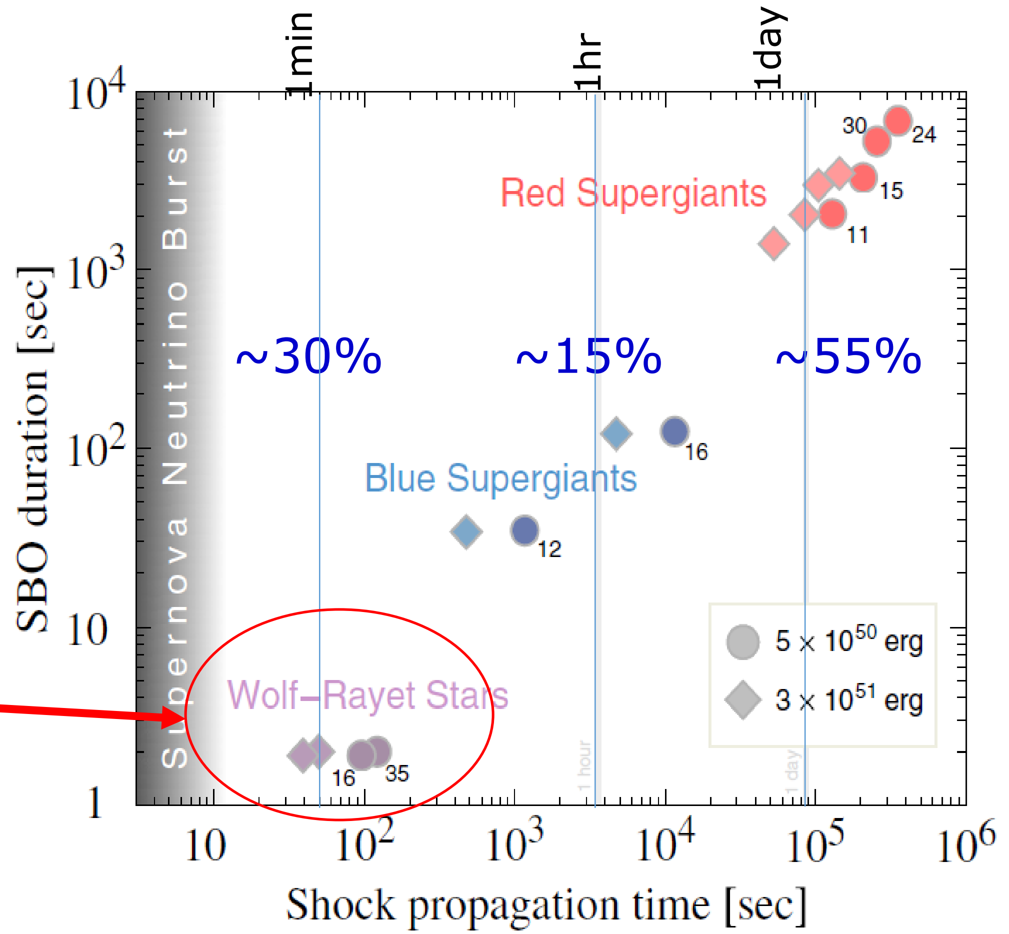


Nakamura et al (2016)



SN monitor and SN direction fitter R&D

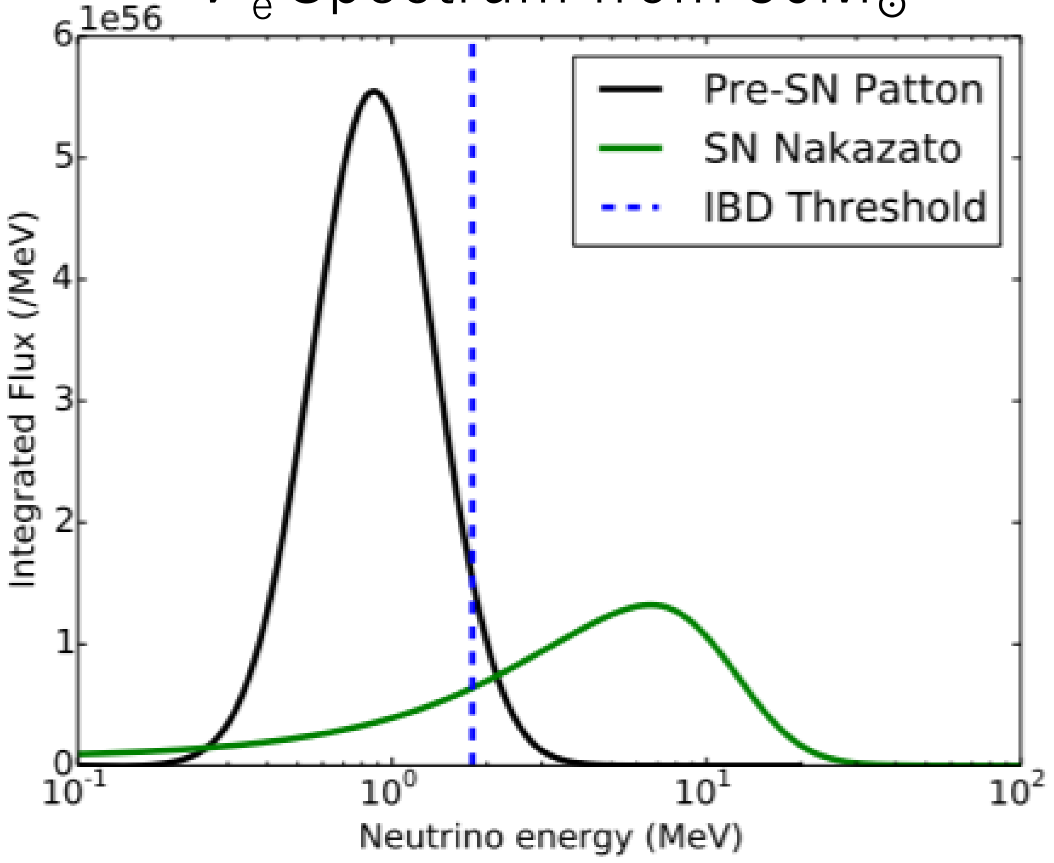
- Implementation of the new SN direction fitter including n-tag information
  - Will be ready soon
- Intelligent trigger for Gd signal search
  - Current trigger threshold of Gd signal; 3.5 MeV = efficiency ~75%
  - Trig. threshold can be 2.5 MeV(= eff. ~100%) with more processing power
- GPU & machine learning
  - Current direction fitter : ~10min for 10kpc SN
  - Must be reduced to 1min or faster (e.g. W.R)
- Latency of SN monitor
  - Currently 1 hour after checks by experts
  - We want to improve to few min to circulate SN direction without human checks



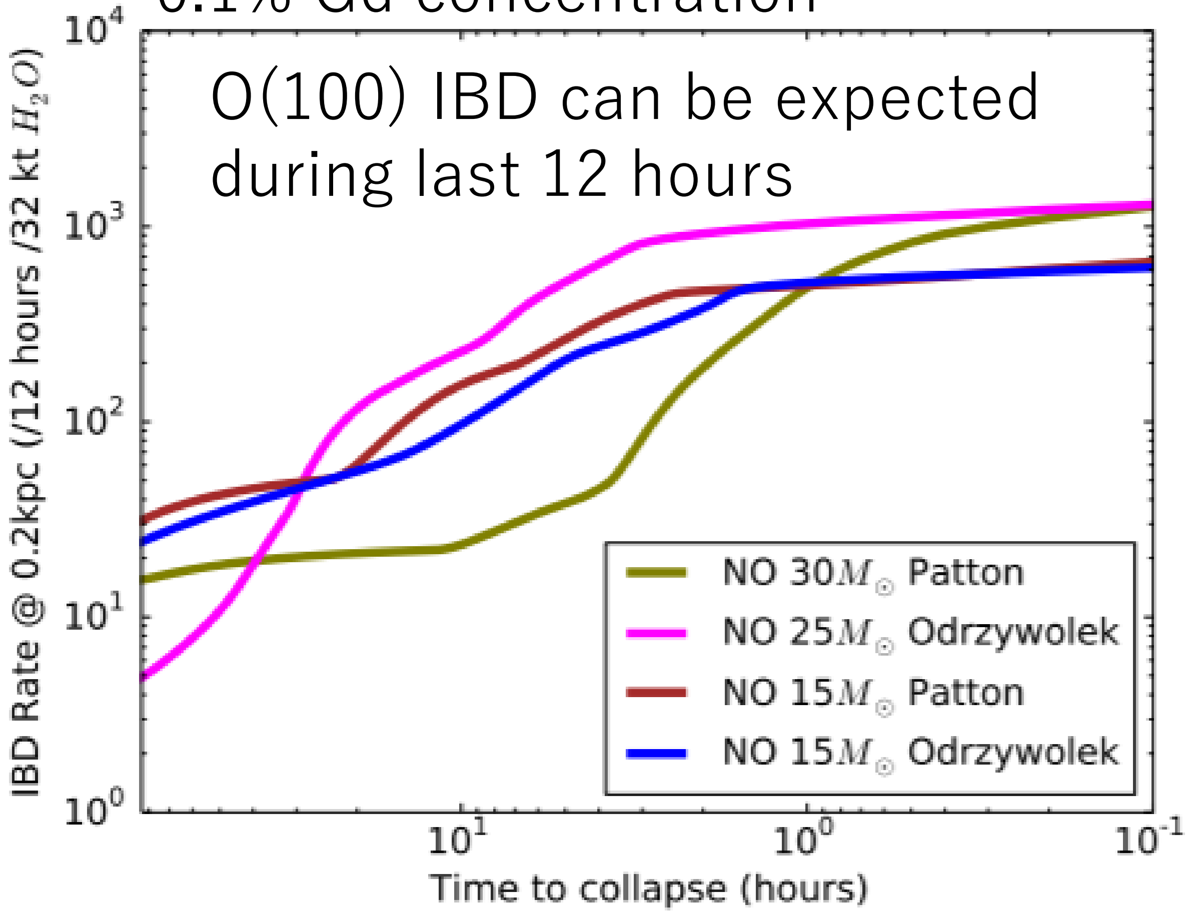
M Kistler et al.,ApJ 778 (2013) 81

Pre-SN (Si burning) neutrinos

$\overline{\nu}_e$ Spectrum from 30M$_\odot$



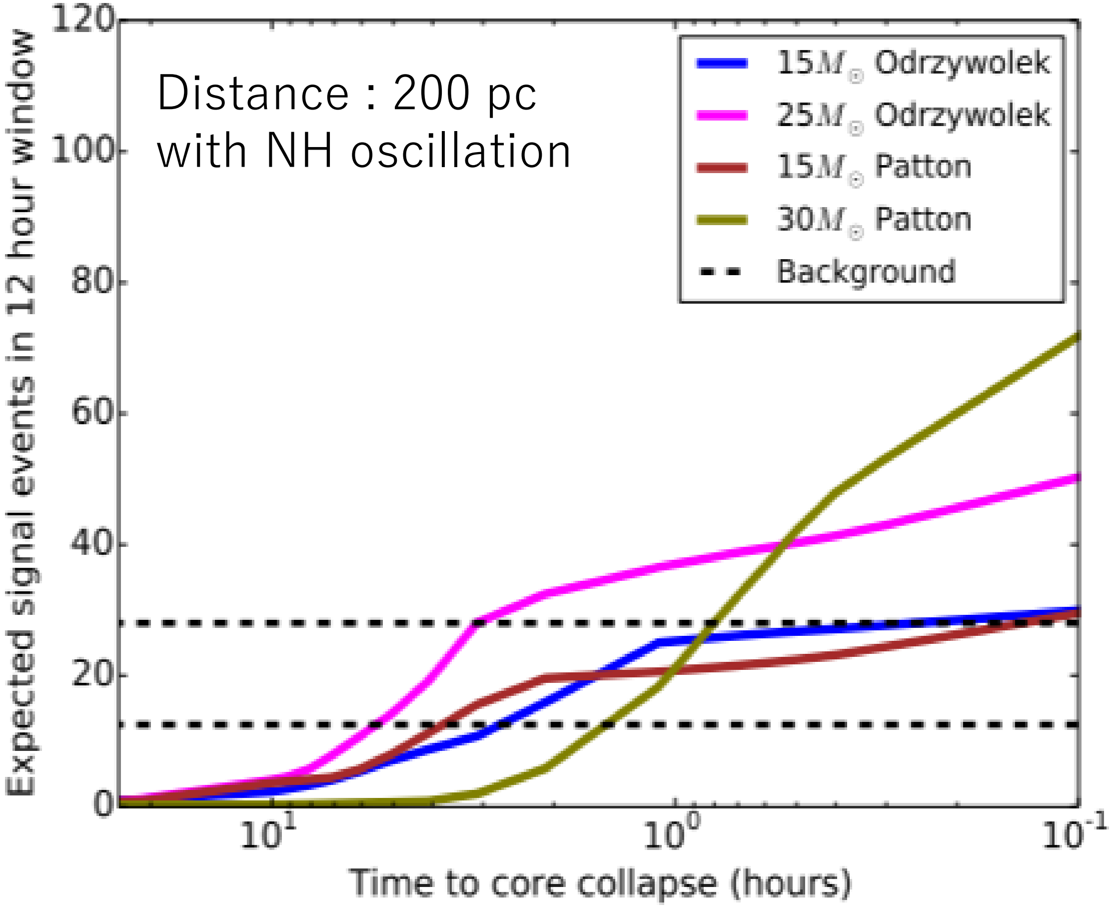
0.1% Gd concentration

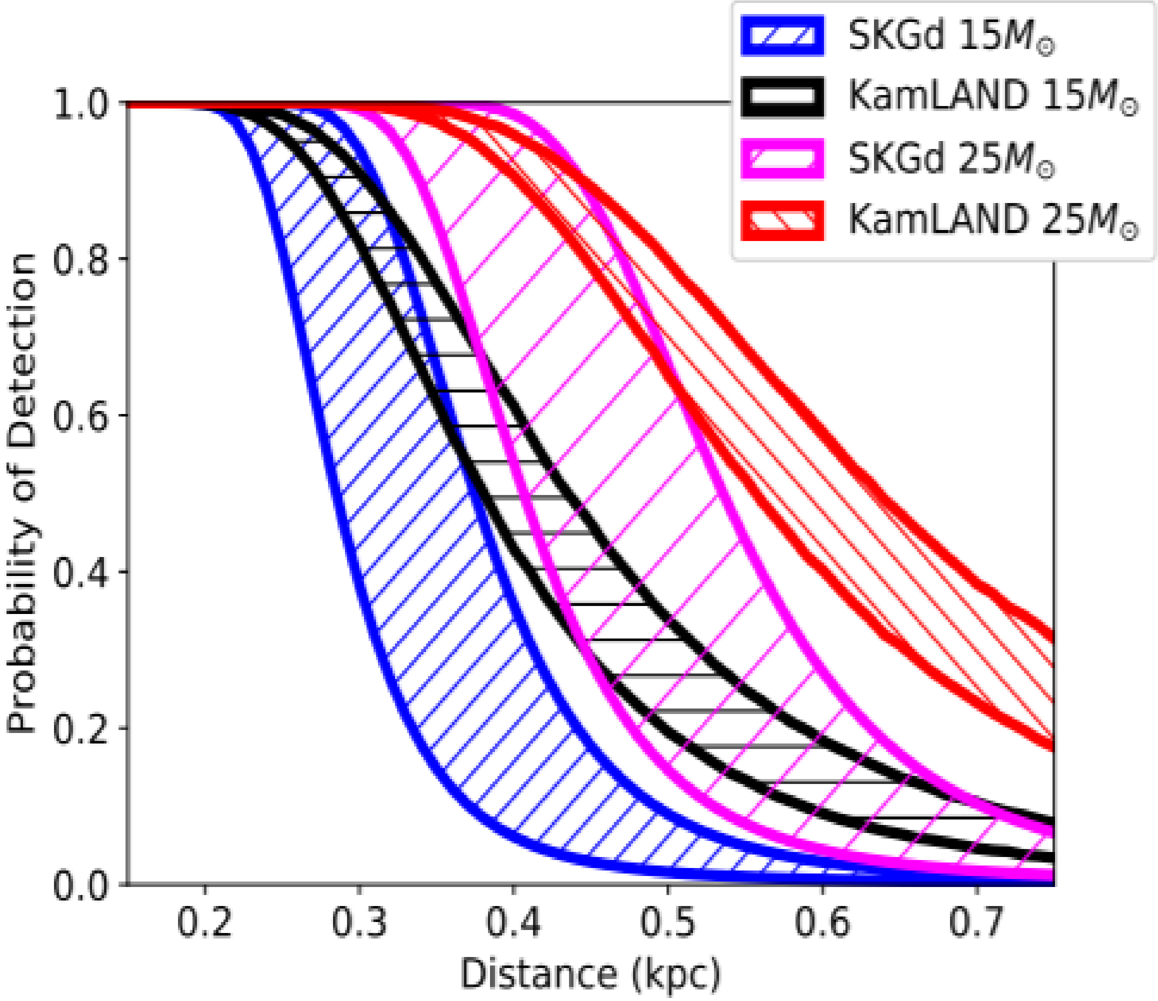


C. Simpson et al (SK Coll.), Astrophys. J. 885, 2 (2019)

Detection probability 0.1% Gd concentration

Number of events after event selection





Model: Odrzywolek, Alarm level： 3σ from BG

Enough sensitivity to Betelgeuse.

Summary

- SK-Gd started!
- First Gd loading was done in Jul-Aug last year.
  - Gd concentration is uniform
  - Water transparency is good
- More Gd will be added in next year
- Supernova detection
  - Better pointing accuracy with Gd
    - Aiming to get SN direction within 1 min
  - Good sensitivity to pre-SN signals
    - Pre-SN alarm will be implemented soon