Radiopurity program for SuperK-Gd

M.Ikeda

(ICRR, Kamioka Obs)

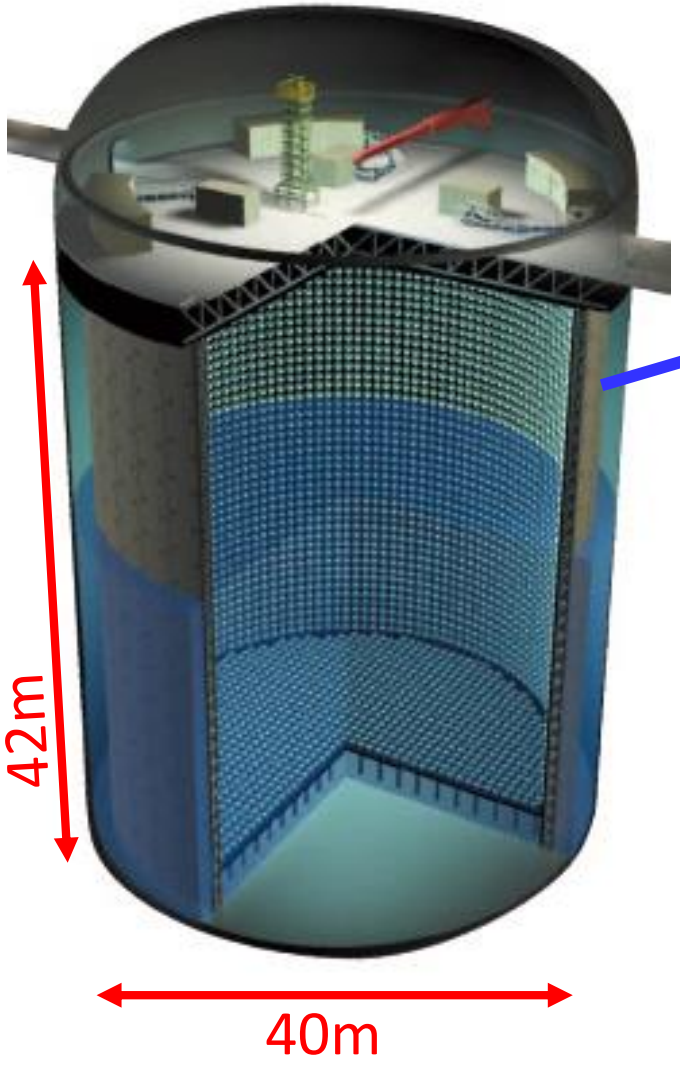
@LRT2019

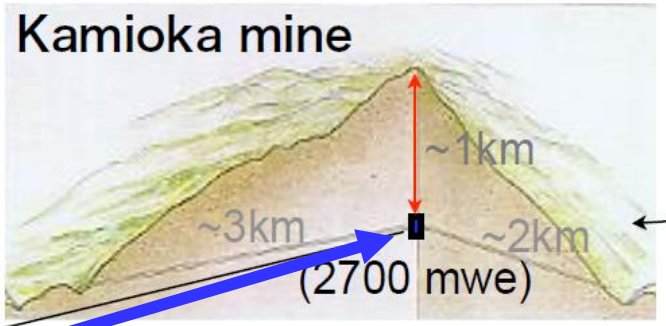
May, 20th, 2019

Contents

Super-Kamiokande

50000 tons of
Water Cherenkov detector



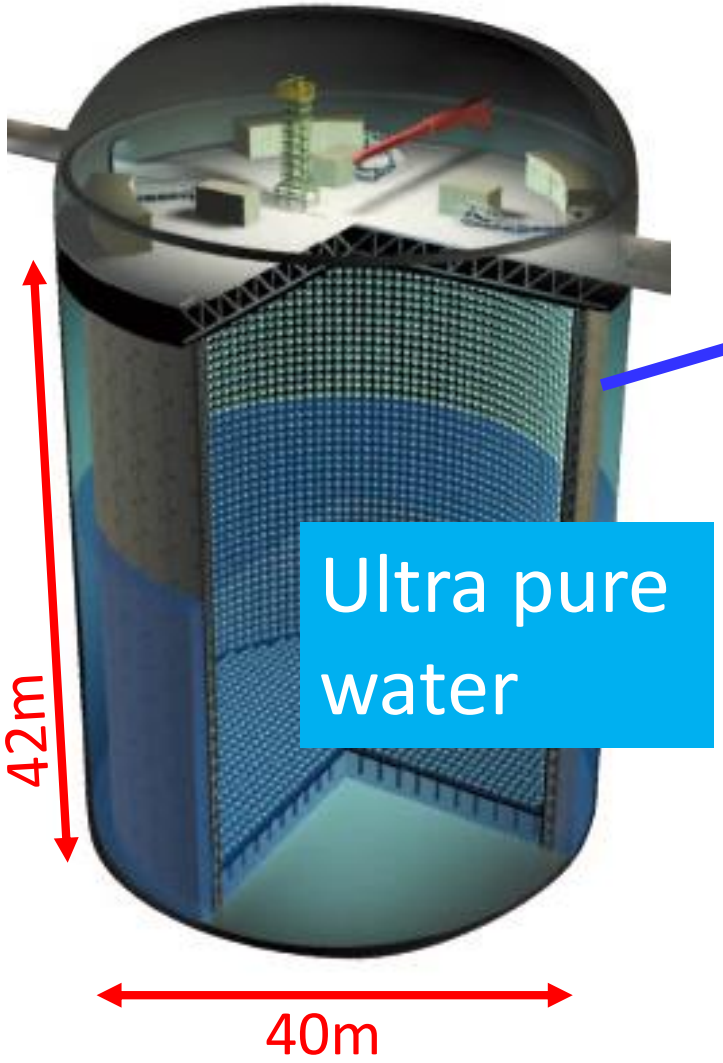


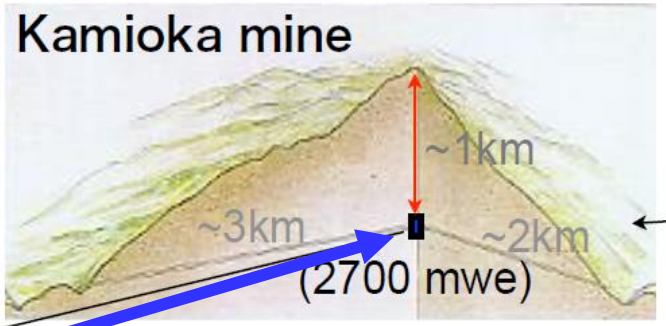
(For Solar neutrino analysis)

Phase	Period	Livetime	Fid. vol.	ID PMTs	KinE thr.
I	1996.4~ 2001.7	1496 (days)	22.5 (kton)	11146 (40%)	4.5 (MeV)
II	2002.10~ 2005.10	791		5182 (20%)	6.5
III	2006.7~ 2008.8	548	22.5 (>5.5 MeV) 13.3 (<5.5 MeV)	11129 (40%)	4.5
IV	2008.9~ 2019.1	2860	22.5 (>5.5MeV) 16.5 (4.5<E<5.5) 8.85(<4.5MeV)		3.5
V	2019.2~				

Super-Kamiokande

50000 tons of
Water Cherenkov detector





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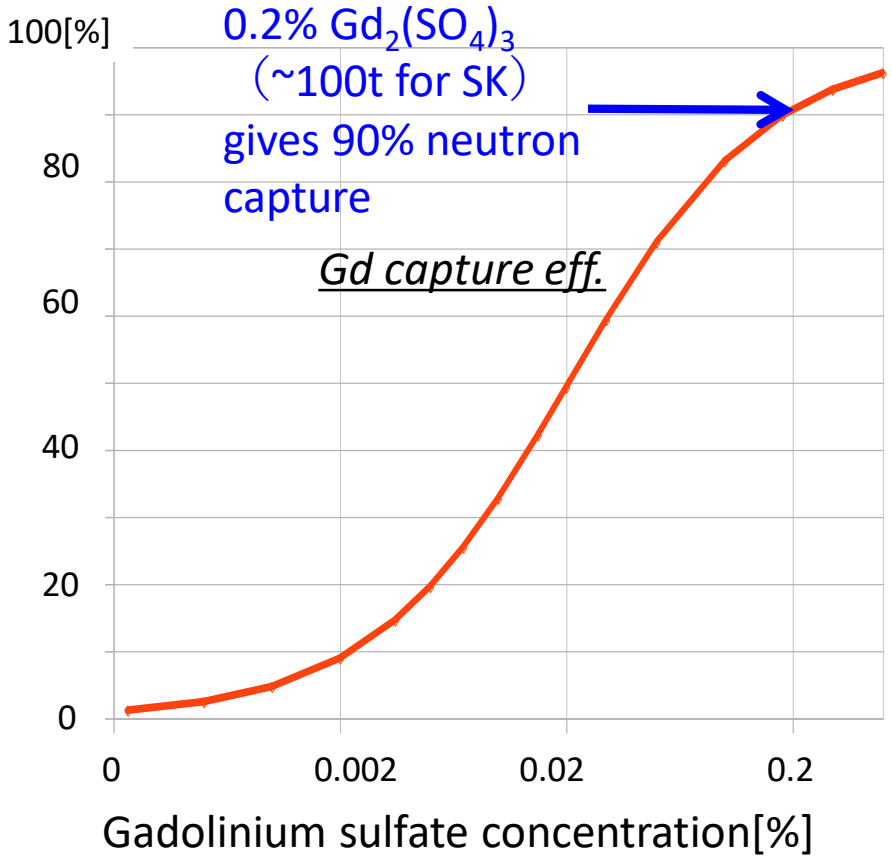
Super K-Gd Beacom and Vagins PRL93,171101 (2004)

- Large cross section for thermal neutron (48.89kb)
- Neutron captured Gd emits 3-4 γ ray in total 8 MeV
- **We can tag $\bar{\nu}_e$ by using the delayed coincidence technique.**



Physics targets:

(1) Supernova relic neutrino (SRN)

(2) Improve pointing accuracy for galactic supernova

(3) Precursor of nearby supernova by Si-burning neutrinos

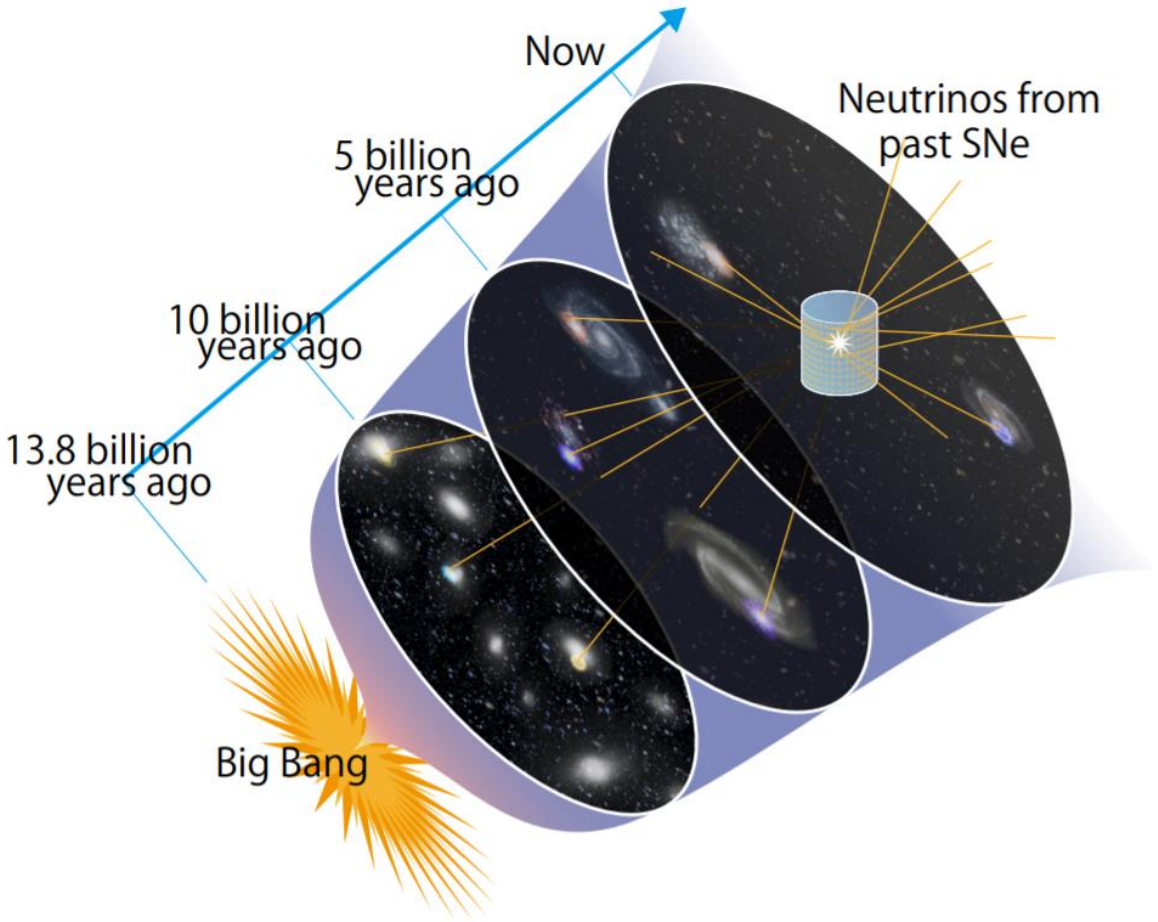
(4) Reduce proton decay background

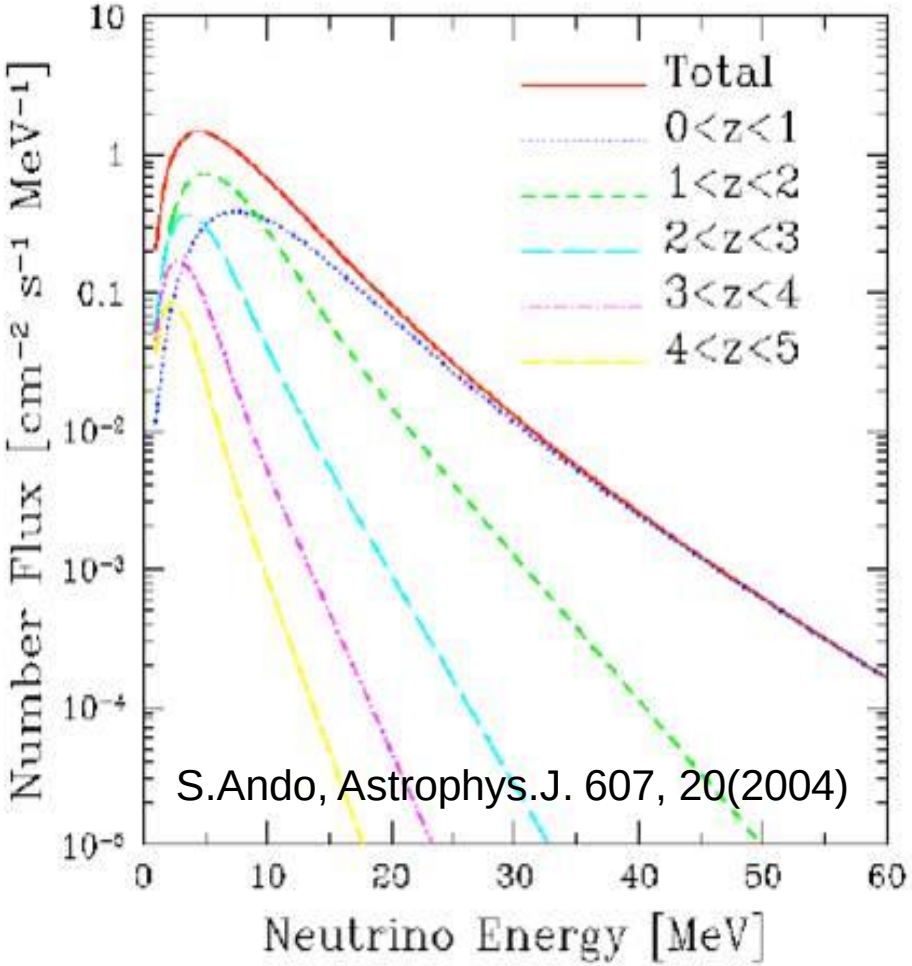
(5) Neutrino/anti-neutrino discrimination (Long-baseline and atm nu's)

(6) Reactor neutrinos

Supernova Relic Neutrino (SRN)

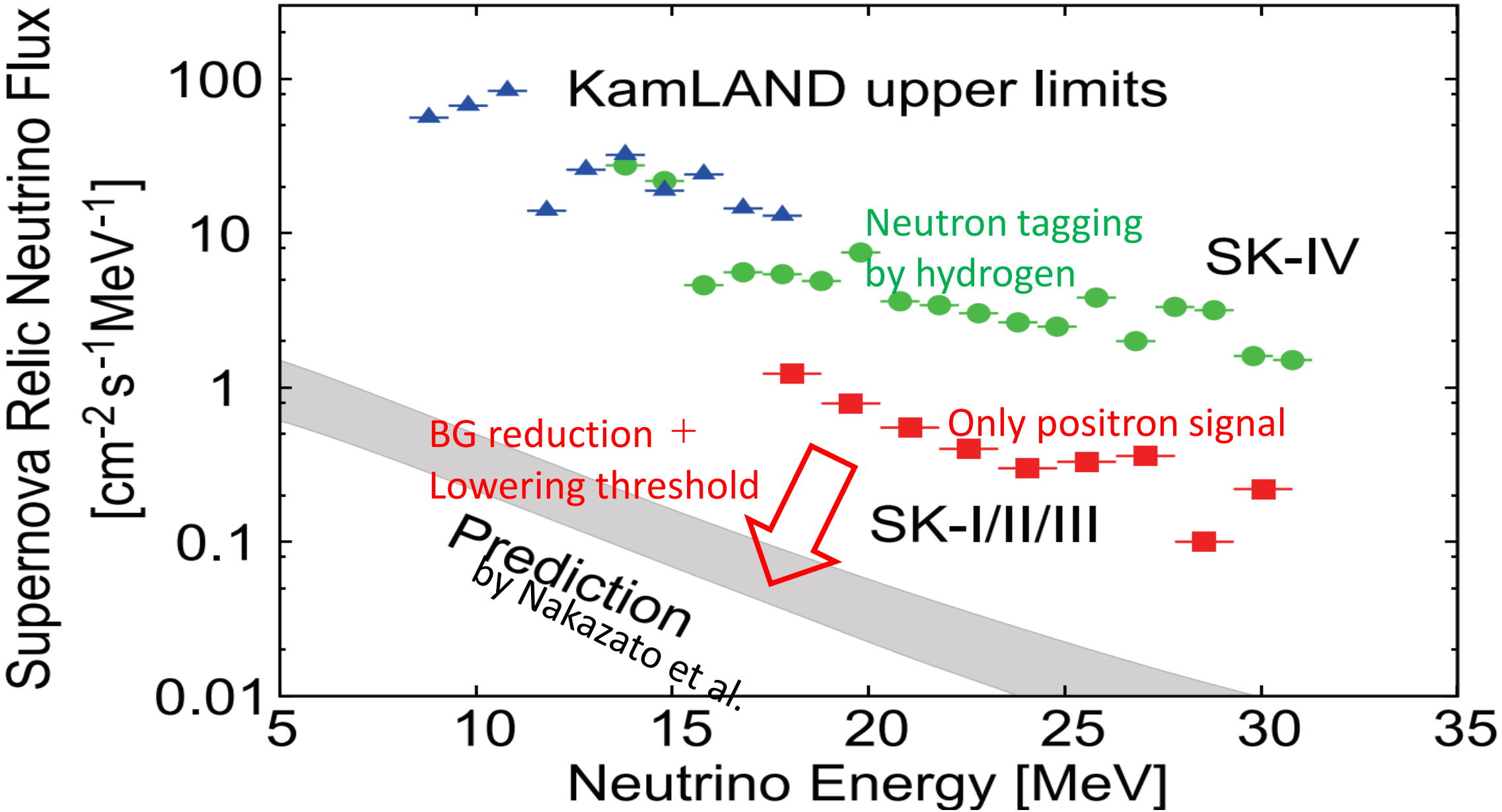
Discovery of neutrinos from past supernovae!



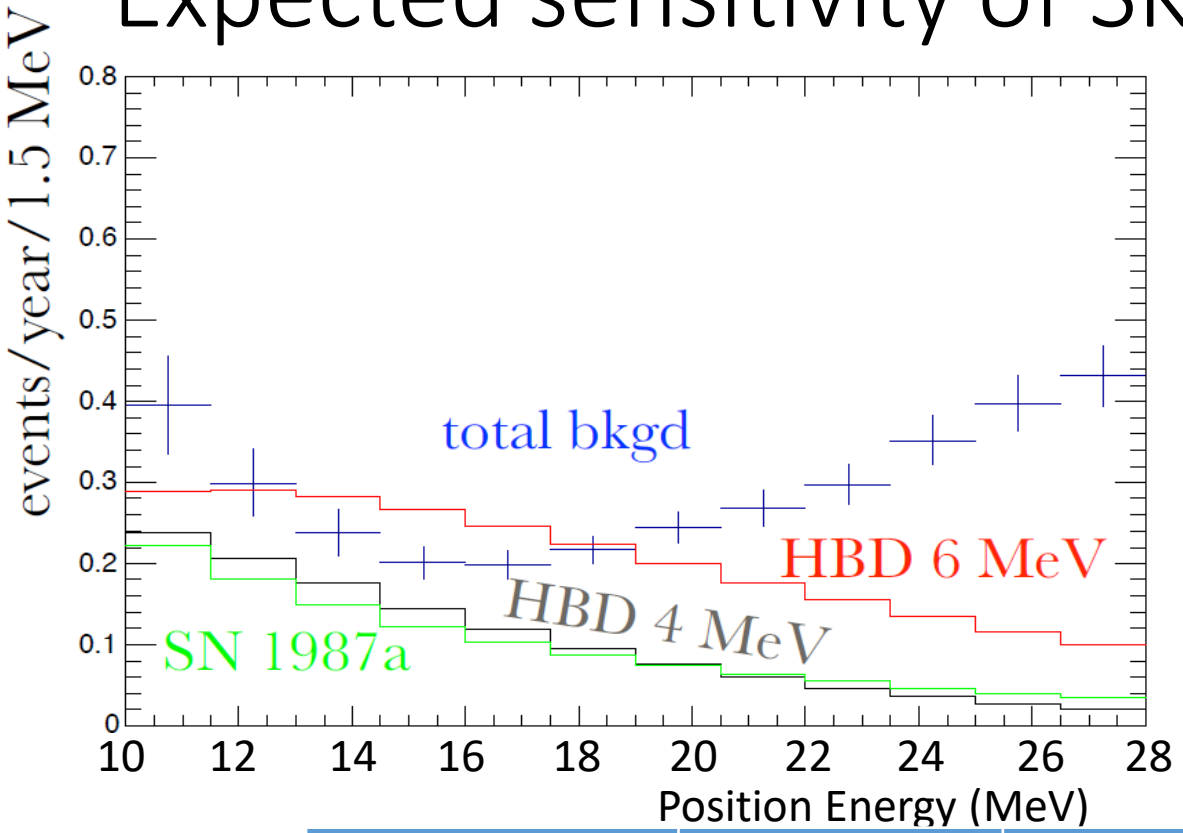


Theoretical flux prediction : 0.3~1.5 /cm2/s (17.3MeV threshold)

Current SRN searches



Expected sensitivity of SK-Gd preliminary



SRN flux;
Horiuchi, Beacom and Dwek, PRD, 79, 083013 (2009)

BG assumption in SK-Gd

- ν_μ CC BG become 1/4
- ν_e CC BG become 2/3
- NC elastic BG 1/3
  （requiring only one neutron）

Model	10-16MeV (evts/10yrs)	16-28MeV (evts/10yrs)	Total (10-28MeV)	Significance (2 energy bin)
HBD 8MeV	11.3	19.9	31.2	5.3 σ
HBD 6MeV	11.3	13.5	24.8	4.3 σ
HBD 4MeV	7.7	4.8	12.5	2.5 σ
HBD SN1987a	5.1	6.8	11.9	2.1 σ
BG	10	24	34	----

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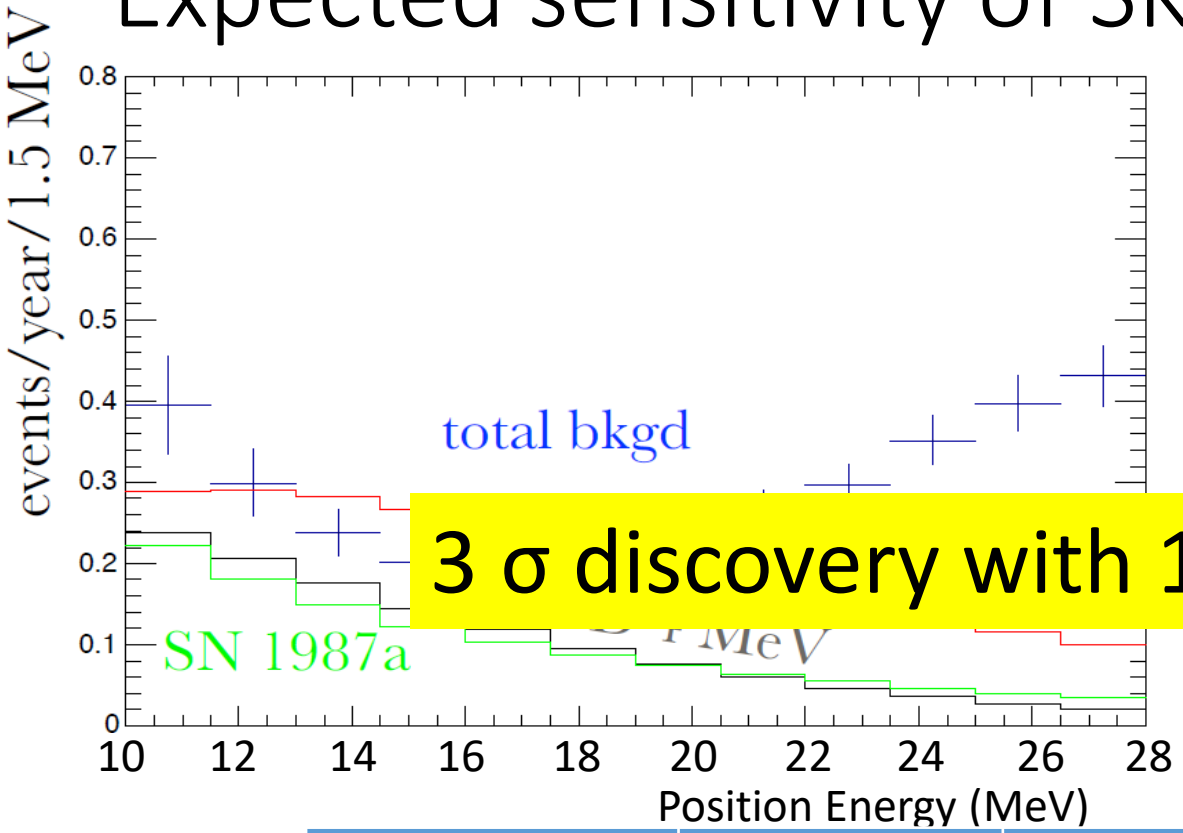

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3 σ discovery with 10 years observation

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Radio impurities in Gd sulfate powder

Requirements of RI in Gd powder

Requirement for each isotope assuming 0.2% Gd sulfate loading

Isotope	SRN	Solar
^{238}U	< 5	-
^{226}Ra	-	< 0.5
^{232}Th	-	< 0.05
^{228}Ra	-	< 0.05
^{228}Th	-	< 0.05
^{235}U	-	< 3
$^{227}Ac/Th$	-	< 3

Unit：mBq/kg($Gd_2(SO_4)_3$)

← γ and neutrons from S.F.

←^{214}Bi : β（Q=3.27MeV）

^{208}Tl : γ（=2.6MeV）

neutrons from decay chain
< solar ν BG level.

We set requirements so that these will be less than current BG levels in Super-K

RI in Gd powder before R&D

Requirement for each isotope assuming 0.2% Gd sulfate loading

Isotope	SRN	Solar	Before 2015
^{238}U	< 5	-	50
^{226}Ra	-	< 0.5	5
^{232}Th	-	< 0.05	
^{228}Ra	-	< 0.05	10
^{228}Th	-	< 0.05	100
^{235}U	-	< 3	32
$^{227}Ac/Th$	-	< 3	300

Unit：mBq/kg($Gd_2(SO_4)_3$) $8H_2O$

1/10 ~ 1/1000 reductions were needed!

R&D of clean Gd

Researchers :
Evaluation of “ultra low” RI.
Company side :
make sample based on our input


New ICPMS in Kamioka (2016.Dec)

- Ge detectors
  - Easy to make samples
  - Many detectors
  - Good sensitivity: < 0.5 mBq/kg ($Gd_2(SO_4)_3 \cdot 8H_2O$) for Ra/Th
  - Can check whole decay chain
- ICP-MS
  - Super high sensitivity Th~0.1 mBq/kg($Gd_2(SO_4)_3 \cdot 8H_2O$)
- Rn emanation
  - Ra can be measured at ~0.1mBq/kg

Ge measurement at Canfranc

LSC
Laboratorio Subterráneo de Canfranc

Slide by Iulian Bandac
https://agenda.infn.it/event/18729/

Ultra-Low Background Measurements Service

Name	V [cm3]	M [kg]	FWHM @ 1332 keV [keV]	Integral (60-2700) keV [cts/kg/day]	Tl-208 2614.5 keV [cts/kg/day]	Bi-214 609.3 keV [cts/kg/day]	Co-60 1332.5 keV [cts/kg/day]	K-40 1460.8 keV [cts/kg/day]
GeOroel	420	2.31	1.85	165.3	0.4	2.9	0.1	0.4
Asterix	387	2.13	2.08	189.2	0.2	2.1	0.5	0.3
GeAnayet	410	2.26	1.96	473.3	3.2	1.9	0.1	0.6
GeLatuca	410	2.26	1.86	342.0	3.9	2.8	0.2	0.8
GeTobazo	410	2.26	2.07	491.7	3.8	2.8	0.4	0.7
GeAspe	409	2.25	1.94	477.9	3.8	2.2	0.3	0.9

Sensitivity, assuming secular equilibrium and 10% efficiency:

^{238}U ~ 10 – 100 ppt

^{232}Th ~ 50 – 330 ppt

^{40}K ~ 10 – 100 ppb

During R&D, most of Gd samples have been measured at LSC

R&D history (example of one company)

GOX :Gd oxide, GSF:Gd sulfate. Unit ; mBq/kg(sample)

Table from L.Labarga

Main chain	^{238}U		^{232}Th		^{235}U	
	^{238}U	^{226}Ra	^{228}Ra	^{228}Th	^{235}U	$^{227}Ac/^{227}Th$
Goal*	< 5	< 0.5	< 0.05	< 0.05	< 3	< 3
GOX-1	1221 ± 112	29 ± 2	274 ± 5	233 ± 4	50 ± 4	1813 ± 14
GOX-1'	< 280	< 4	< 10	< 9	< 7	< 11
GSF-1'	< 139	< 2.1	2.8 ± 1.9	1.8 ± 0.9	< 2.4	< 10
GOX-2	< 21	< 1.0	8.2 ± 0.7	1.4 ± 0.5	< 0.9	< 3.0
GSF-2	< 59	< 0.7	3.2 ± 1.0	< 1.4	< 1.2	< 4.1
GSF-2'	< 20	< 0.64	< 0.67	0.5 ± 0.2	< 0.7	< 2.3
GSF-3-1	< 9.7	< 0.19	< 0.24	< 0.28	< 0.35	< 1.7
GSF-3-2	< 12	< 0.21	< 0.26	< 0.31	< 0.41	< 1.4
GSF-3-3	< 11	< 0.21	< 0.30	< 0.30	< 0.42	< 1.6
GSF-4	< 9.7	< 0.14	< 0.29	< 0.32	< 0.4	< 1.5

* Goal for 0.2% Gd-sulfate loading

All these measurements done at LSC

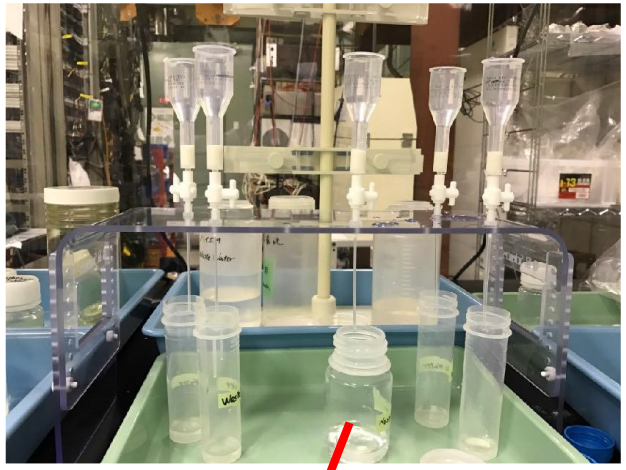
Evaluation of super-low level U/Th

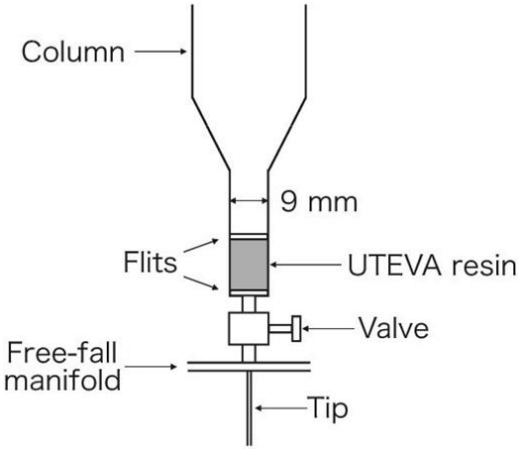
- We have developped a method to measure super-low level U/Th in Gd powder
- Requiements:

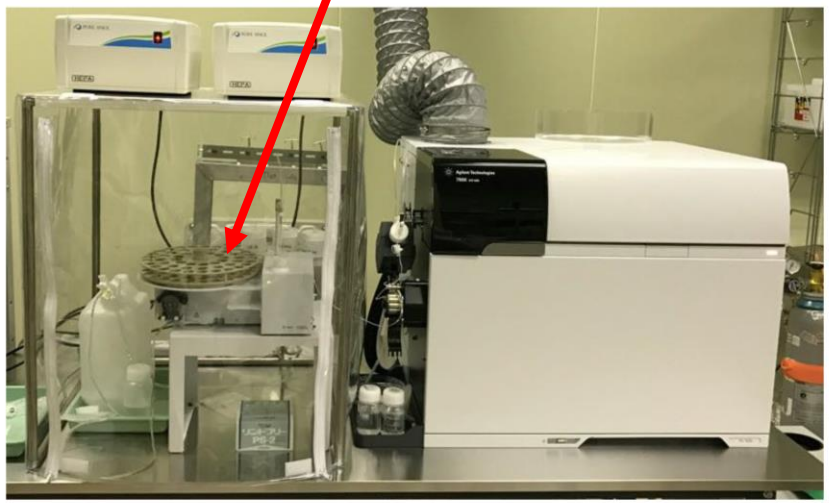
  ^{238}U < 400ppb (5mBq/kg),

  ^{232}Th< 12ppt (0.05mBq/kg)

  - Separation and extraction of U/Th from Gd solution using resin
    - To remove matrix effect of Gd
    - S.Ito et al. PTEP 2017 113H01







Auto-sampler is covered by clean booth.→Class 100

“Ultra” pure Gd sulfate powder

* Goal for 0.2% Gd-sulfate loading

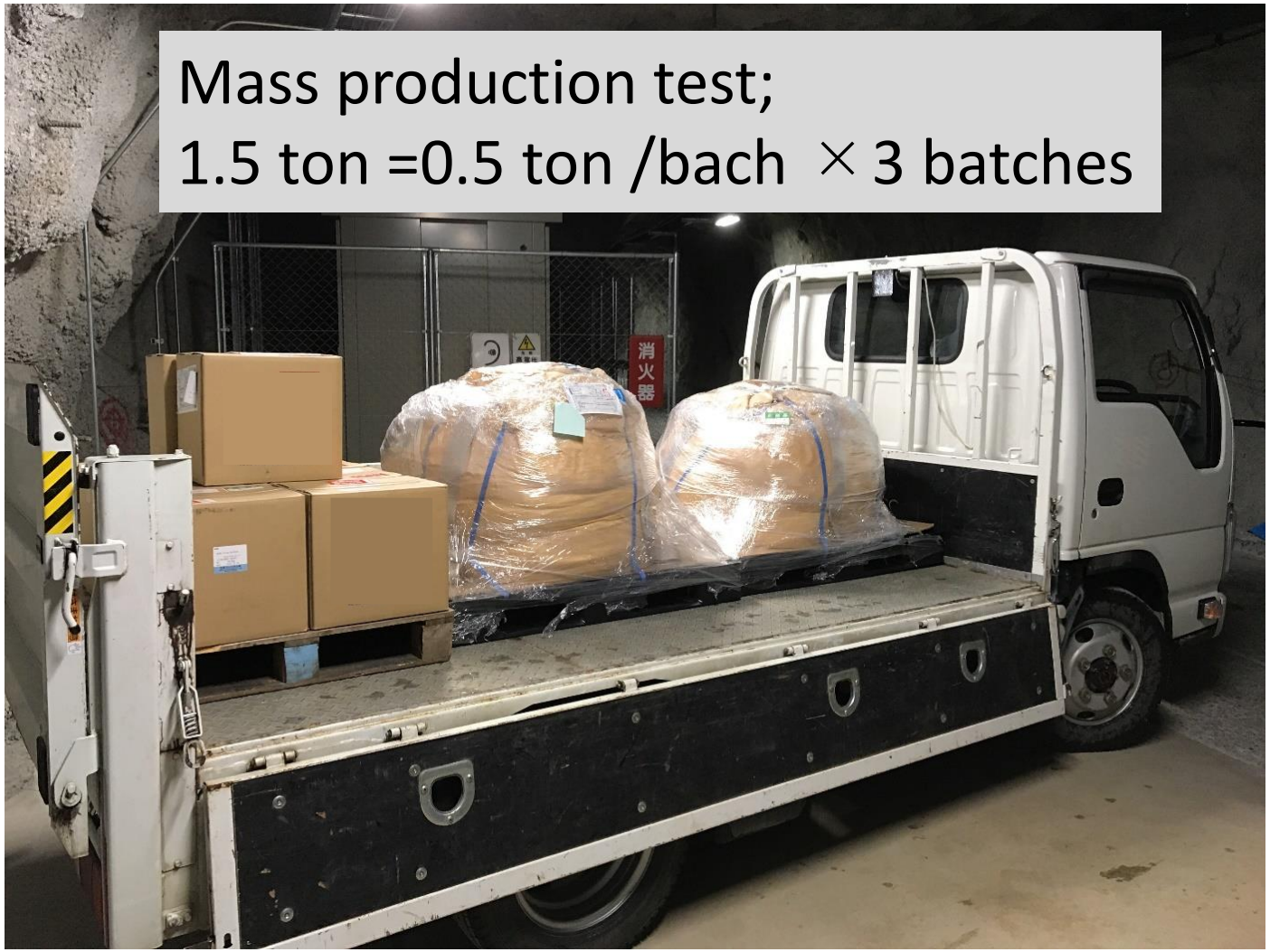
Chain	Isotope	Typical	Goal*	Company A		Company B		Company C	
				Ge	ICPMS	Ge	ICPMS	Ge	ICPMS
^{238}U	^{238}U	50	< 5	-	~ 0.04	< 11	< 0.04	< 10	< 0.04
	^{226}Ra	5	< 0.5	-	—	<0.2	—	< 0.2	—
^{232}Th	^{232}Th	100	< 0.05	-	~ 0.09		0.02	—	0.06
	^{228}Ra	10	< 0.05	-	—	< 0.3	—	< 0.2	—
	^{228}Th	100	< 0.05	-	—	< 0.3	—	< 0.3	—
^{235}U	^{235}U	30	< 3	-	—	< 0.4	—	< 0.3	—
	^{227}Ac/Th	300	< 3	-	—	< 1.7	—	< 1.2	—

Unit: [mBq/kg $(Gd_2SO_4)_3$ $8H_2O$]

Company B achieved goals for U, 226Ra and 232Th

First mass production of ultra high purity Gd sulfate

Kamioka mine @2018/12/21



Quality check at Kamioka

Goal (mBq/kg)		Bach 1	Bach 2	Batch 3
^{238}U < 5	ICPMS	< 0.02	0.02	0.04
	Ge	<9.45	<9.89	<28.4
^{232}Th< 0.05	ICPMS	0.04	0.02	0.04
	Ge	<0.20	<0.21	0.16
^{226}Ra< 0.5	Ge	0.46 ± 0.24	<0.33	<0.20

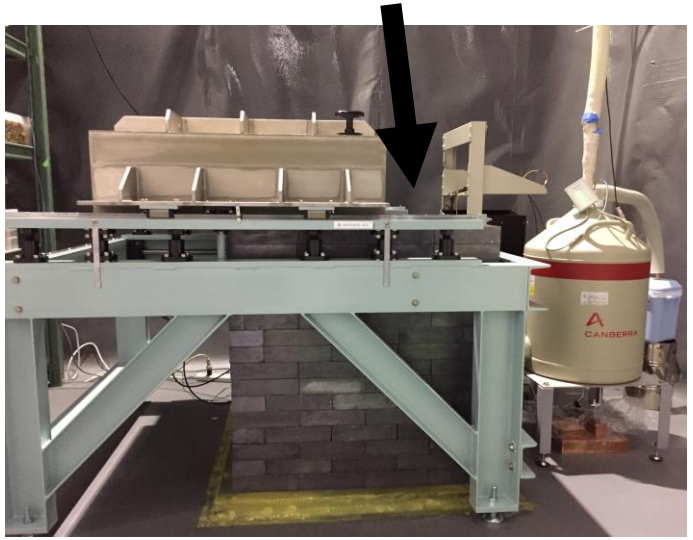
We confirmed ^{226}Ra is also less than our requirement.
Now, mass production for 14t of Gd sulfate is on going

- This is for the first loading to Super-K
- It comes with 28 batches.
- For each batch, we need to check its RI.

Ultra-Low Background HPGe in Kamioka

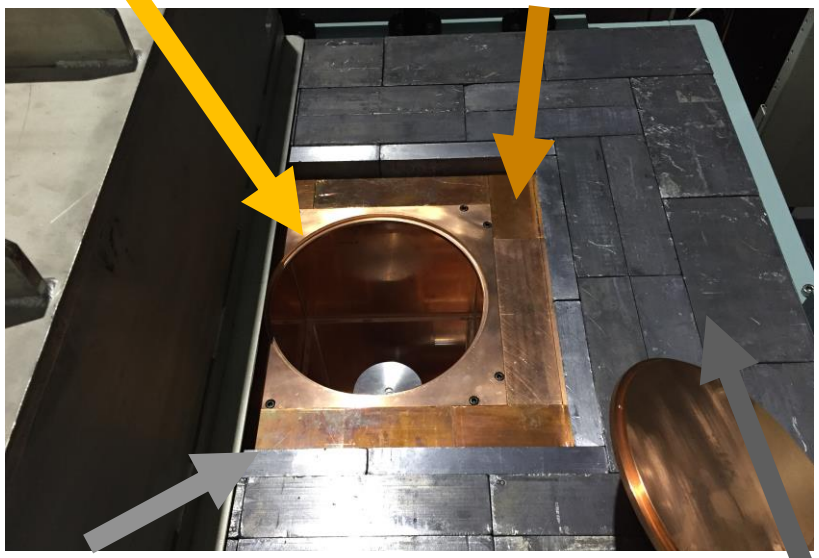
Slide from K.Ichimura

Total 21 lead layer
Top 4 layer : movable



HPGe : made by Canberra France,
80% relative efficiency

1 cm 6N grade Cu ,5 cm Cu



2.5 cm low Pb(~5 Bq/kg) lead

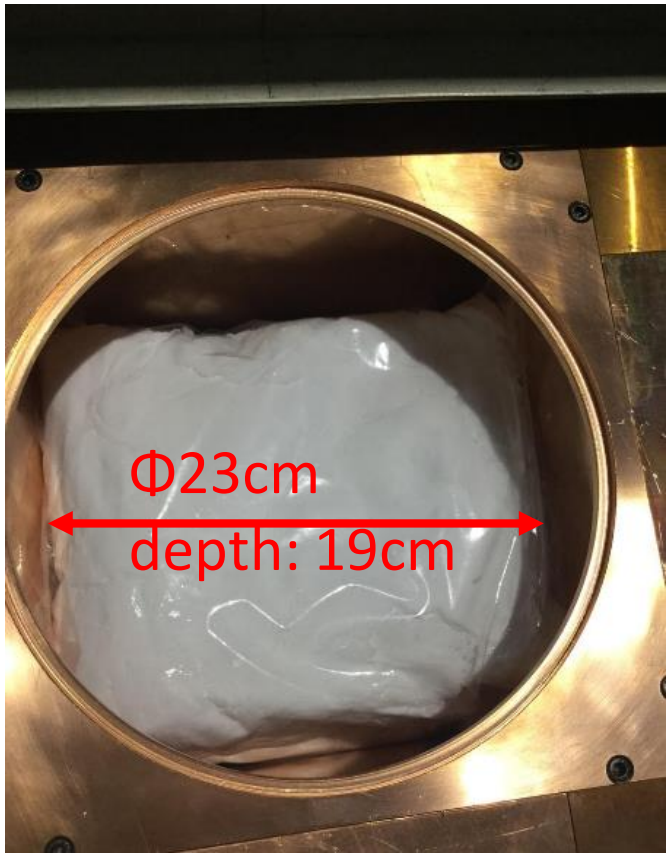
20 cm lead

BG level	Integral (60-2700 keV)	^{208}Tl 2614.5 keV	^{214}Bi 609.3 keV	^{60}Co 1332.5 keV	^{40}K 1460.8 keV
[cts/kg/day]	111.1	0.14	0.49	0.44	0.57

High sensitivity Ge in Kamioka

- High sensitivity measurement for clean Gd-sulfate
  - Sample amount : 8kg
  - Sensitivity for ^{226}Ra :

    < 0.4mBq/kg with 12 days



* Develop new ultra low RI HPGe detector by lowering RI in HPGe detector itself.

  Discussion with manufacture is ongoing

* Ra concentration by resin[1] is under development

[1]S.Ito et.al Prog.Theor.Exp.Phys.2018,091H01, pp.1-6,

Recently joined to SK-Gd; HPGe Detector Backgrounds at Boulby

Slide from M.Thiesse

Detector Name	Volume [cm3]	Mass [kg]	FWHM @1332 keV [keV]	Integral (60-2700) keV [cts/kg/day]	Tl-208 2614 keV [cts/kg/day]	Bi-214 609 keV [cts/kg/day]	Co-60 1332 keV [cts/kg/day]	K-40 1460 keV [cts/kg/day]
Belmont	600	3.2	1.92	150.0	0.3	1.8	1.1	0.9
Roseberry	170	0.9	1.58	253.9	0.1	2.9	0.4	0.8
Merrybent	375	2.0	1.87	255.5	0.4	7.1	1.0	1.3
Chaloner	150	0.8	1.56	1194.0	1.1	12.7	2.0	12.7
Lumpsey*	263	1.4	1.66	4416.2	12.4	64.3	1.6	7.4
Lunehead	375	2.0	1.86	674.6	2.8	8.5	2.0	8.8
Wilton**	131	0.4	1.88					

* Temporarily out of service for refurbishment to S-ULB standard.

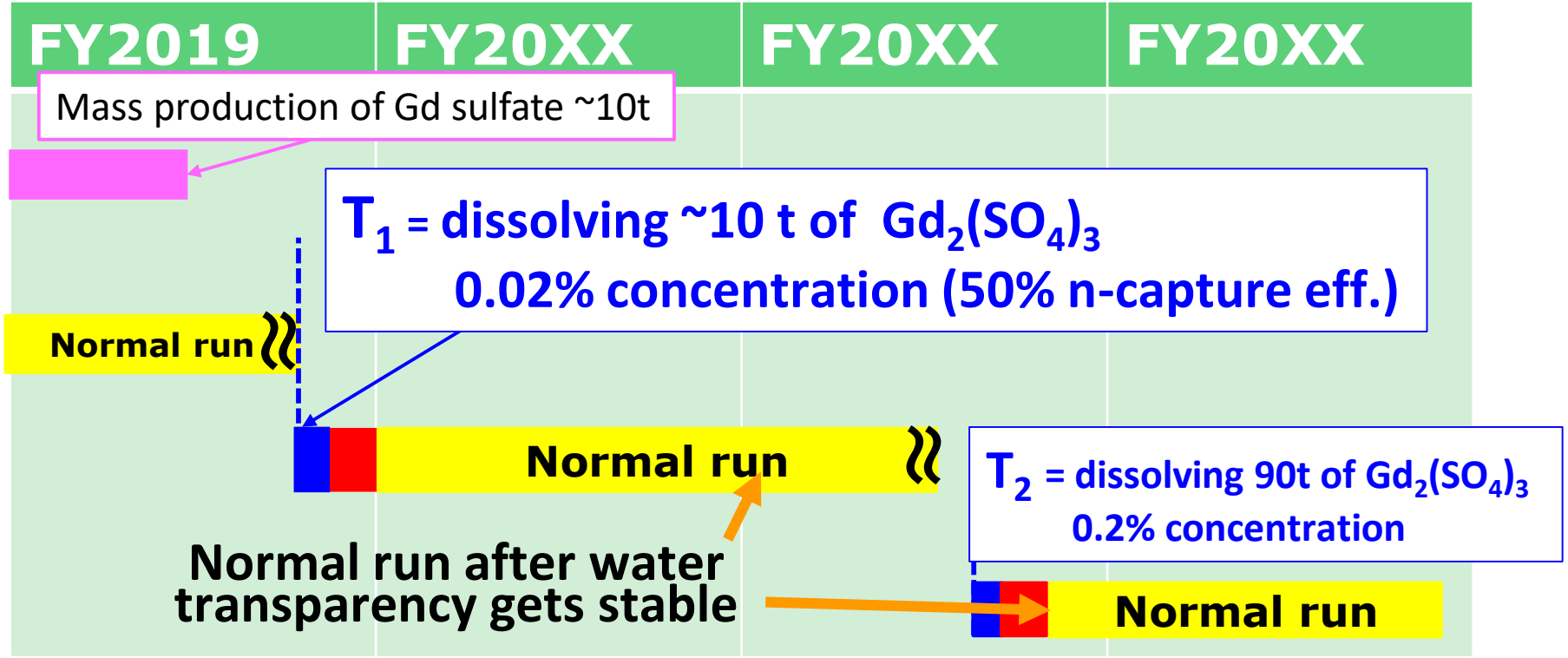
** For pre-screening. Not normally used for material assay.

See Paul's talk for more detail

Dedicated Rn removal system installation in progress. Backgrounds of Bi-214 expected to significantly reduce in very near future.

Schedule of SK-Gd

- Tank open work in Jul.2018-Jan.2019 was successful!
- Detailed schedule planning is on-going taking into account T2K beam availability.
- Earliest possible Gd in SK would be in late FY 2019.



Summary

- SK-Gd will enhance physics sensitivities for Super-K
  - Main target; 3σ discovery of SRN neutrinos with 10 years observation.
- Radio impurities in Gd sulfate powder
  - We achieved our goal, and R&D of clean Gd-sulfate was completed.
  - Now, the mass production for the first loading (14 tons) is on going.
  - Thanks to all efforts on Ge detectors in LSC, Boulby, and Kamioka, we are now ready to check all the samples from the mass production.
- Schedule
  - The first loading to get 50% neutron capture efficiency will be done within this FY2019.
    - Detail schedule will be made with T2K