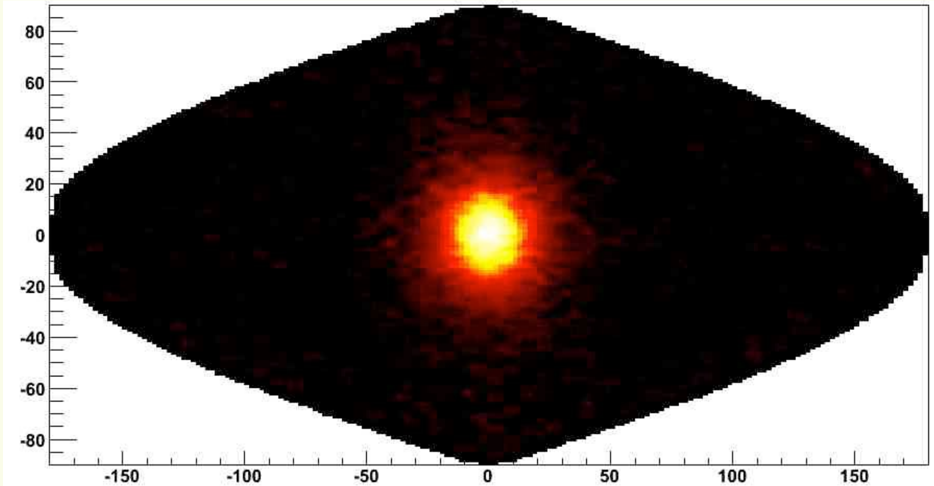
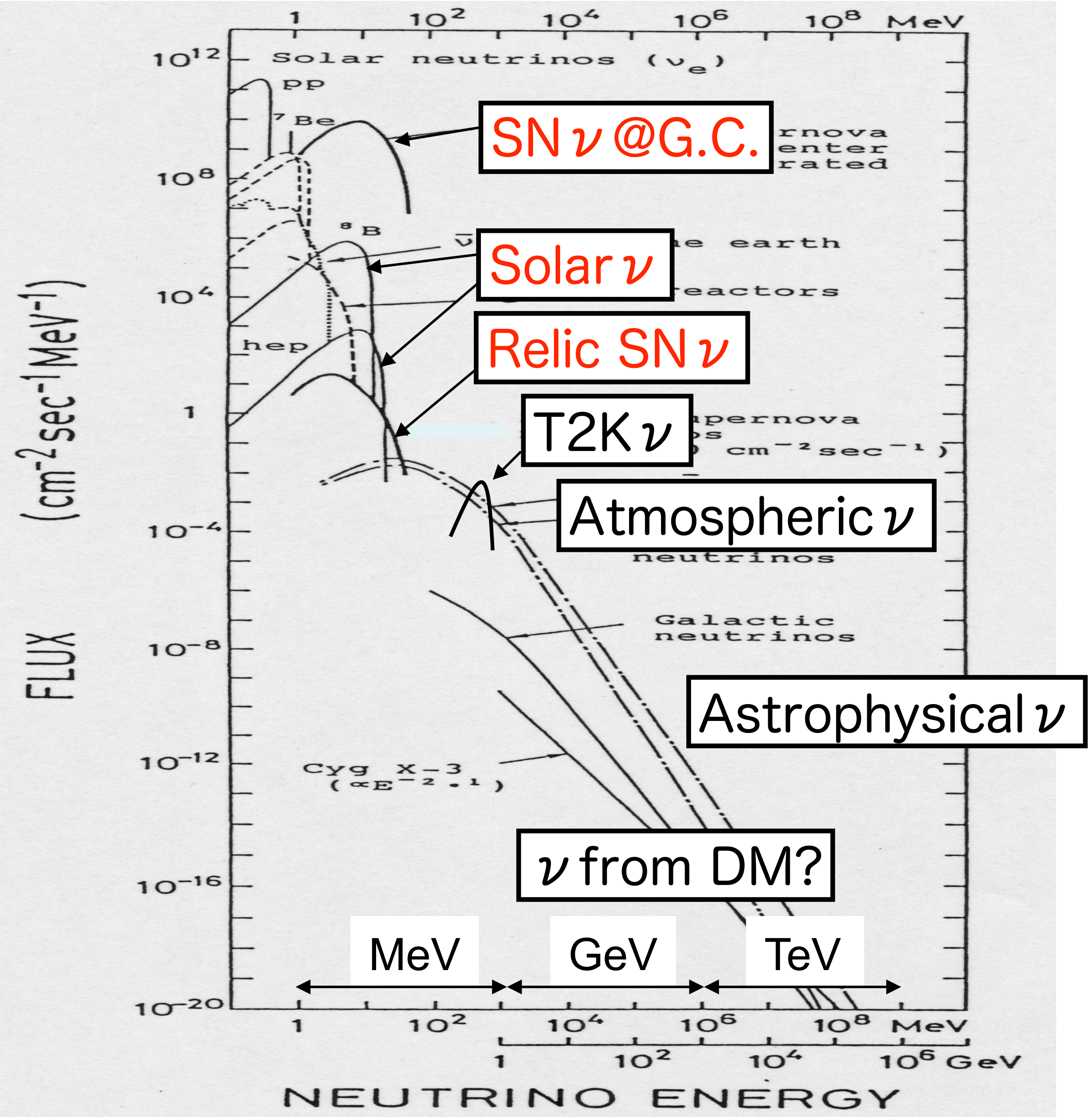
Low energy ν physics with Hyper-K



Yusuke Koshio (Okayama U.)

Workshop for Neutrino Programs with facilities in Japan @J-PARC on 6th Aug., 2015

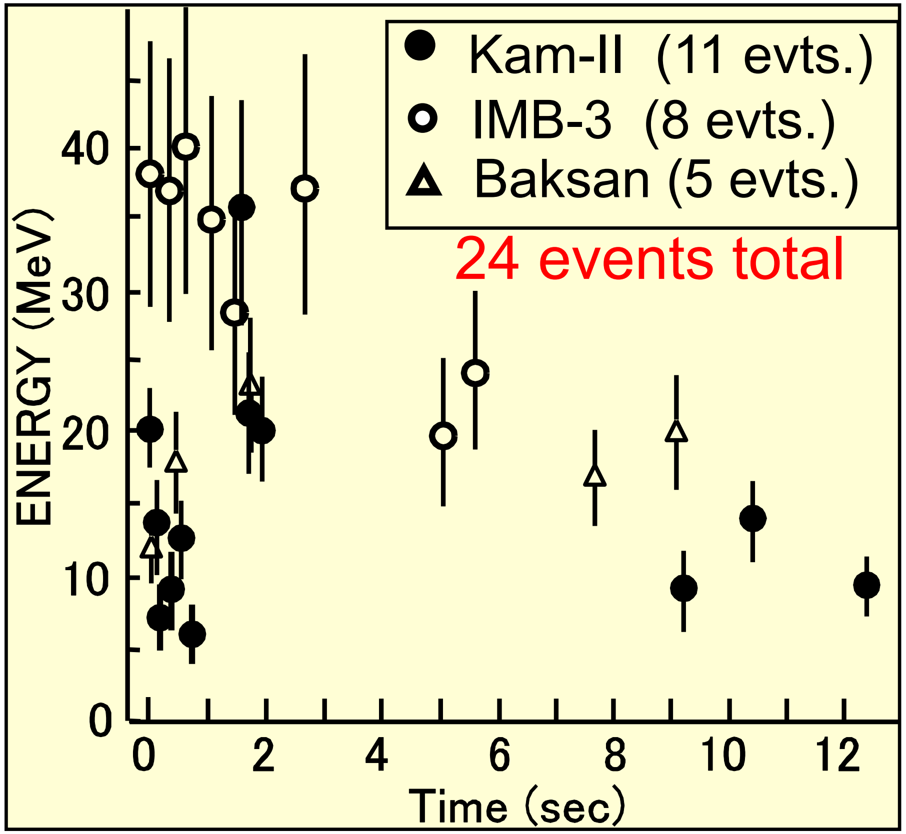
Neutrino sources



Supernova neutrino

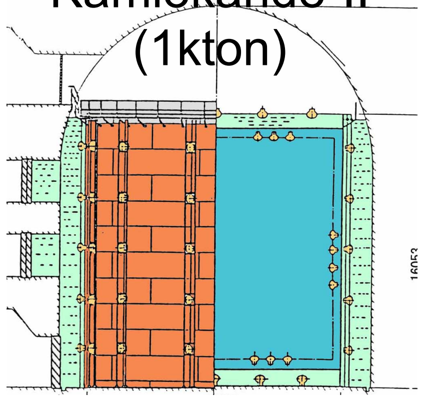
Supernova 1987A

23rd Feb. 1987, 7:35 (UT), @50kpc

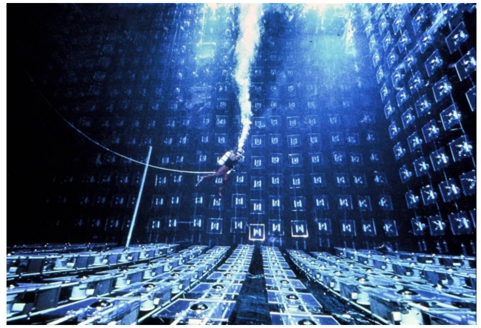


Water Cherenkov

Kamiokande-II
(1kton)

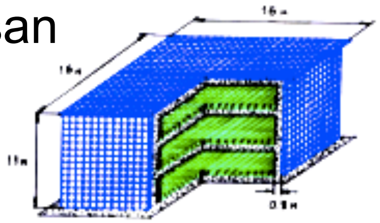


IMB-3 (8kton)



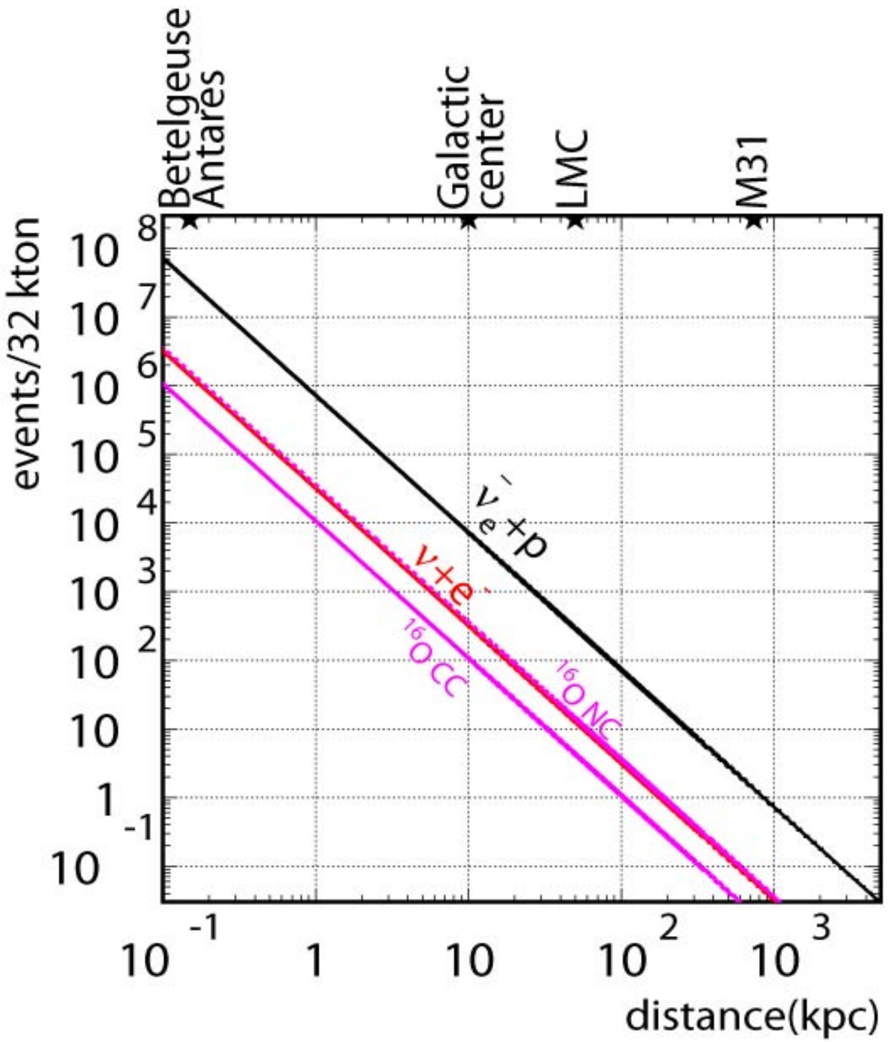
Liquid Scintillator

Baksan

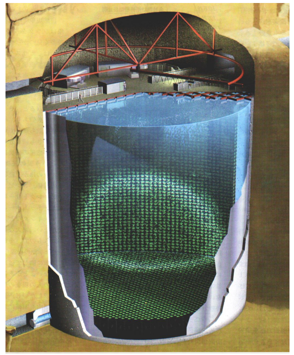


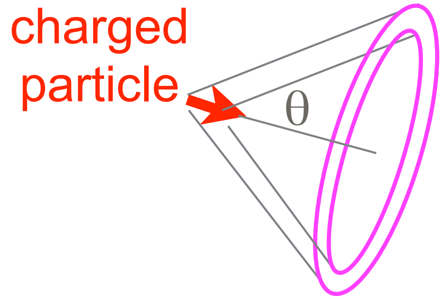
If it happens now?

Super-Kamiokande



50kton Water Cherenkov detector





<u>Expected number of event</u>

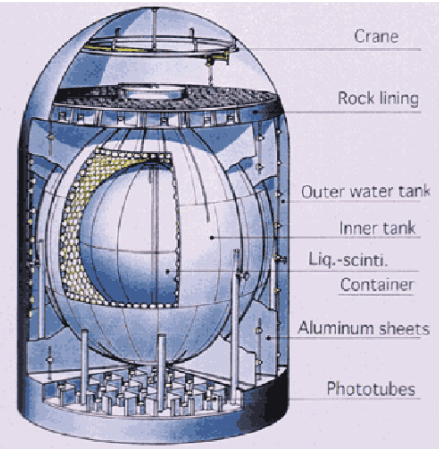
~7300 ev (inverse beta decay)
~100 ev (^{16}O CC)
~300 ev (νe elastic scattering)
~360 ev (^{16}O NC γ)

at 10kpc, 4.5MeV energy threshold

Livermore simulation
Totani, Sato, Dalhed, Wilson, ApJ. 496 (1998) 216

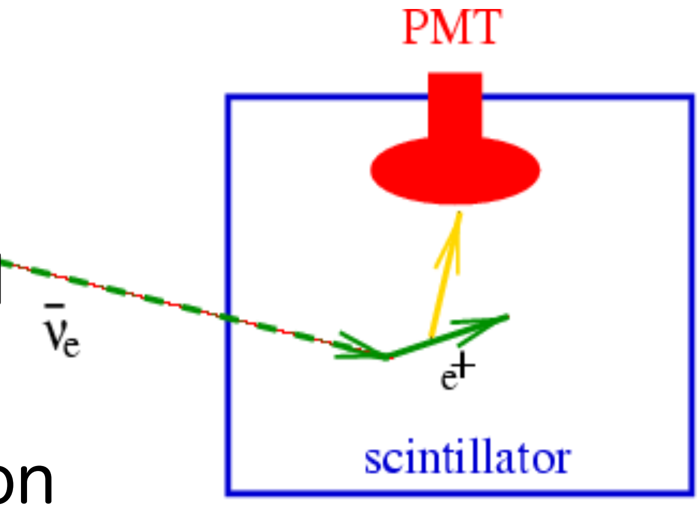
KamLAND

1000 ton Liquid scintillator



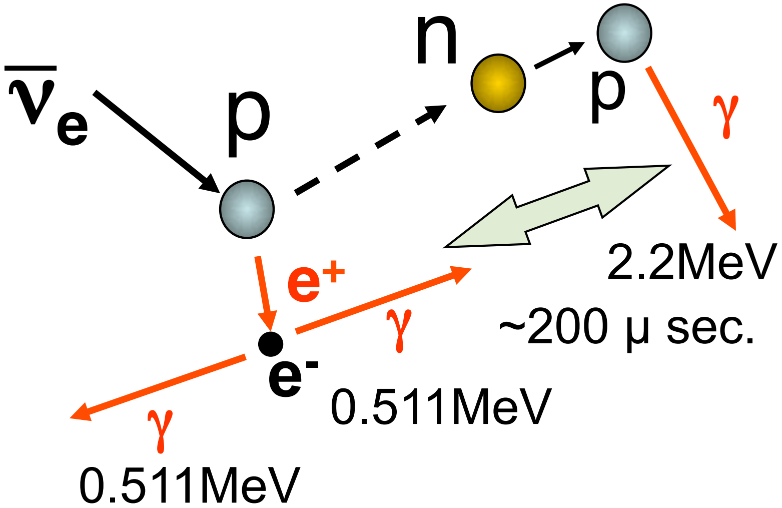
- ✓ Large volume
- ✓ Low energy threshold
- ✓ Good $\overline{\nu}_e$ sensitive
- ✓ Good energy resolution

$$7.25\%/\sqrt{E/(MeV)}$$



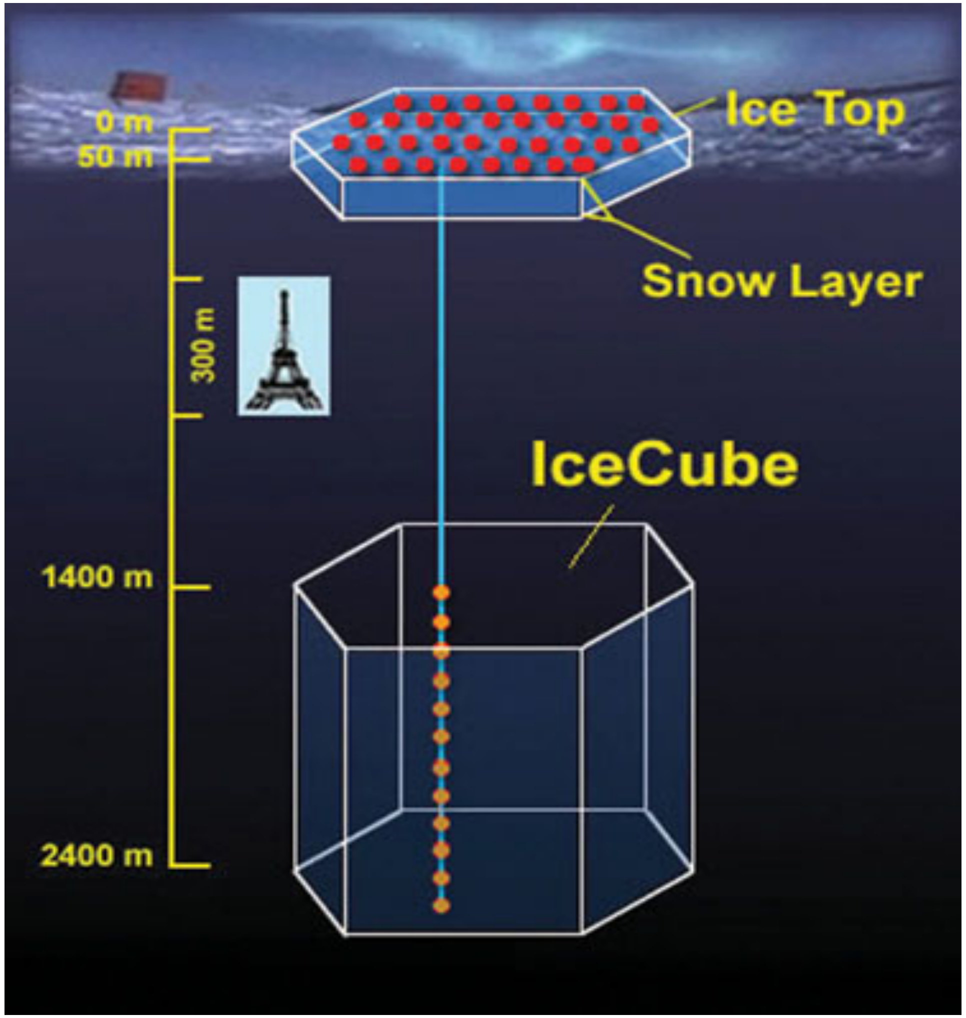
<u>Expected number of event at 10kpc</u>

~300 ev (inverse beta decay)
~60 ev (^{12}C CC)
~20 ev (νe elastic scattering)
~300 ev (ν+p→ν+p)

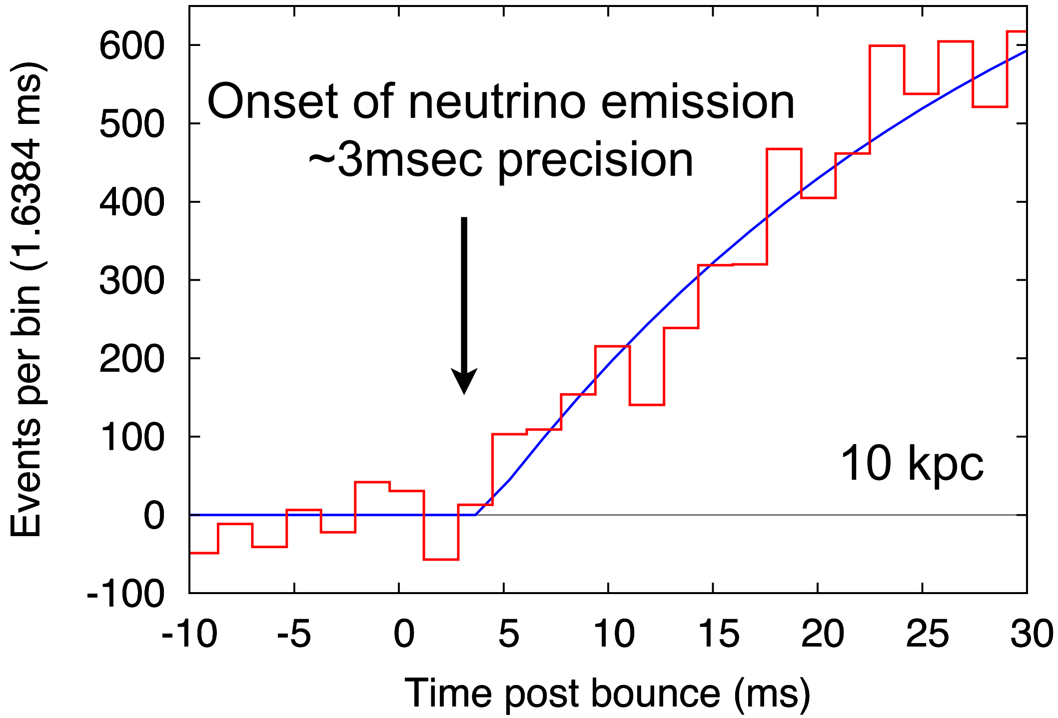


IceCUBE

Giga-ton detector



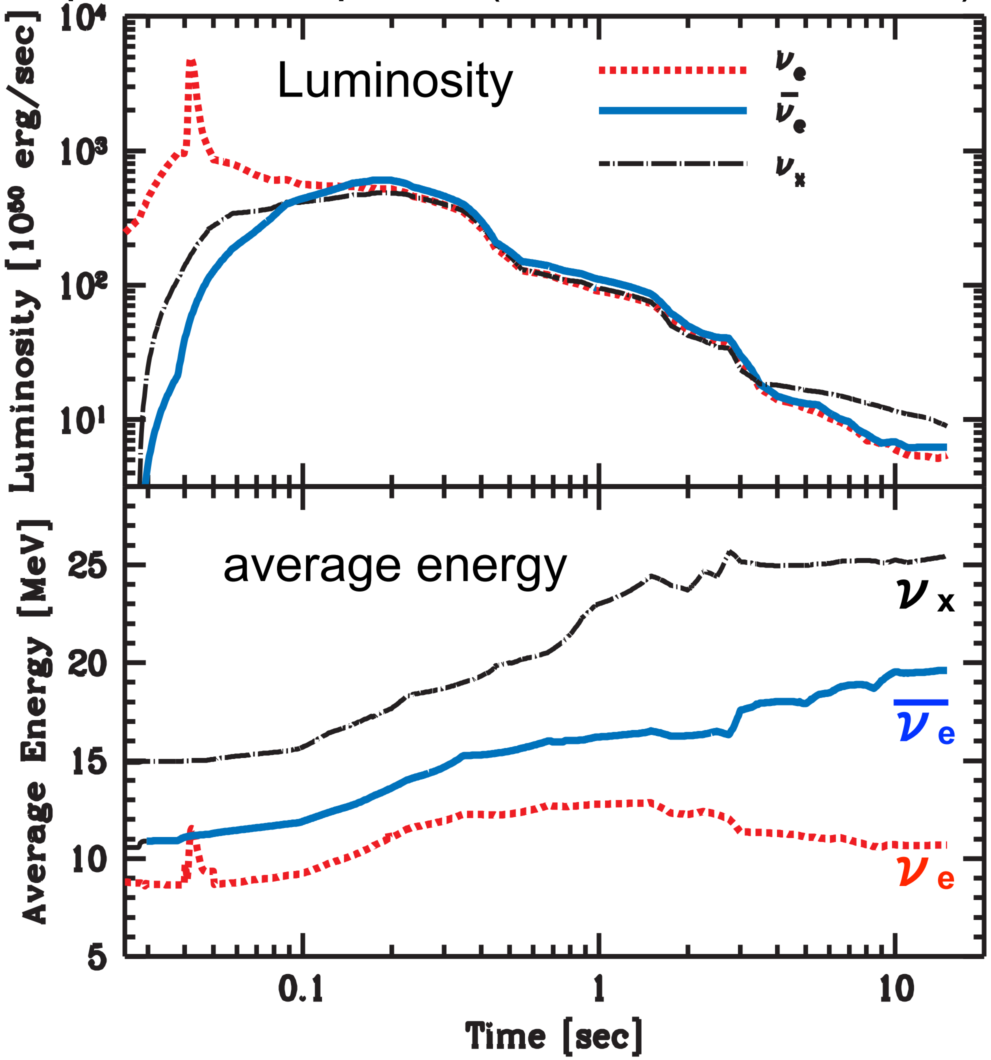
Precise measurement of the arrival time by dark rate rising



Halzen, Raffelt : arXiv : 0908.2317

Physics motivation

Expected time profile (Livermore simulation)



What we can learn

✓Core collapse physics
- explosion mechanism
- proto-neutron star cooling
- black hole formation

✓Multi-messenger analysis
- with gravitational wave, gamma-ray, X-ray, telescope..

✓Neutrino physics
- neutrino oscillation

Measurements of neutrino flavor, energy, time profile are the key points

How often in our Galaxy?

Star Formation Rate (SFR) and Supernova Rate (SNR) Estimates for the Galaxy

Diehl et. al. 0601015

Authors	SFR [$M_\odot y^{-1}$]	SNR [$century^{-1}$]	Comments
Smith et al. 1978	**5.3**	2.7	
Talbot 1980	**0.8**	0.41	
Guesten et al. 1982	**13.0**	6.6	
Turner 1984	**3.0**	1.53	
Mezger 1987	**5.1**	2.6	
McKee 1989	**3.6** (R) **2.4** (IR)	1.84 1.22	
van den Bergh 1990	2.9 ± 1.5	**1.5 ± 0.8**	„the best estimate“
van den Bergh & Tammann 1991	7.8	**4**	extragalactic scaling
Radio Supernova Remnants	6.5 ± 3.9	**3.3 ± 2.0**	very unreliable
Historic Supernova Record	11.4 ± 4.7	**5.8 ± 2.4**	very unreliable
Cappellaro et al. 1993	2.7 ± 1.7	**1.4 ± 0.9**	extragalactic scaling
van den Bergh & McClure 1994	4.9 ± 1.7	**2.5 ± 0.9**	extragalactic scaling
Pagel 1994	**6.0**	3.1	
McKee & Williams 1997	**4.0**	2.0	used for calibration
Timmes, Diehl, Hartmann 1997	5.1 ± 4	**2.6 ± 2.0**	based on ^{26}Al method
Stahler & Palla 2004	**4 ± 2**	2 ± 1	Textbook
Reed 2005	2-4	**1-2**	
Diehl et al. 2005	3.8 ± 2.2	**1.9 ± 1.1**	this work

Table 1: *Star formation and core-collapse supernova rates from different methods.*

Generally a few per century.

Latest estimate of galactic core-collapse supernova rate is $3.2^{+7.3}_{-2.6}$ per century.

Adams et. al. 1306.0559

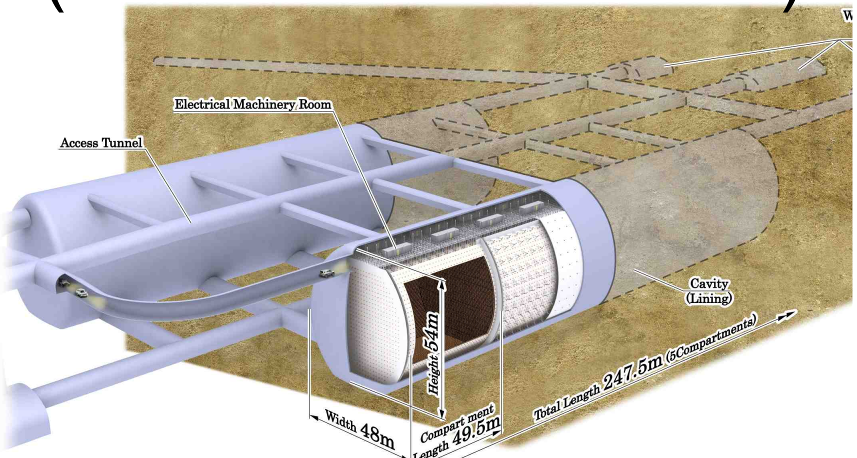
31.25 years per SN

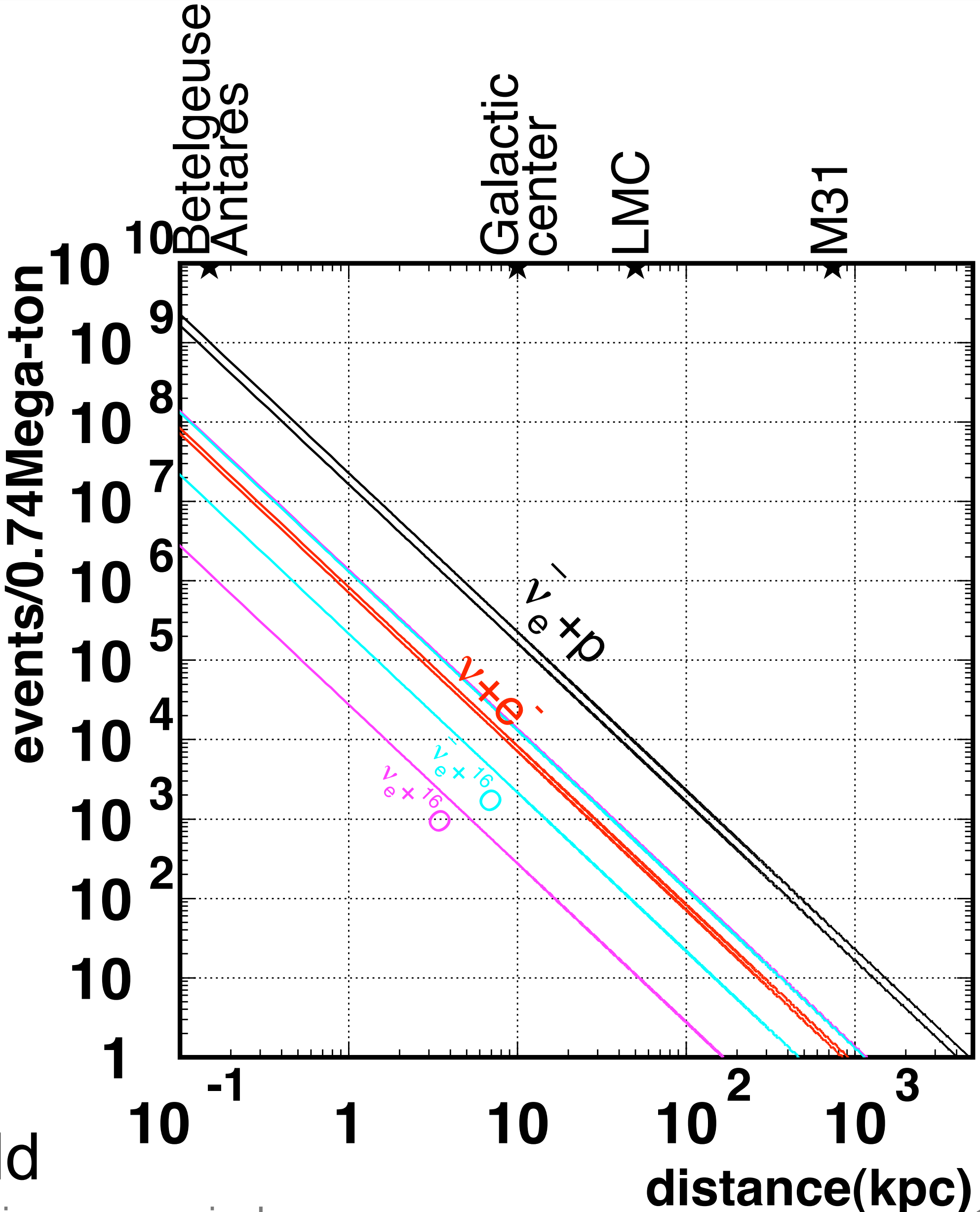
cf. 28.45 years since SN1987A

Hyper-Kamiokande

Hyper-Kamiokande

Water Cherenkov detector (Full volume 0.74Mton)





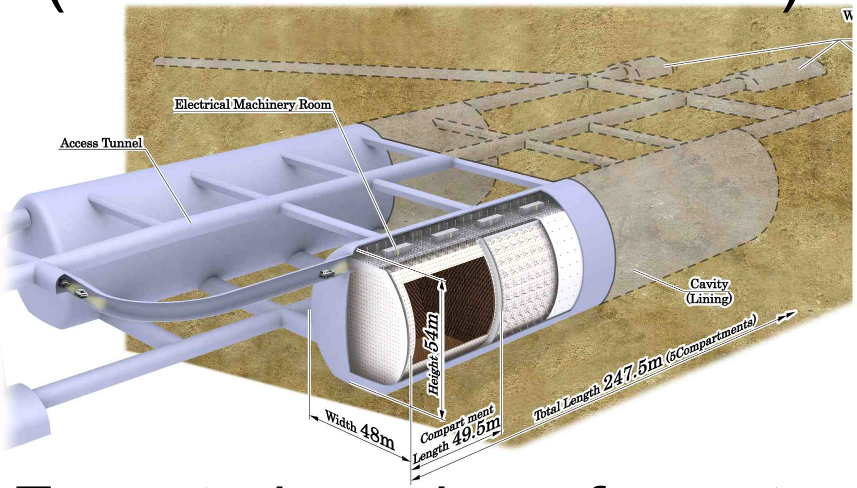
Expected number of event

~168000 ev ($\overline{\nu_e}$ IBD)
~2300 ev (^{16}O CC)
~7000 ev (ν-e es)
~8300 ev (^{16}O NC γ)

at 10kpc, 4.5MeV energy threshold

Hyper-Kamiokande

Water Cherenkov detector
(Full volume 0.74Mton)

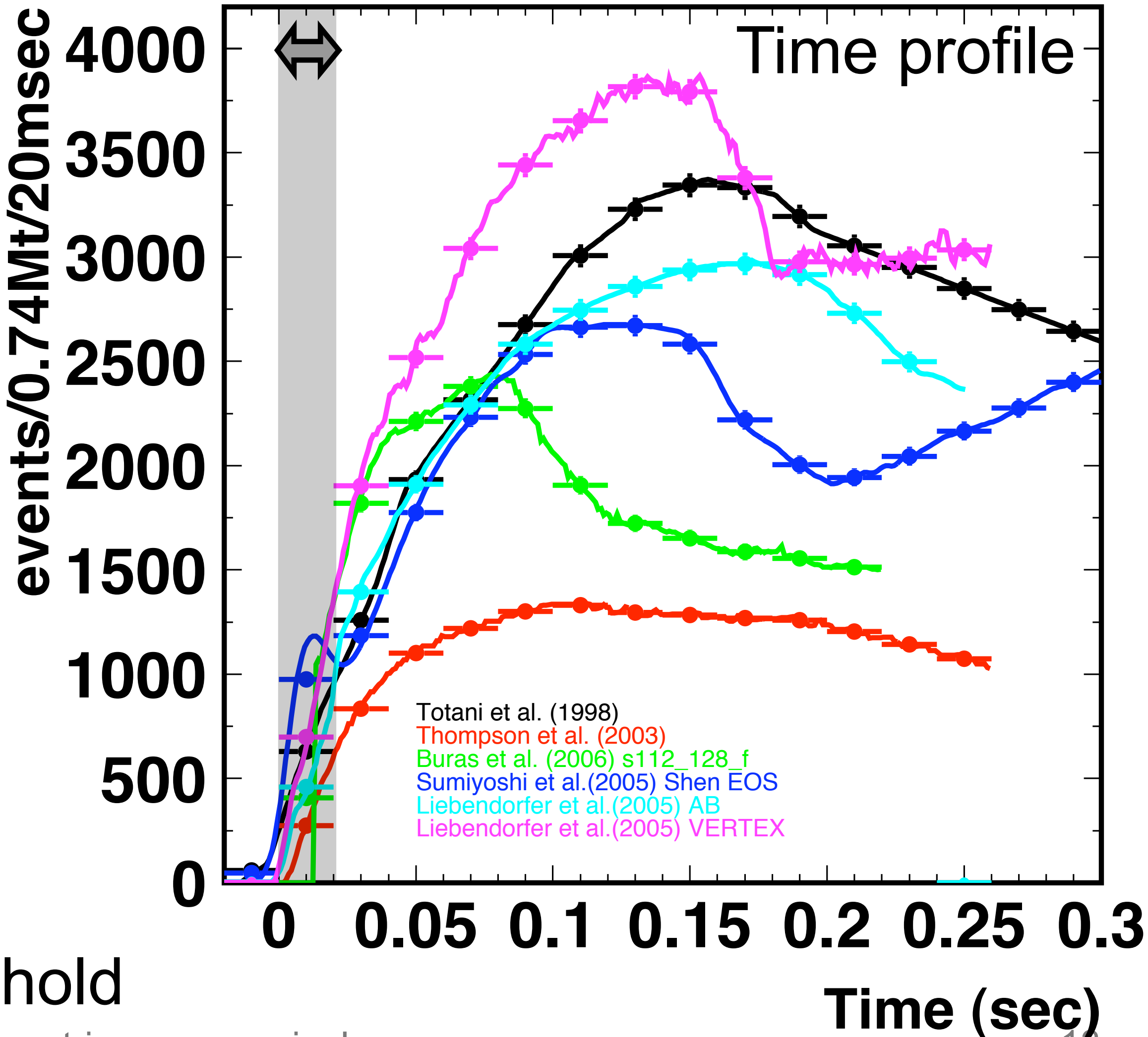


Expected number of event

~168000 ev ($\overline{\nu}_e$ IBD)
~2300 ev (^{16}O CC)
~7000 ev (ν-e es)
~8300 ev (^{16}O NC γ)

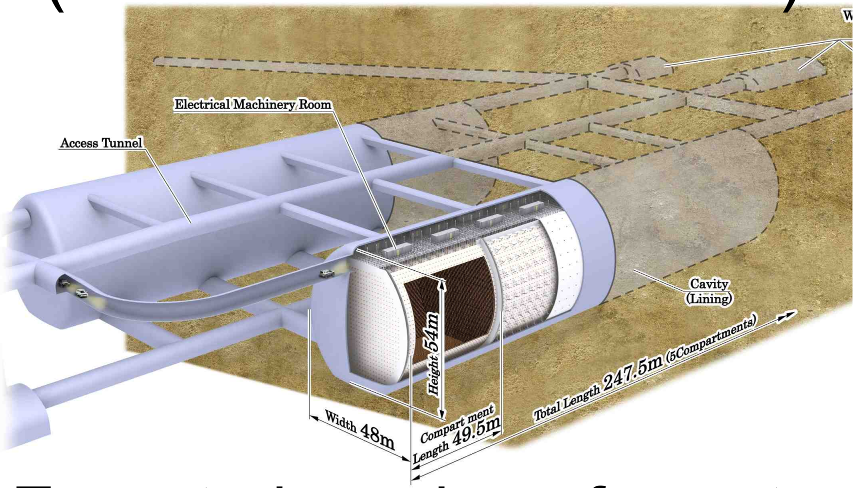
at 10kpc, 4.5MeV energy threshold

Determine starting time
with ~0.03 msec precision.



Hyper-Kamiokande

Water Cherenkov detector
(Full volume 0.74Mton)



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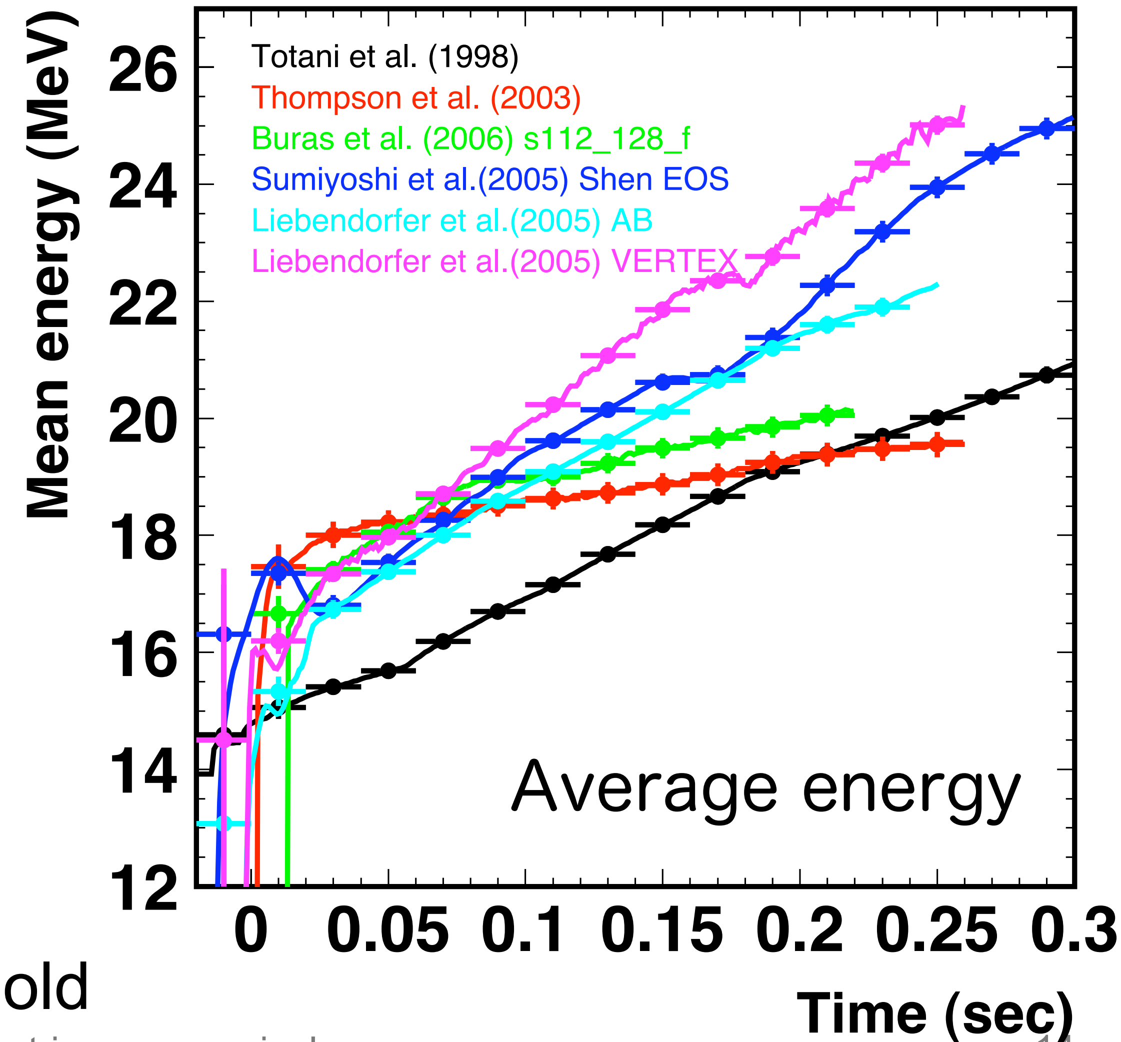
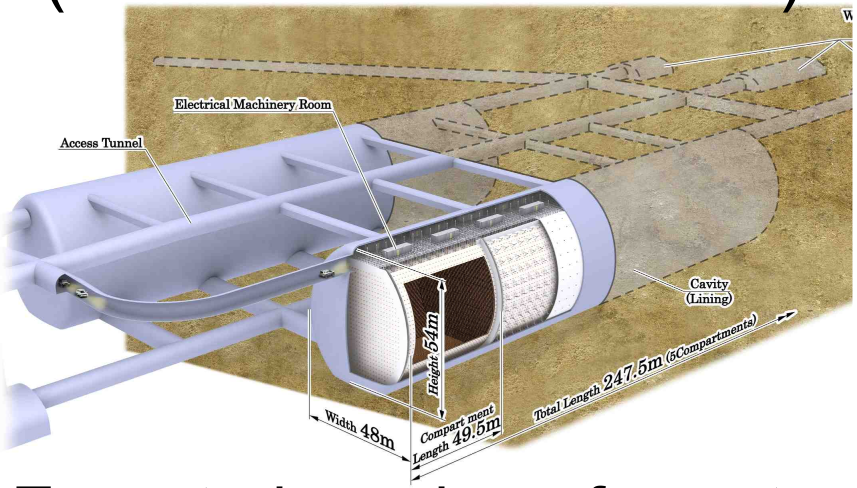
at 10kpc, 4.5MeV energy threshold

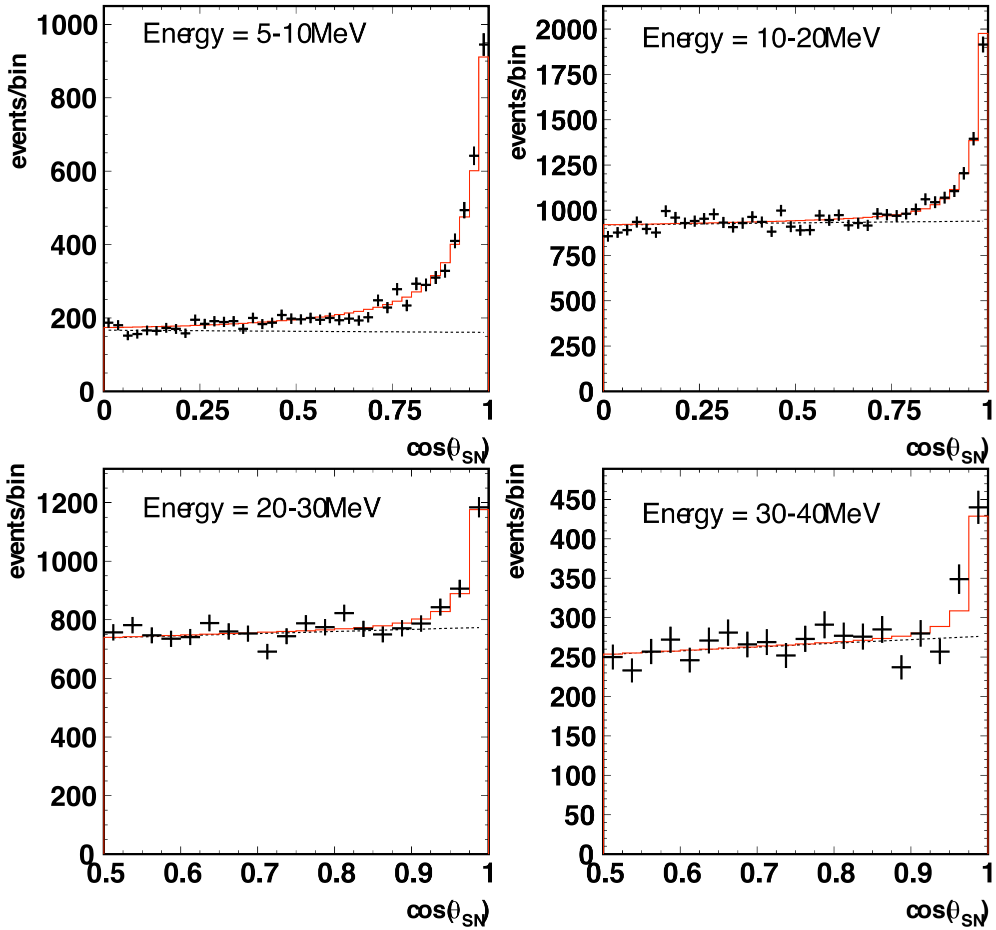


Hyper-Kamiokande

Water Cherenkov detector
(Full volume 0.74Mton)



Angular distribution



<u>Expected number of event</u>

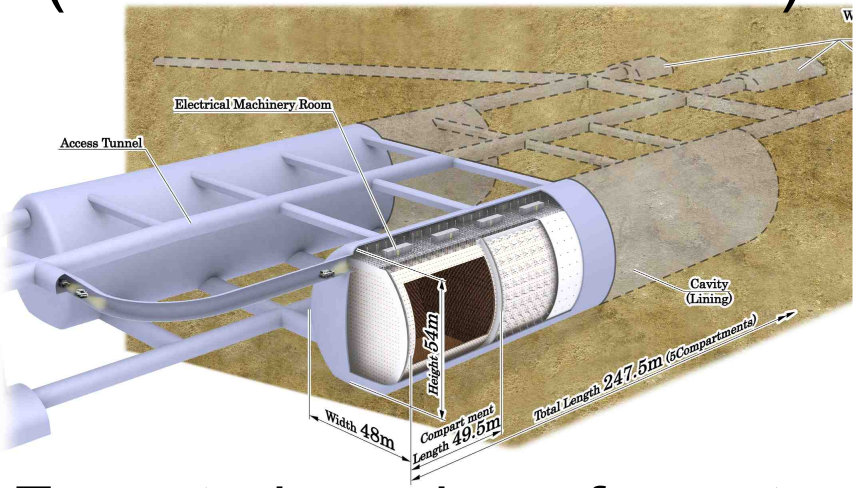
~168000 ev ($\overline{\nu}_e$ IBD)
~2300 ev (^{16}O CC)
~7000 ev (ν-e es)
~8300 ev (^{16}O NC γ)

Angular determination (~2°)

at 10kpc, 4.5MeV energy threshold

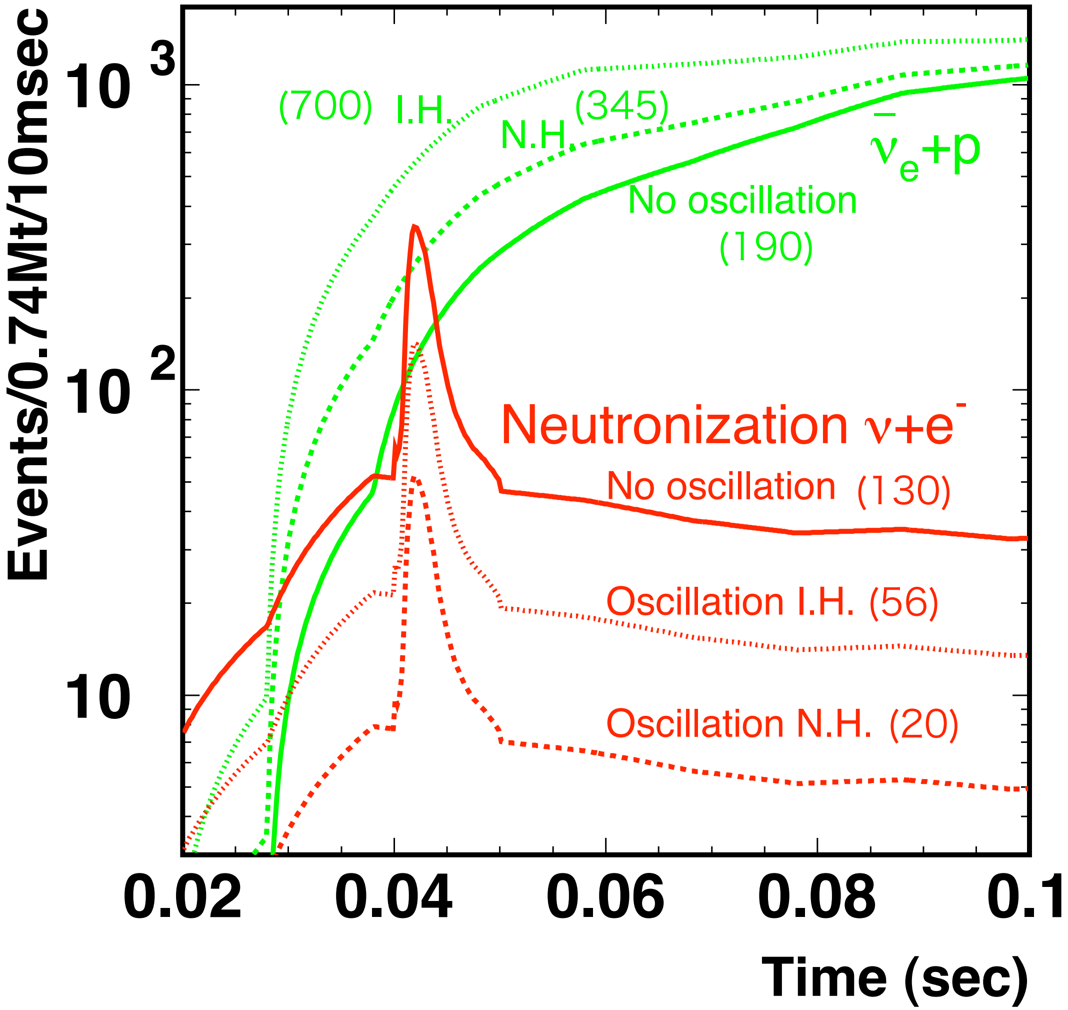
Hyper-Kamiokande

Water Cherenkov detector
(Full volume 0.74Mton)



Expected number of event

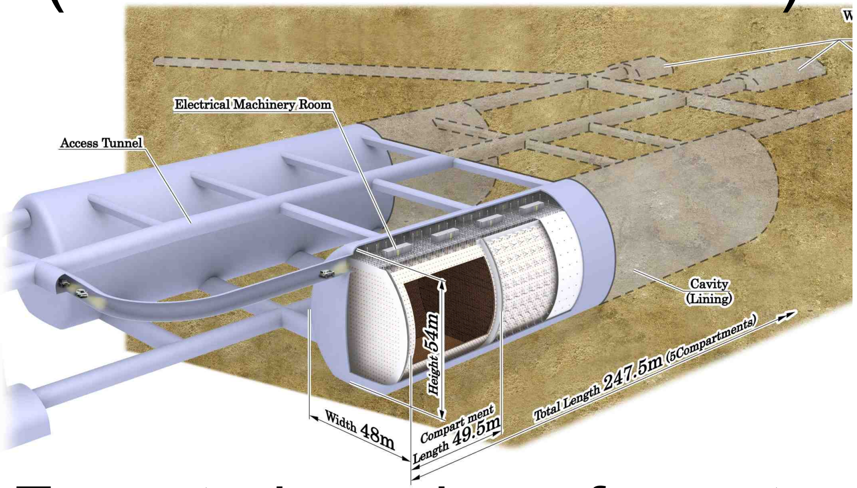
~168000 ev ($\overline{\nu}_e$ IBD)
~2300 ev (^{16}O CC)
~7000 ev (ν-e es)
~8300 ev (^{16}O NC γ)



at 10kpc, 4.5MeV energy threshold

Hyper-Kamiokande

Water Cherenkov detector
(Full volume 0.74Mton)



<u>Expected number of event</u>

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~2300 ev (^{16}O CC)
~7000 ev (ν-e es)
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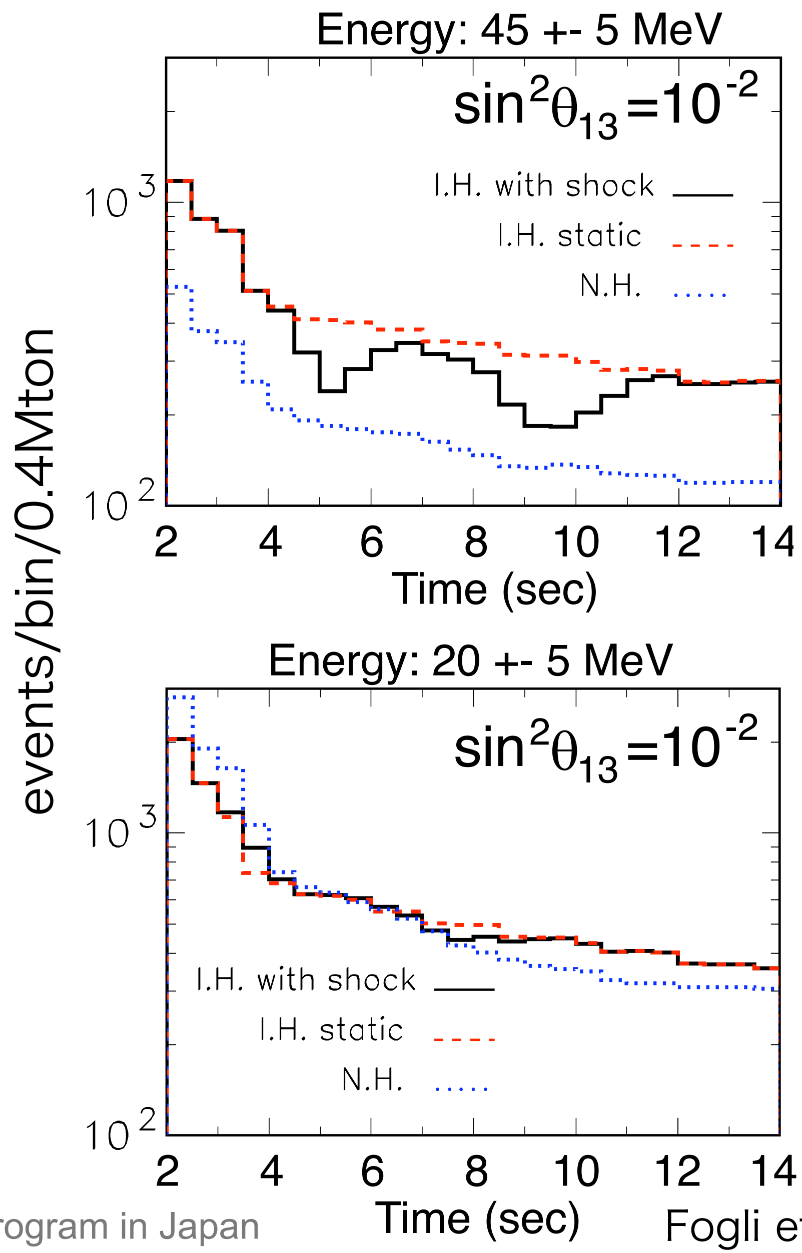
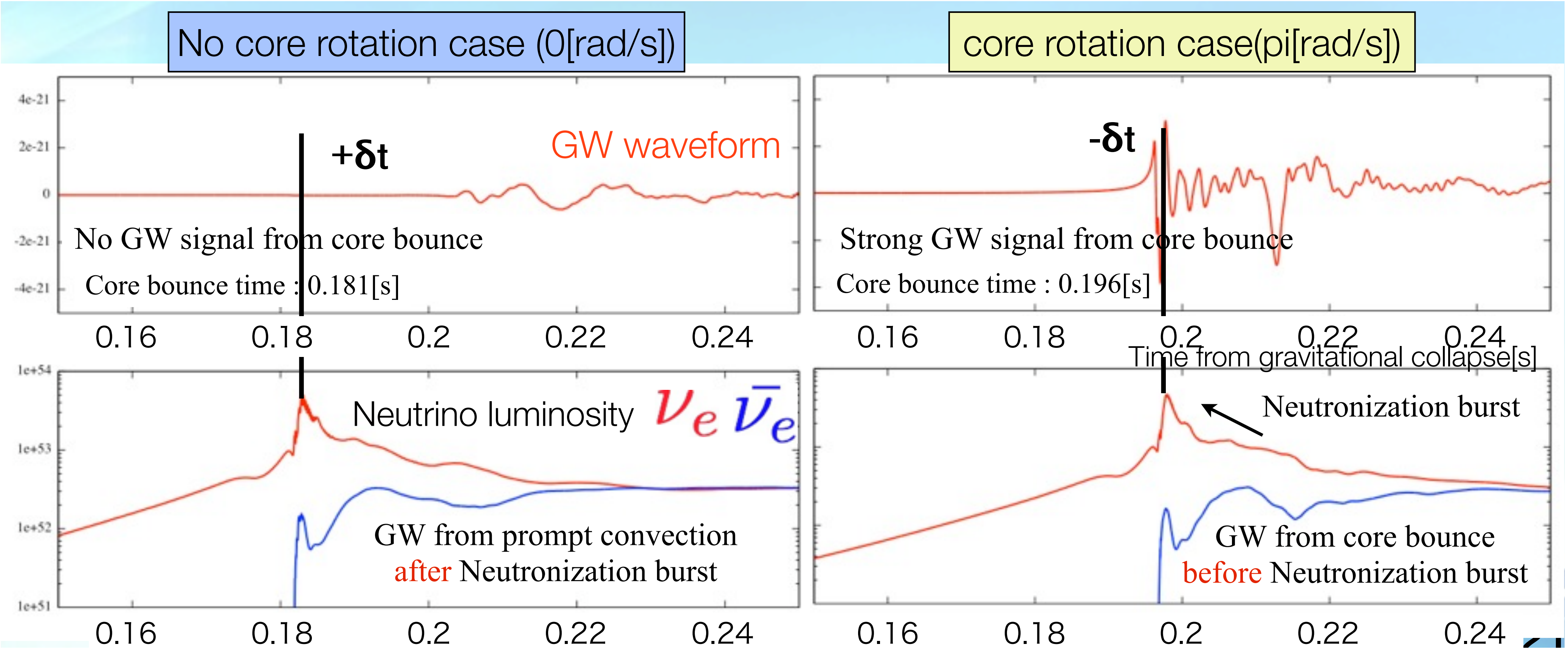
at 10kpc, 4.5MeV energy threshold



Fogli et. al.

Neutrino and gravitational wave

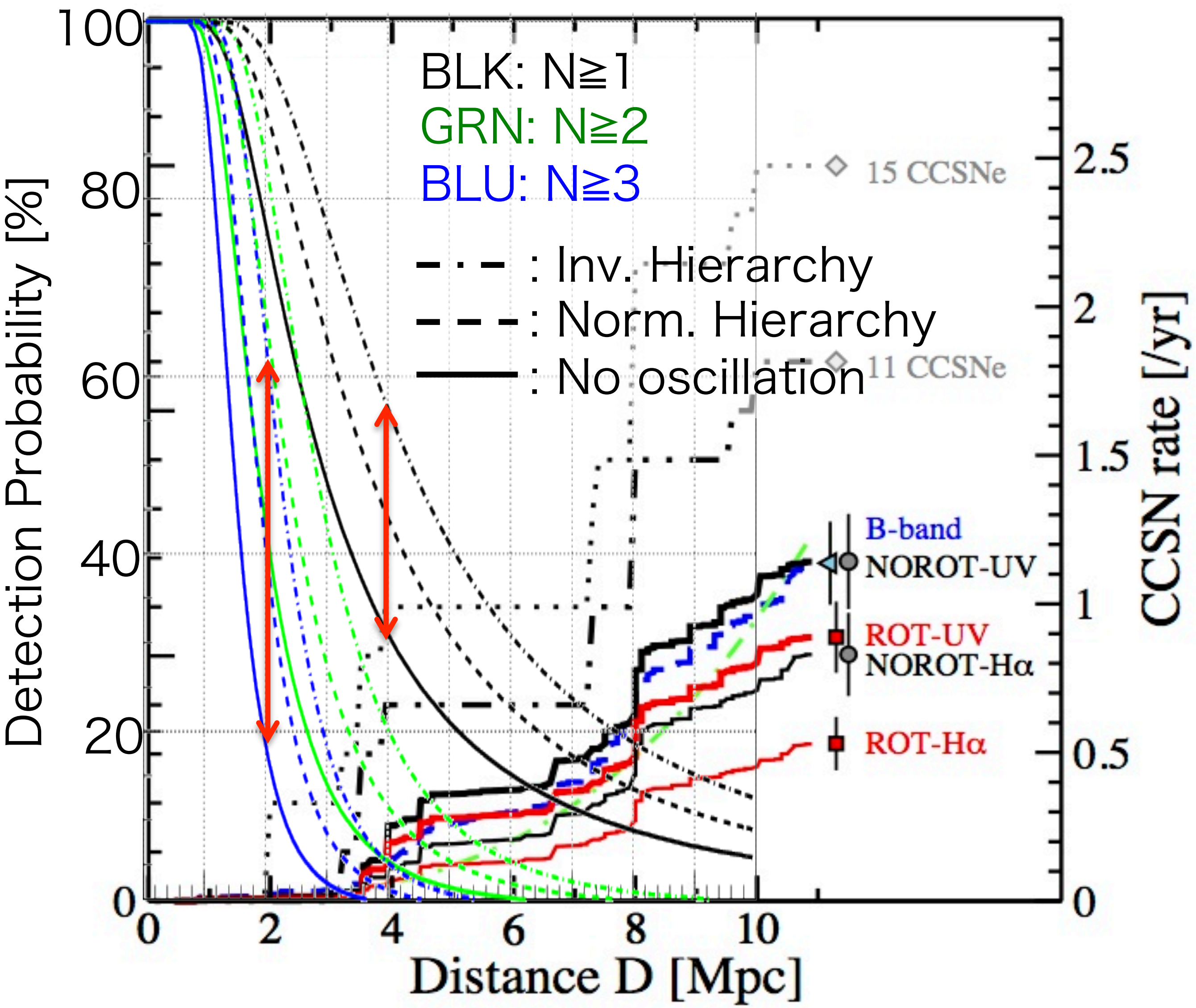


- Both detectors placed in the same mountain is good for the time domain multi-messenger astronomy.
- Realistic detector simulation showed the potential to estimate the progenitor core rotation.

T.Yokozawa's et.al.
arXiv 1410:2050

Nearby Galaxy

SN Distance vs Detection Probability with N Hit Threshold



For SN at 2 Mpc, we will detect N≧3 events at 20-65% probability.

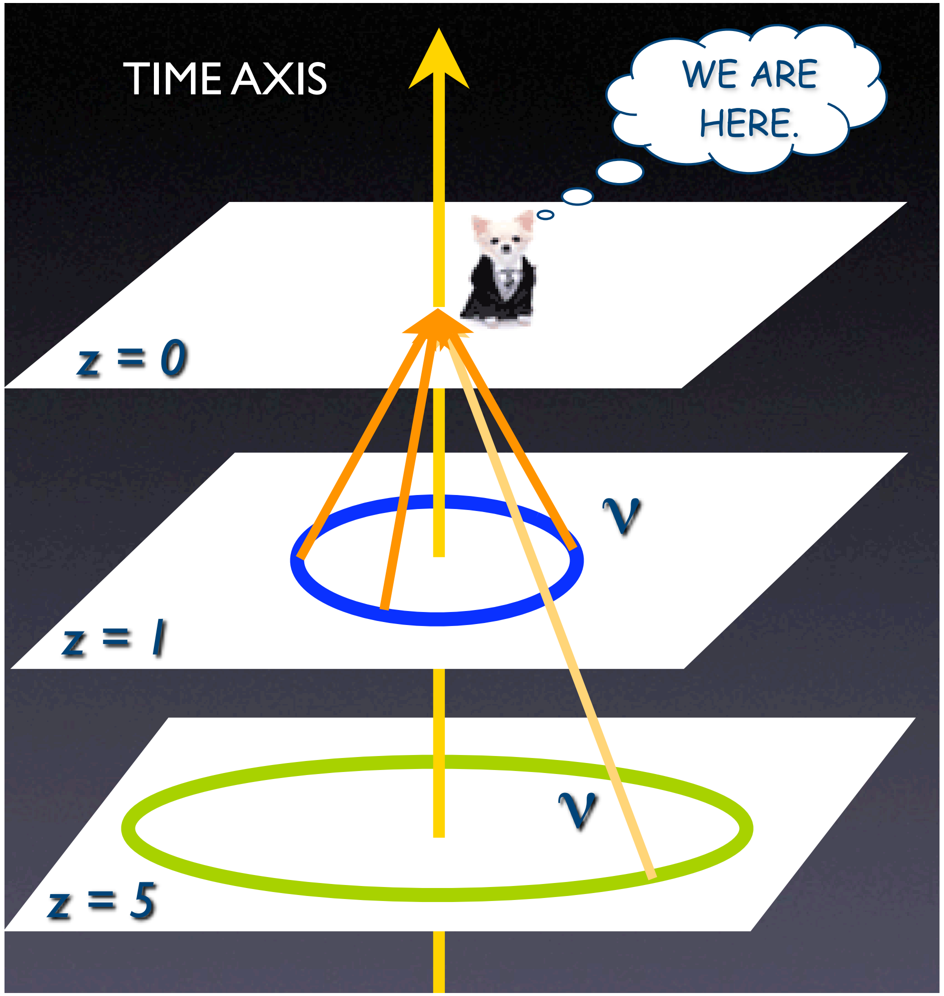
For SN at 4Mpc, N≧1 events are expected at 31-56% probability.

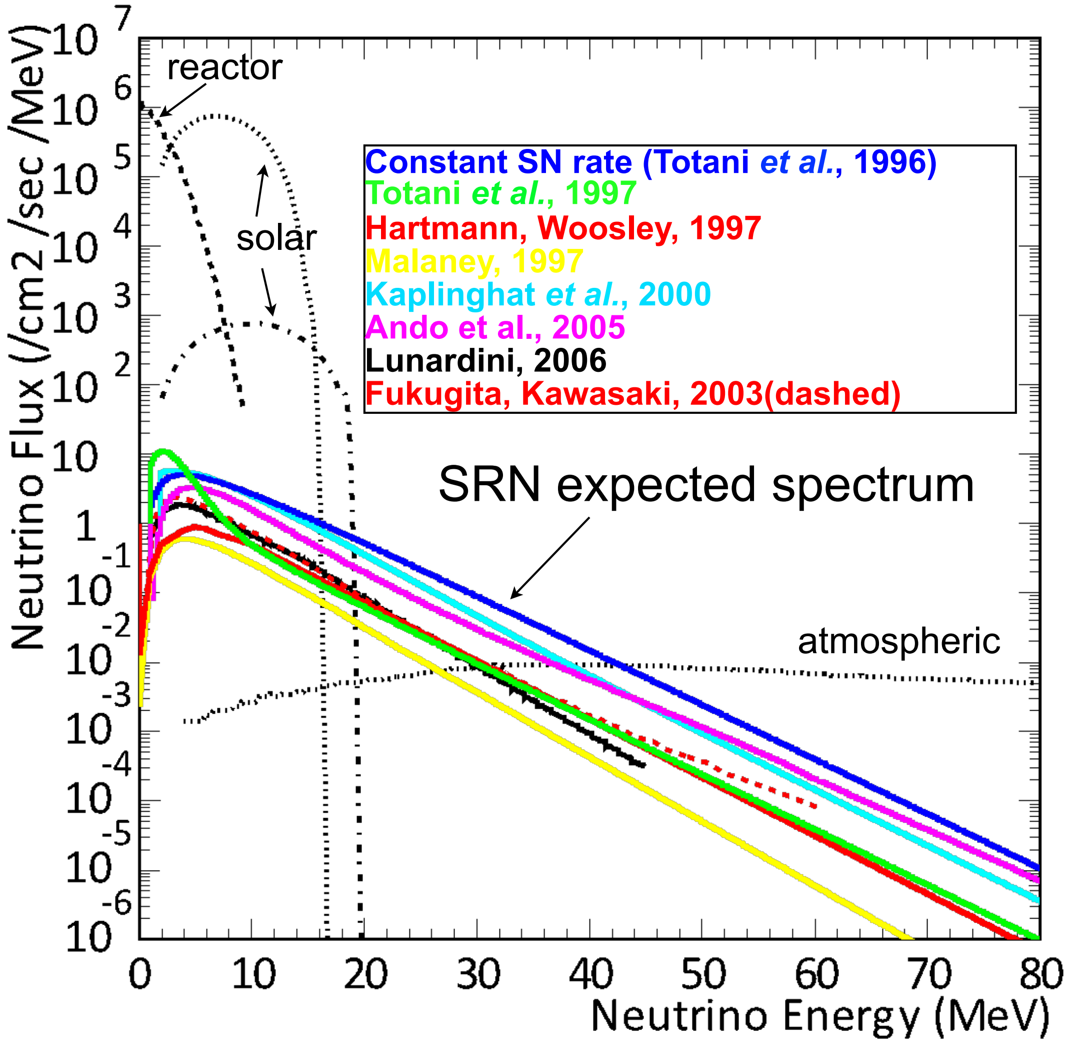
Spallation BG contamination will be $1.3 \sim 2.6 \times 10^{-3}$ events. (2-4 times of SK.)

- with 0.56 kt, in 18 sec. E>18MeV.

Supernova relic neutrino

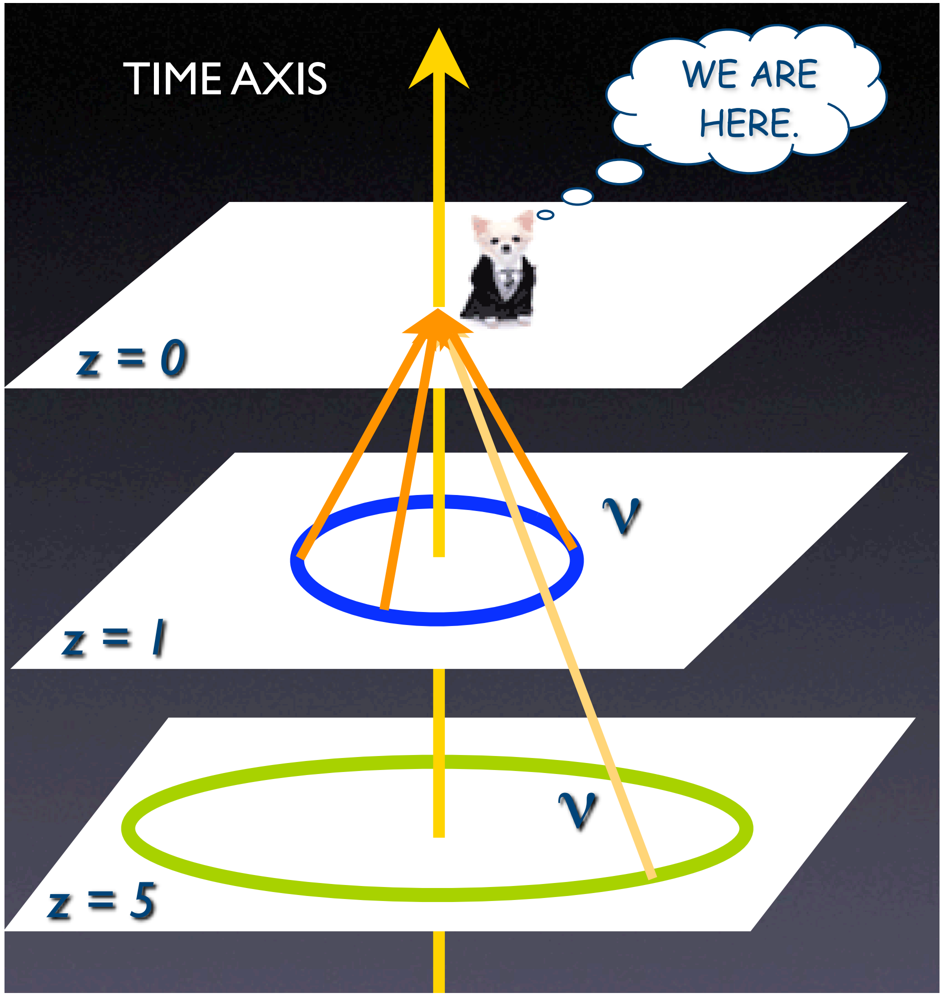
S.Ando



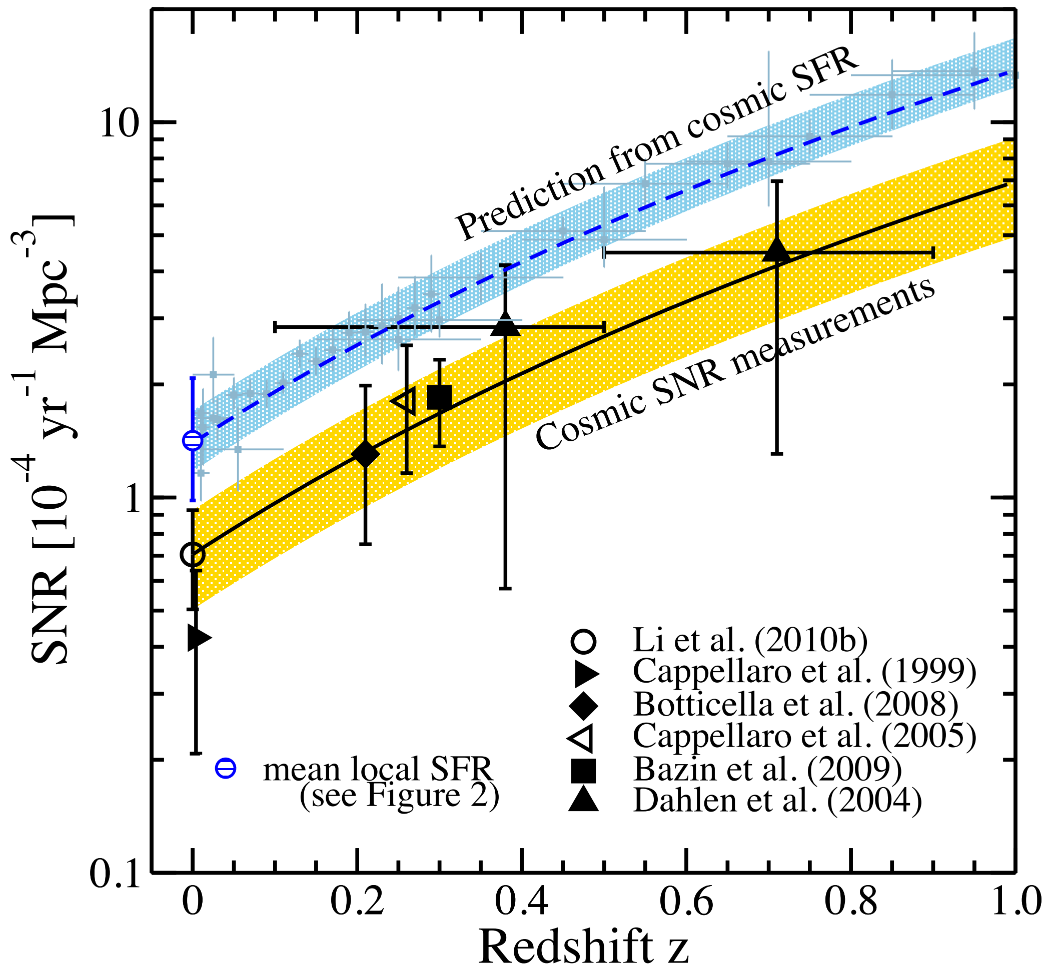


Supernova relic neutrino

S.Ando



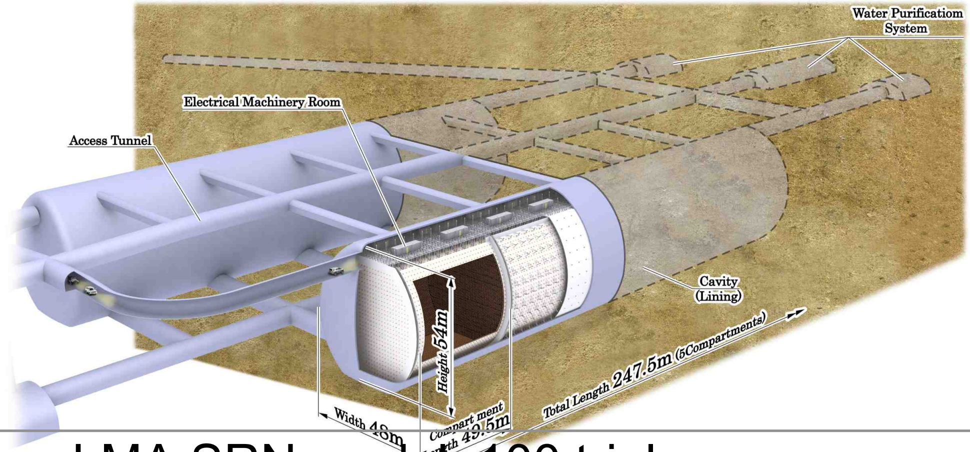
S.Horiuchi 1102.1977



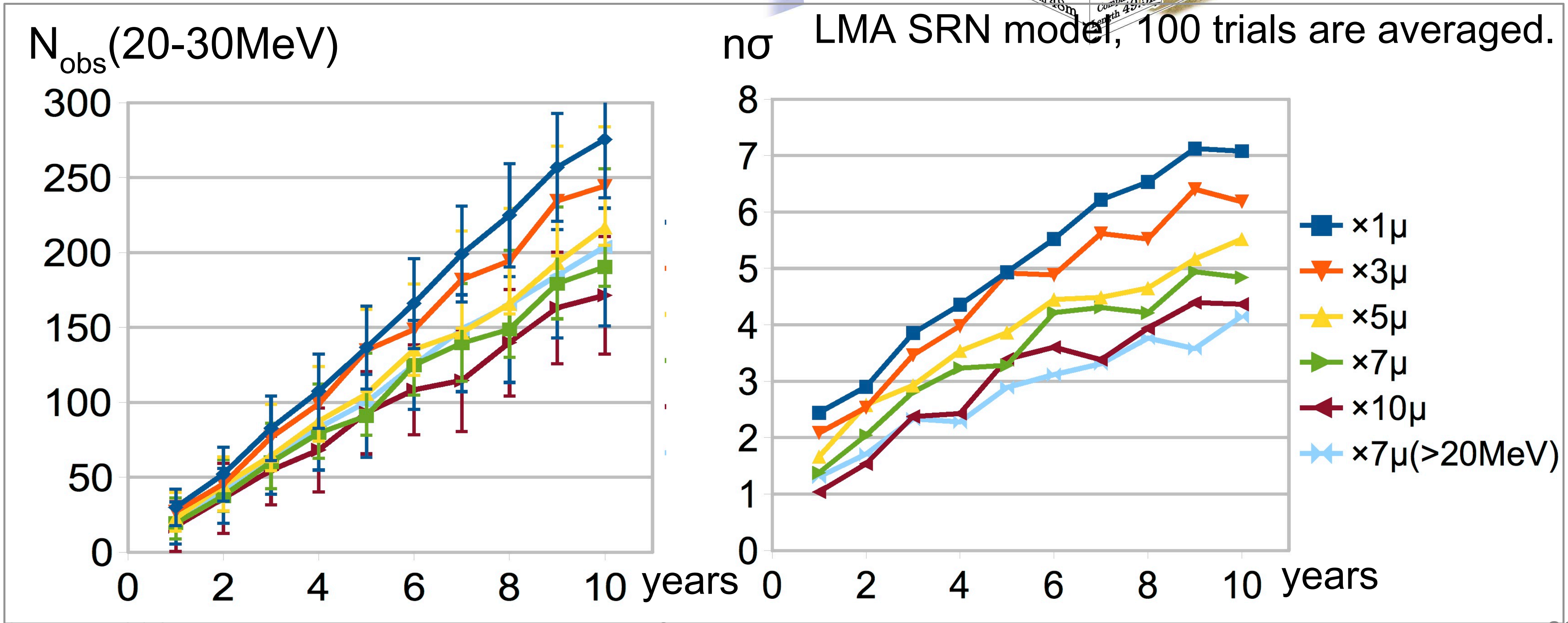
Supernova relic neutrino

Hyper-Kamiokande

Pure water

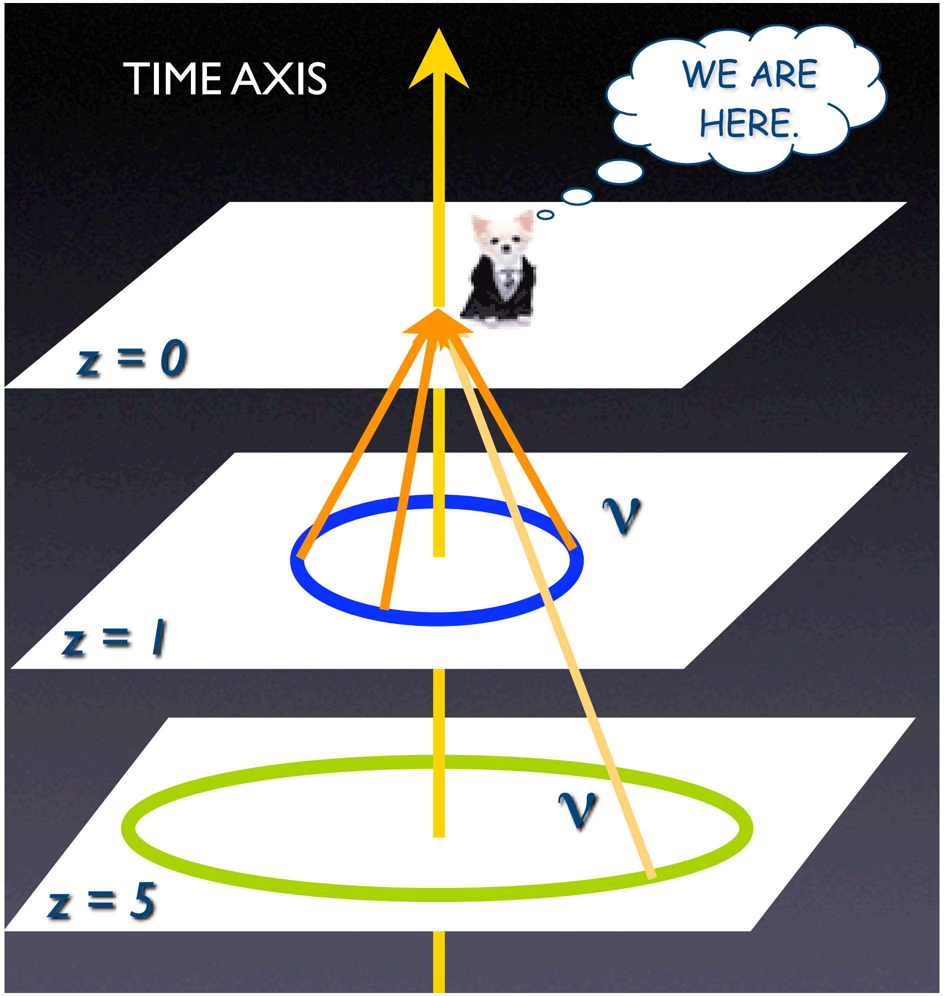


T.Yano et.al

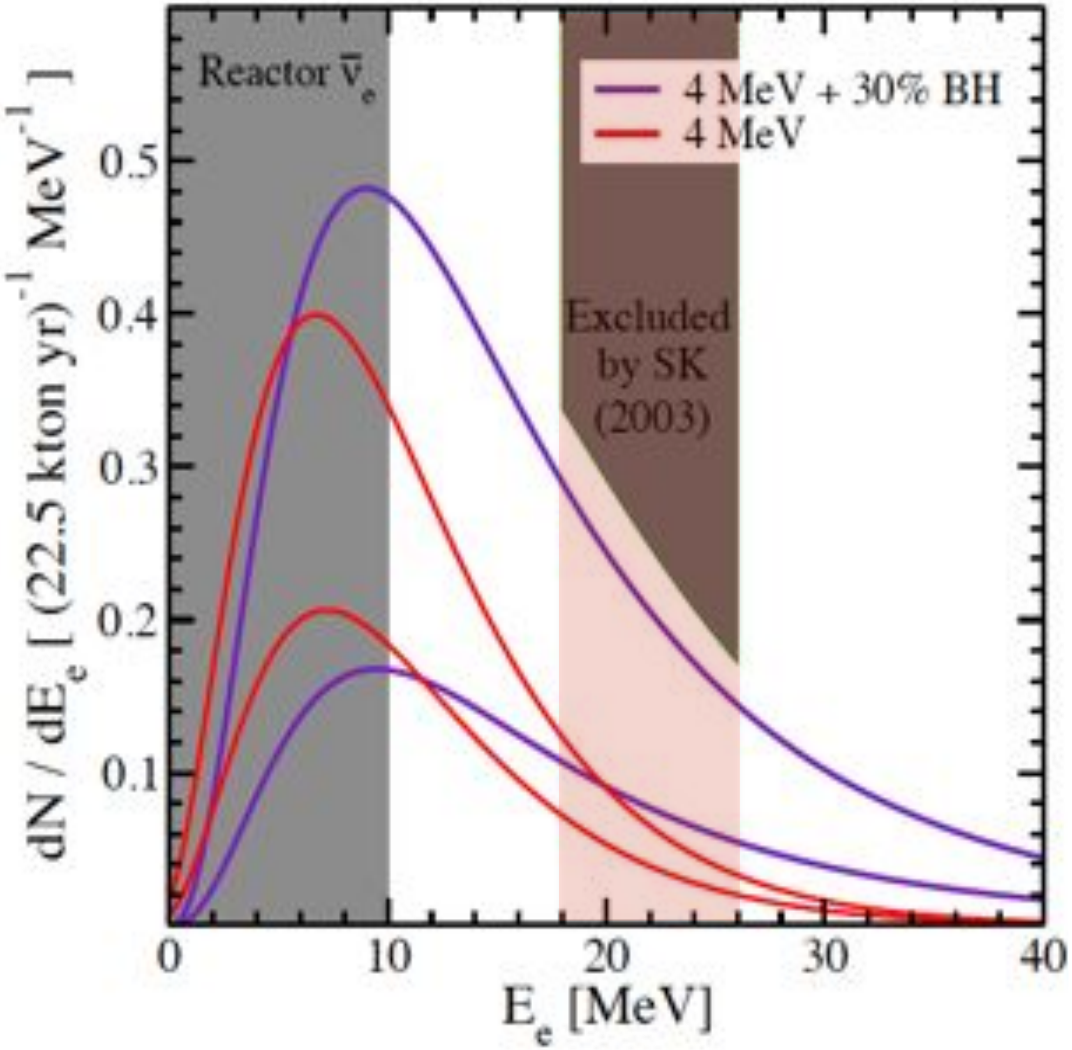


Supernova relic neutrino

S.Ando



S.Horiuchi

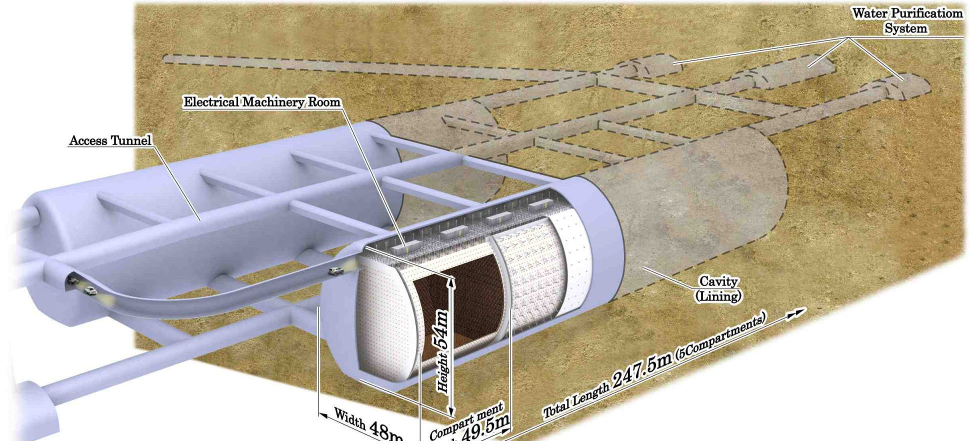


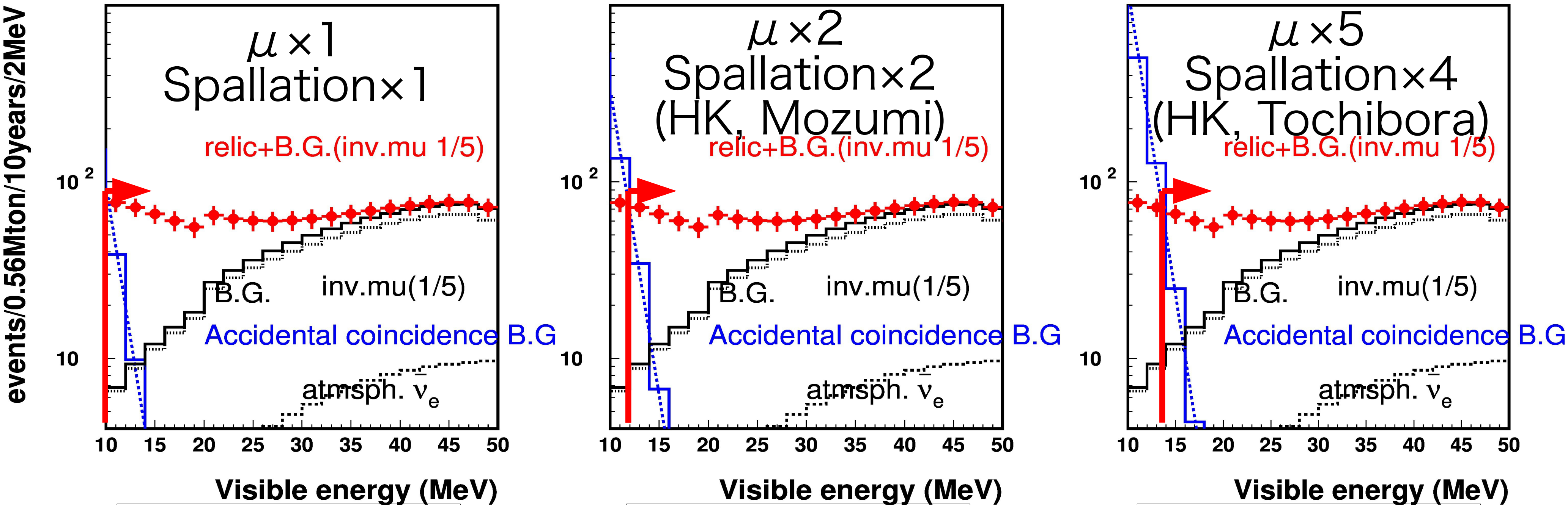
Supernova relic neutrino

Hyper-Kamiokande

Gd loading

T.Yano et.al





E > 10 MeV

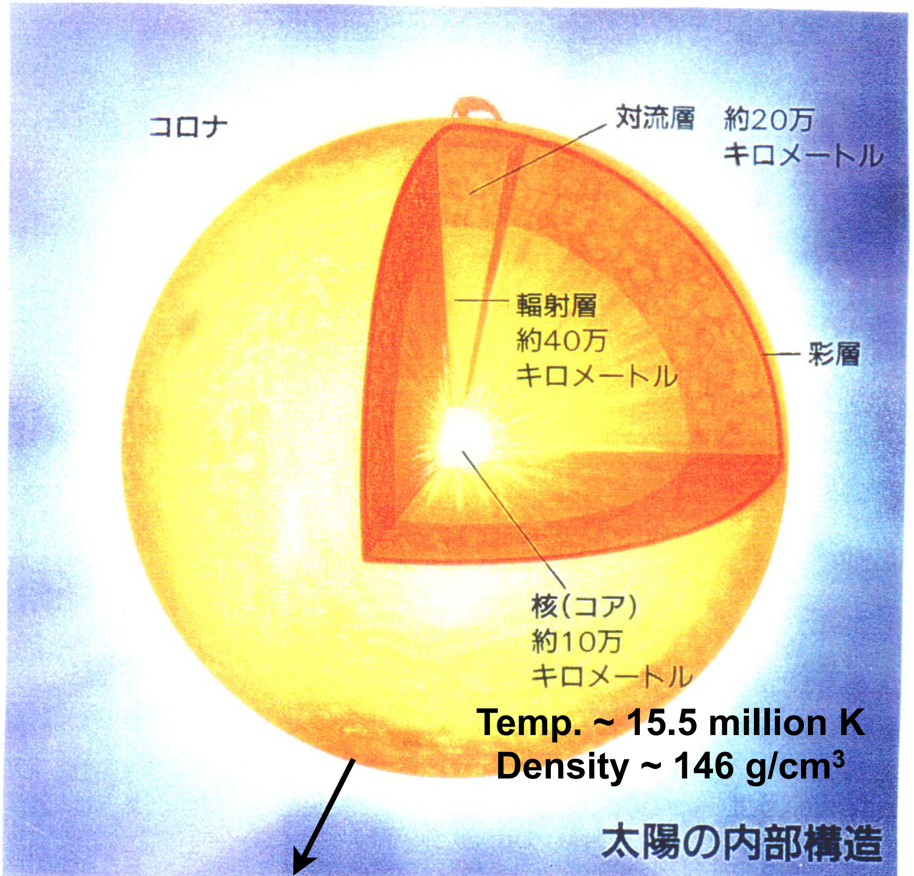
E > 12 MeV

E > 14 MeV

Solar neutrino

Solar neutrino

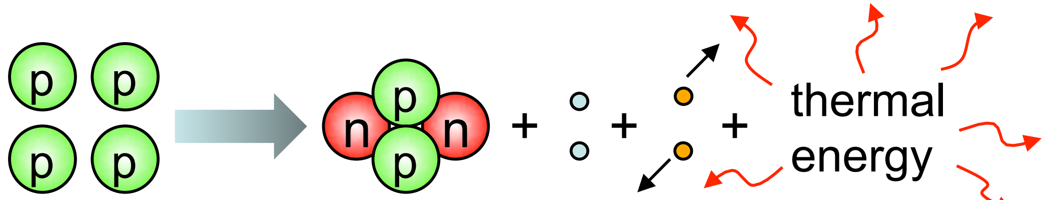
How does the Sun shine?



Photon-measured luminosity

→ ~10^7years radiated from the center to the surface.

Nuclear fusion reaction in the sun



$$4p \rightarrow {}^{4}\mathrm{He} + 2\,e^{+} + 2\,\nu_{e} + 26.7\,\mathrm{MeV}$$

(~6.6×10^{10} neutrinos /sec/cm^2)

This reaction is actually realized via pp-chain and CNO cycle.

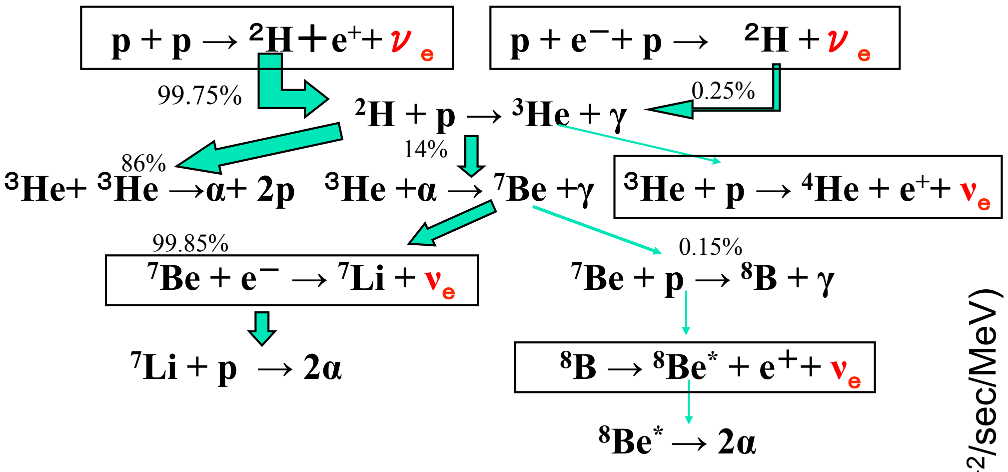
✓Measurement of the current status in the center of the sun

✓Study of

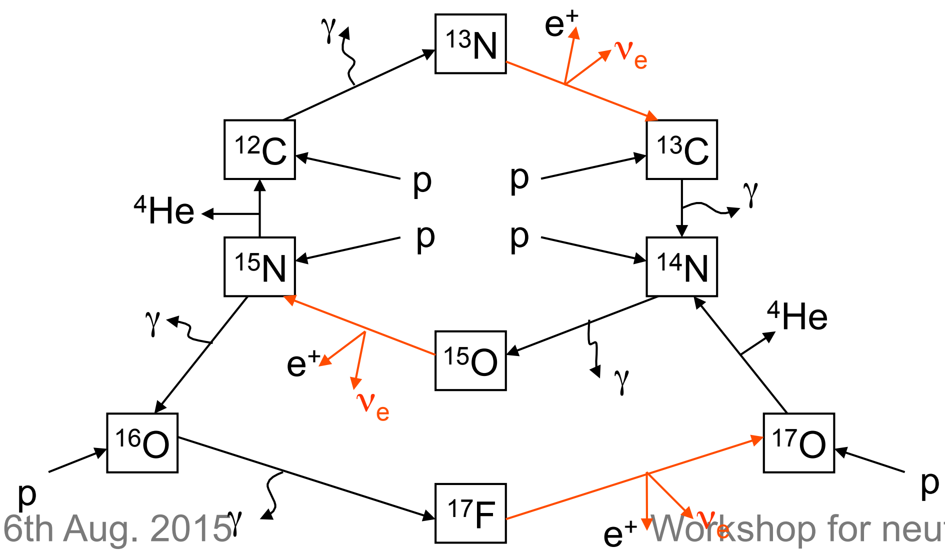
- a mechanism of the energy generation in the sun
- a property of neutrinos

Standard solar model

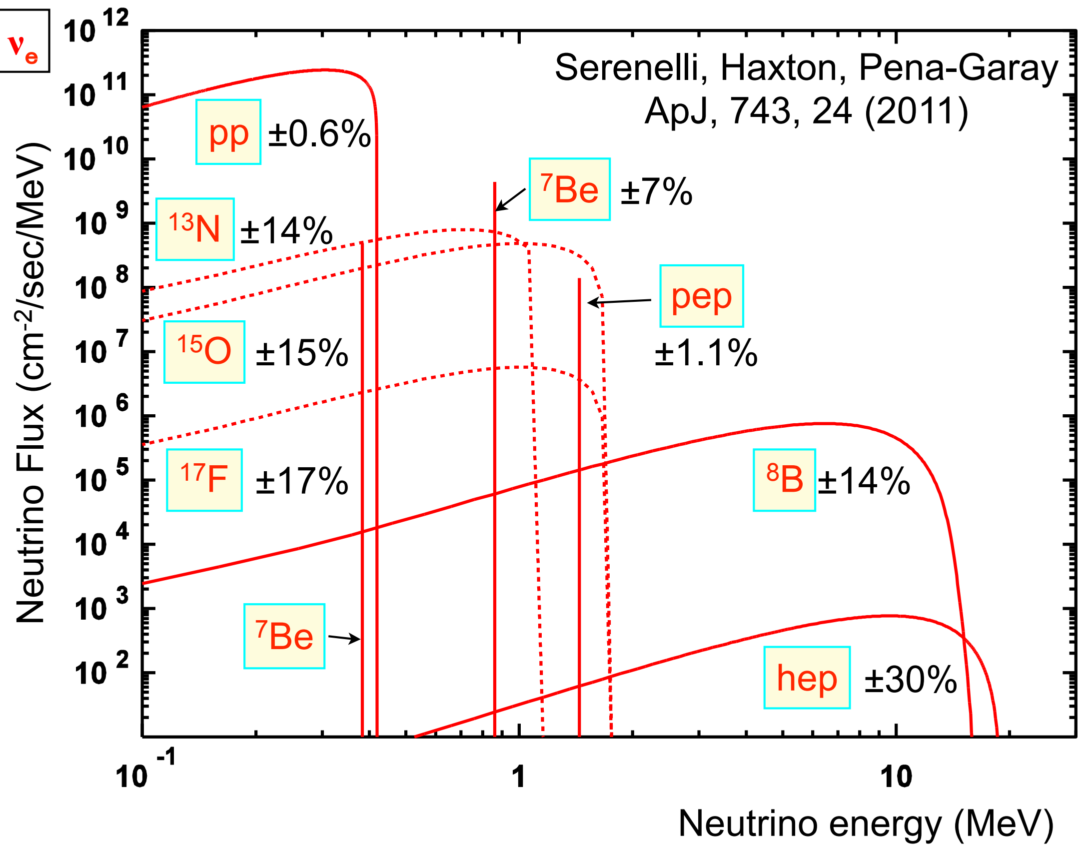
pp-chain



CNO cycle

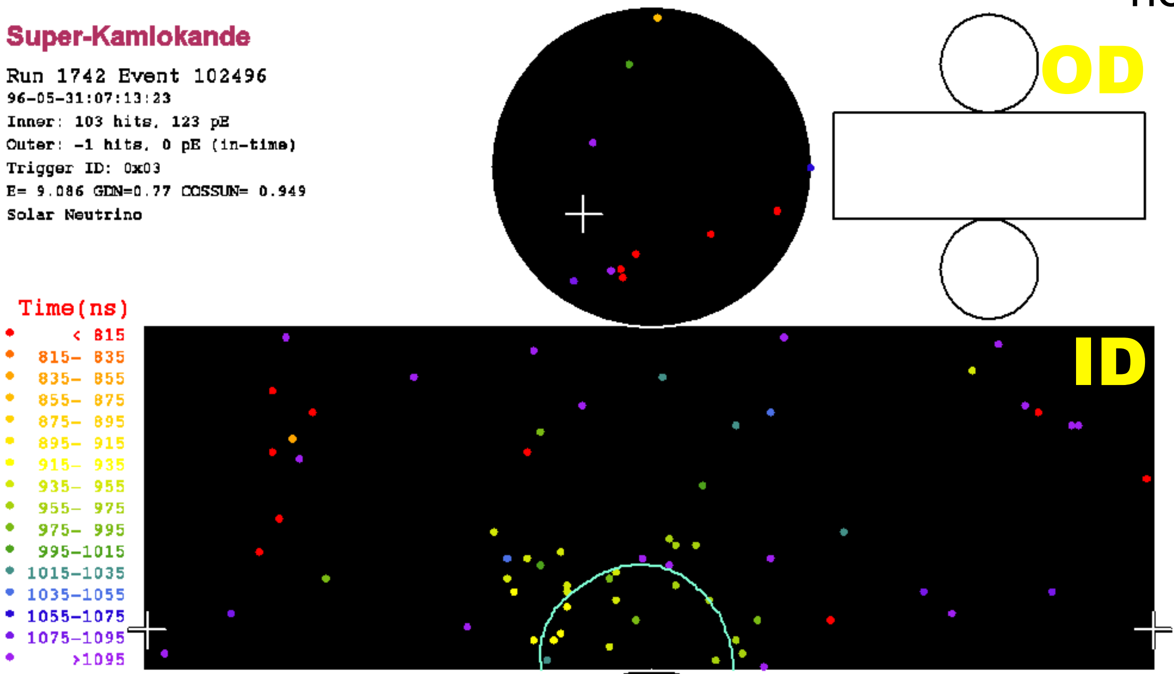


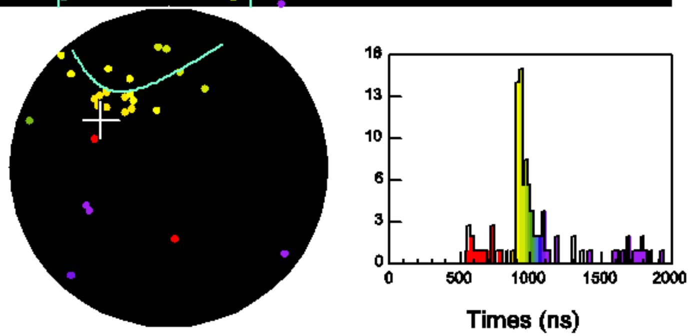
Solar neutrino energy spectrum



Solar neutrino observation

in Water Cherenkov detector





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

neutrino-electron elastic scattering

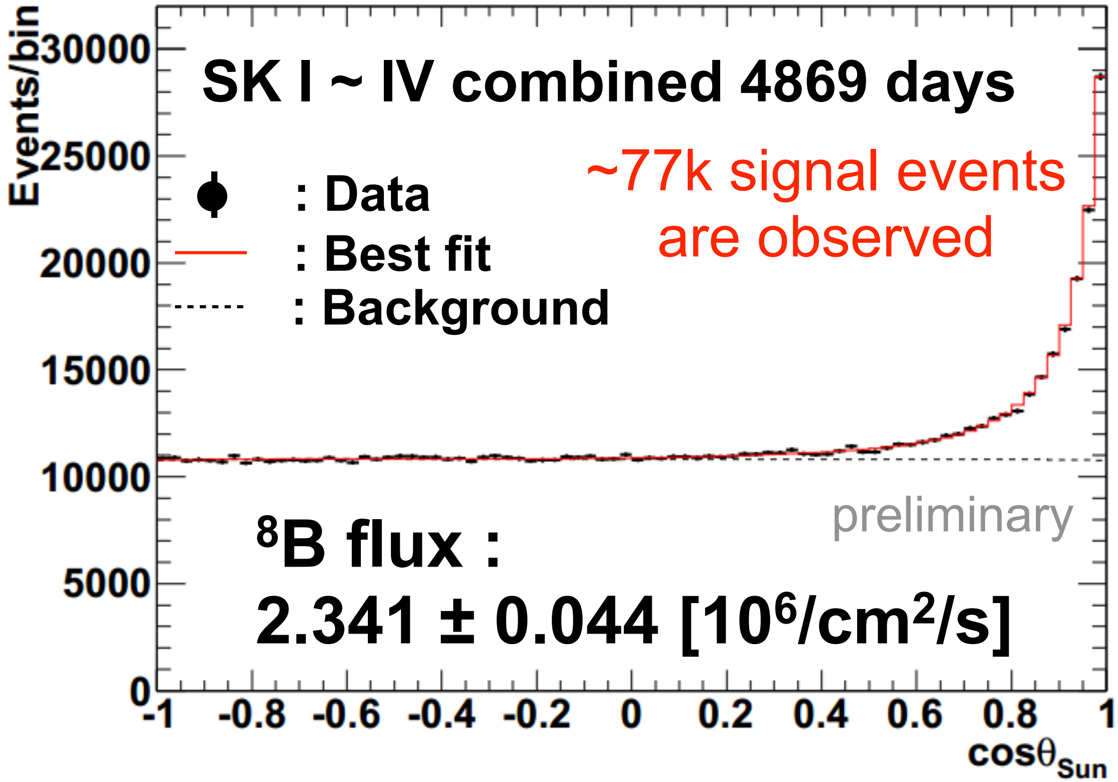
$$\nu + e^- \rightarrow \nu + e^-$$

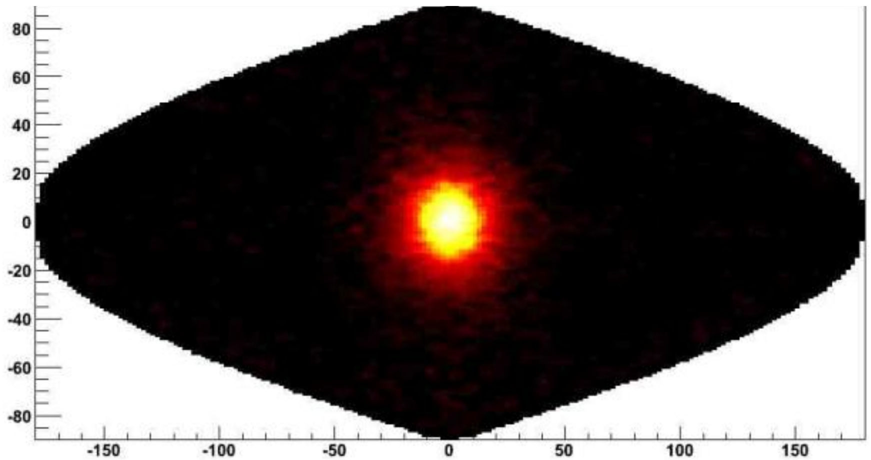
- ✓Find solar direction
- ✓Realtime measurements
  - day-night flux differences
  - seasonal variation
- ✓Energy spectrum

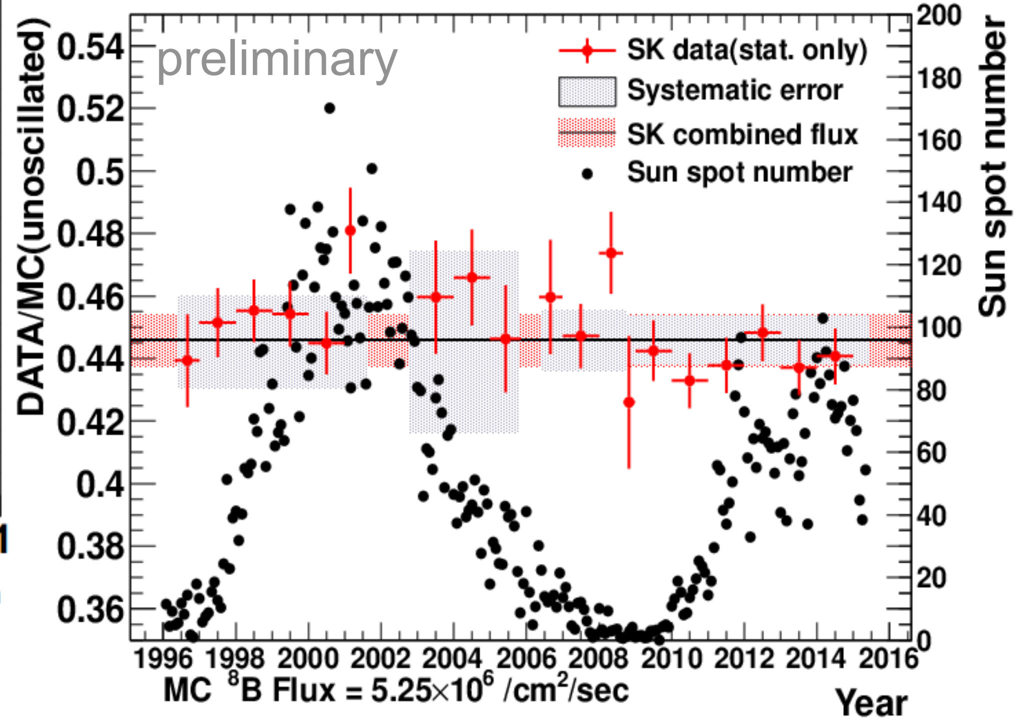
Detector performance in SK

	resolution (10 MeV)	information
vertex	55cm	hit timing
direction	23deg.	hit pattern
energy	14%	# of hits.

Super-Kamiokande



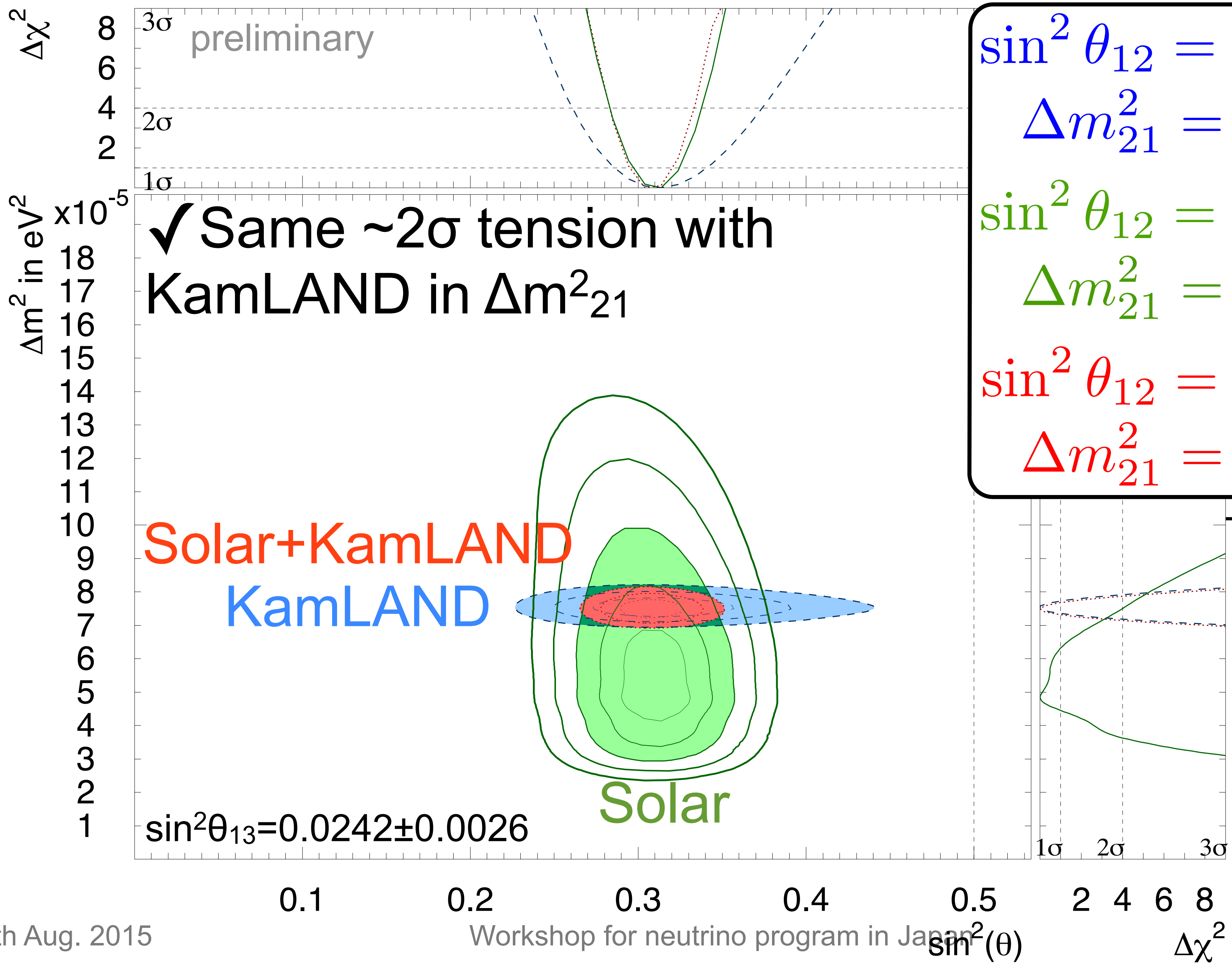




Super-K solar rate measurements are fully consistent with a constant solar neutrino flux emitted by the Sun.

Hyper-Kamiokande

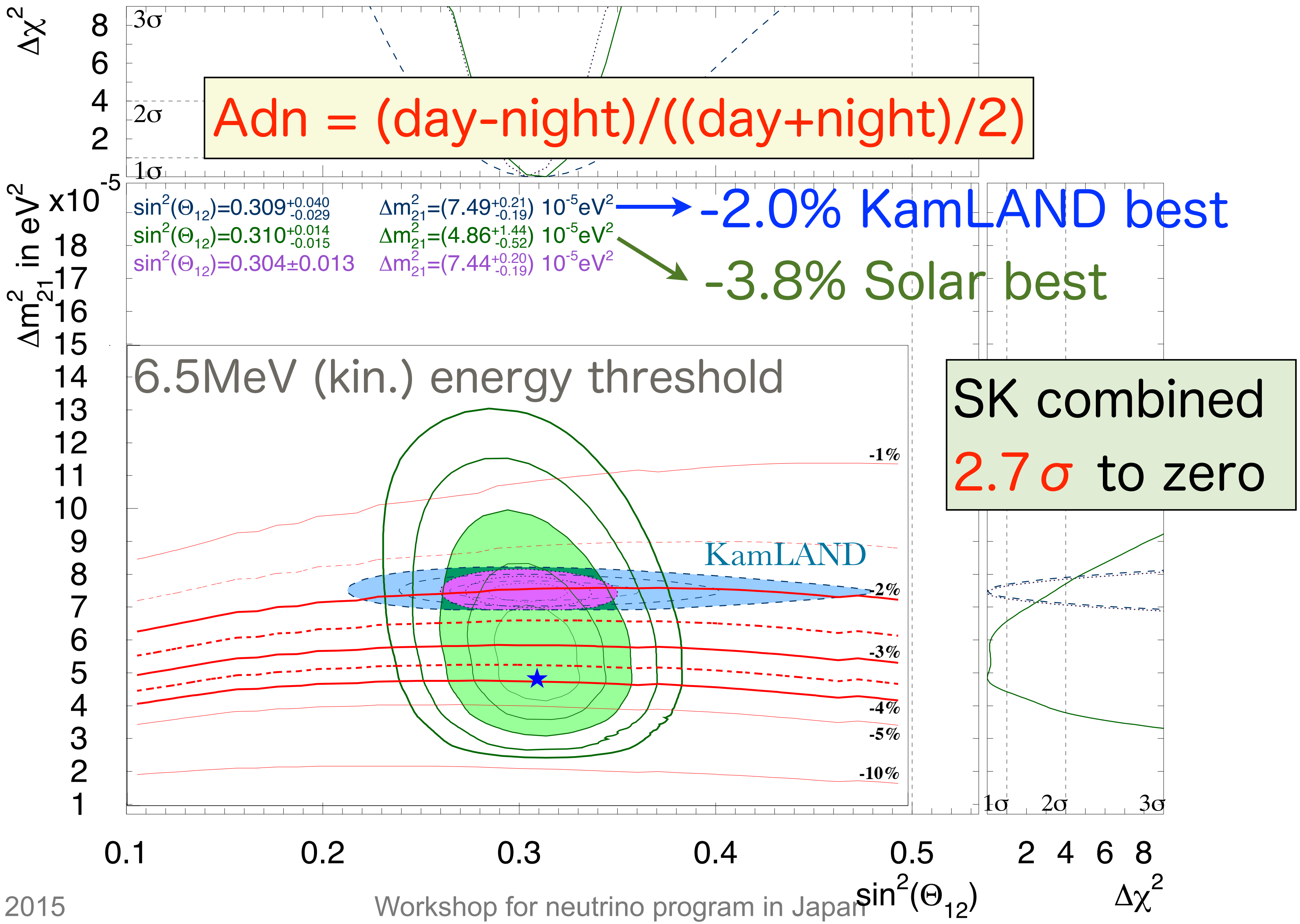
Solar neutrino oscillation



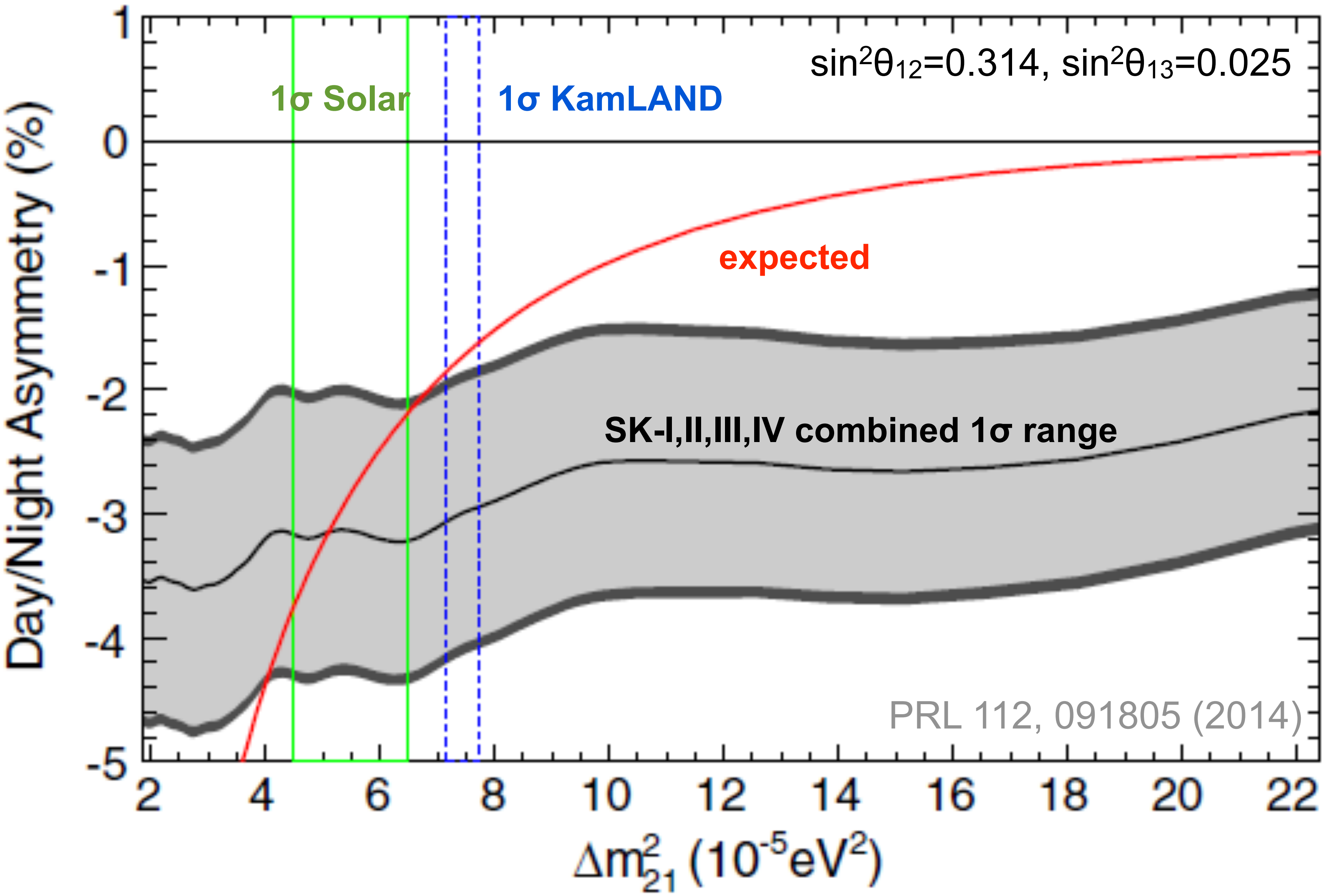
$$\sin^2\theta_{12} = 0.312^{+0.033}_{-0.025}$$
$$\Delta m^2_{21} = 7.54^{+0.19}_{-0.18}$$
$$\sin^2\theta_{12} = 0.311^{+0.014}_{-0.014}$$
$$\Delta m^2_{21} = 4.85^{+1.4}_{-0.59}$$
$$\sin^2\theta_{12} = 0.308^{+0.013}_{-0.013}$$
$$\Delta m^2_{21} = 7.50^{+0.19}_{-0.18}$$

The unit of Δm^2_{21} is 10^{-5} eV^2

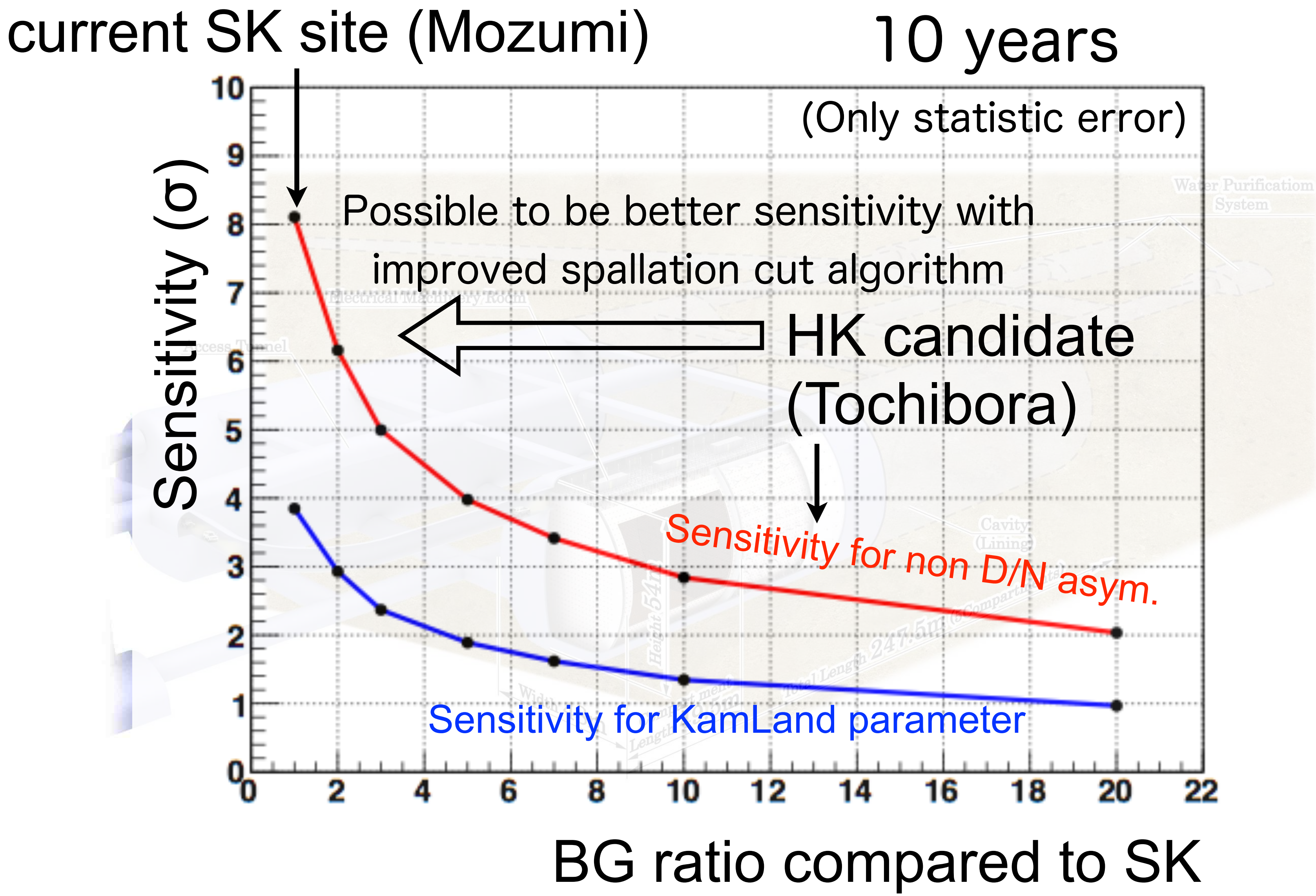
Day-Night asymmetry



Day-Night asymmetry in SK

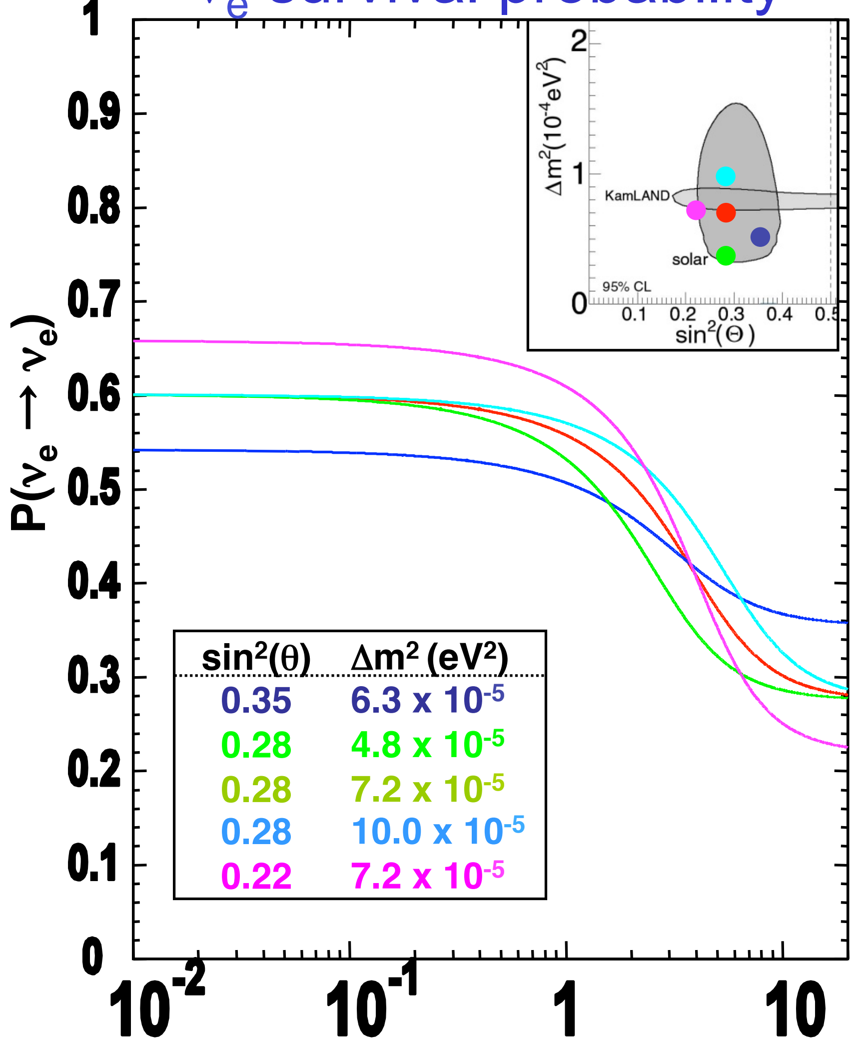


Day-Night asymmetry in HK

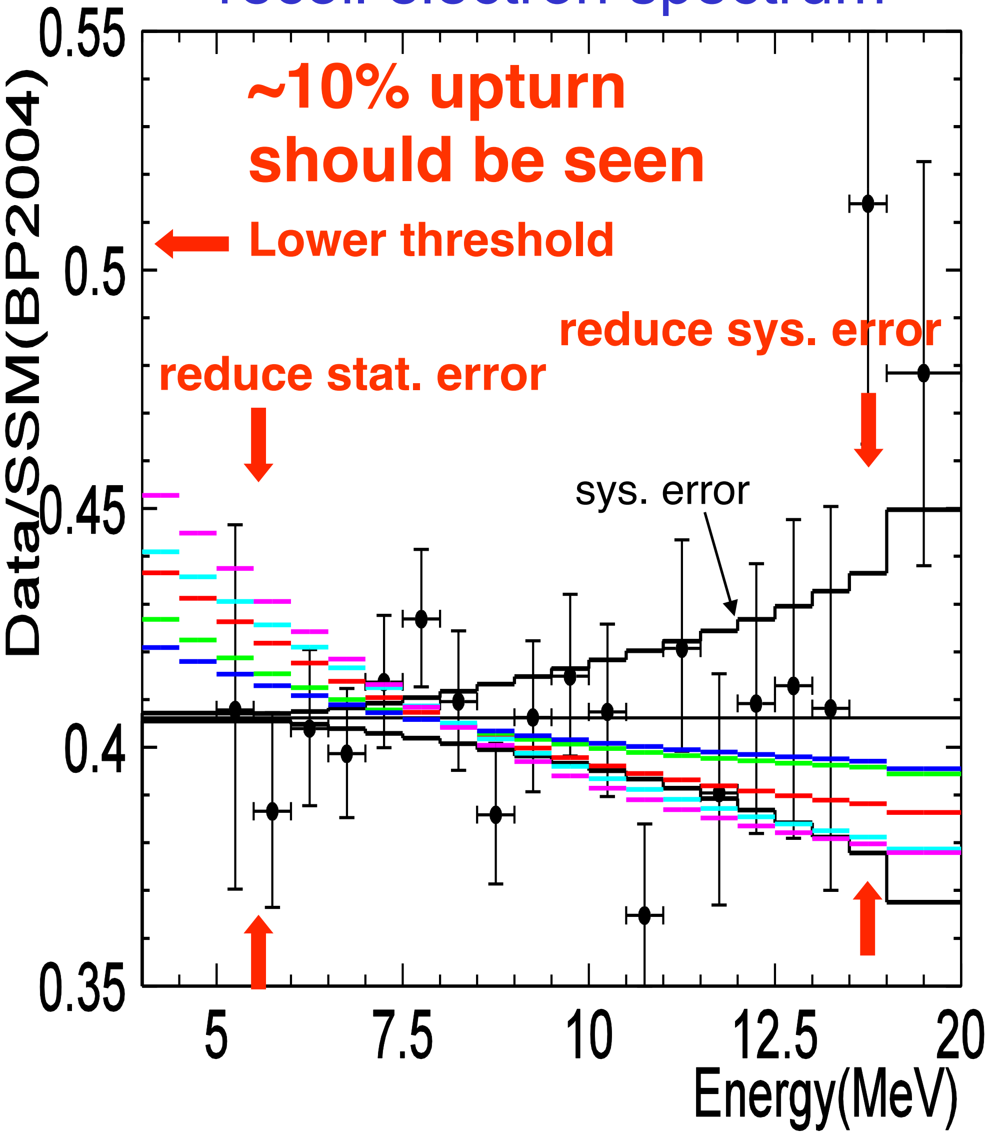


To see the spectrum up-turn

ν_e survival probability

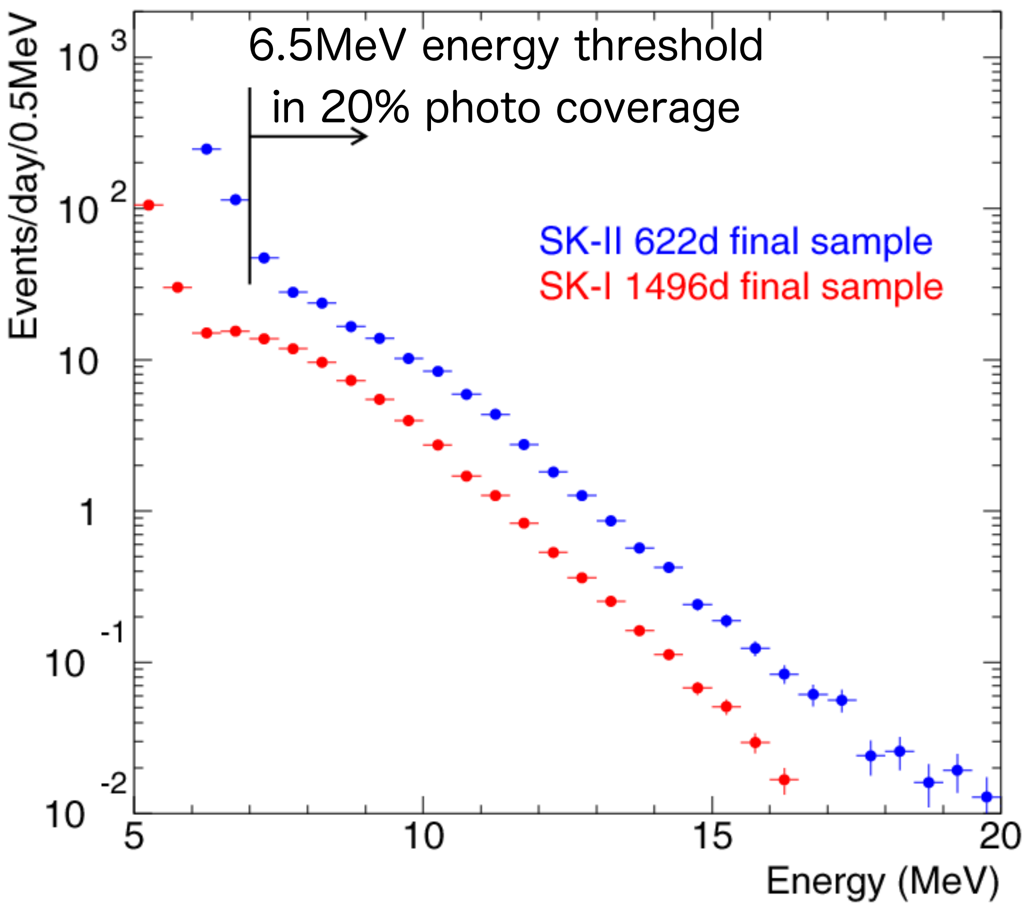


recoil electron spectrum



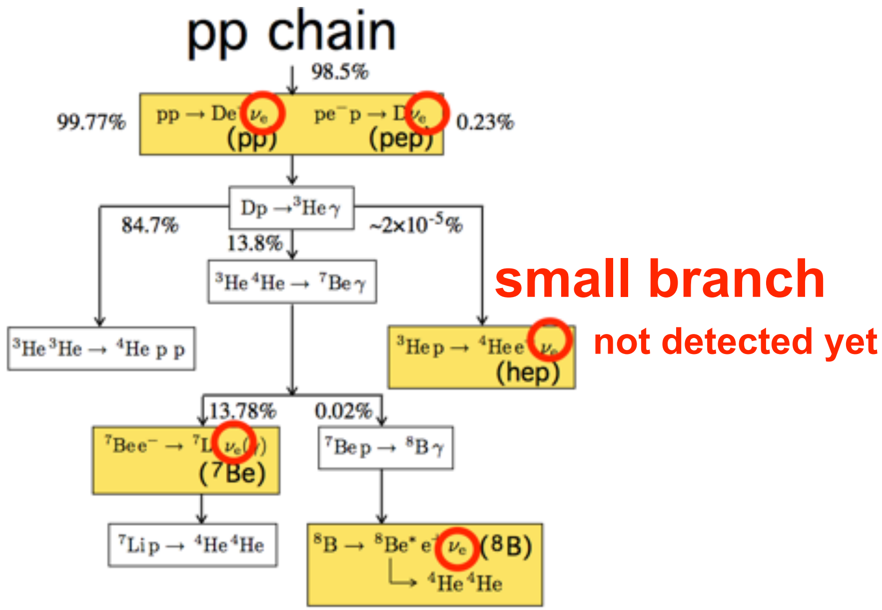
To see the spectrum up-turn

Lowering threshold

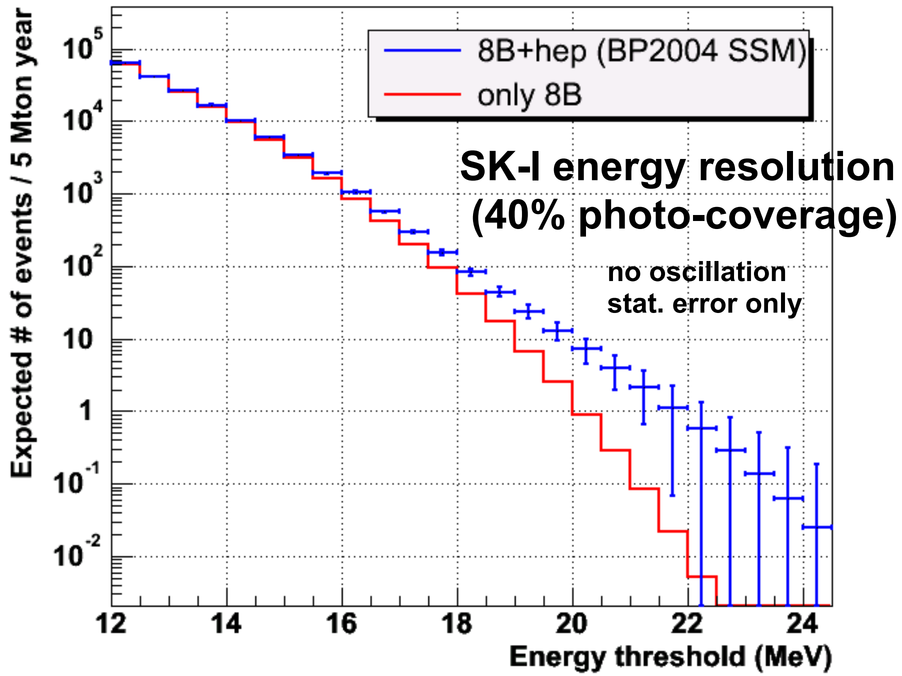


Huge effort of energy calibration

To see hep neutrino



Takeuchi-san's slide



J.N. Bahcall and A.M. Serenelli, Astro. Phys. J. 621, 85 (2005)

Model	pp	pep	hep	^{7}Be	^{8}B	^{13}N	^{15}O	^{17}F
BP04(Yale)	5.94	1.40	7.88	4.86	5.79	5.71	5.03	5.91
BP04(Garching)	5.94	1.41	7.88	4.84	5.74	5.70	4.98	5.87
BS04	5.94	1.40	7.86	4.88	5.87	5.62	4.90	6.01
BS05(^{14}N)	5.99	1.42	7.91	4.89	5.83	3.11	2.38	5.97
BS05(OP)	5.99	1.42	7.93	4.84	5.69	3.07	2.33	5.84
BS05(AGS,OP)	6.06	1.45	8.25	4.34	4.51	2.01	1.45	3.25
BS05(AGS,OPAL)	6.05	1.45	8.23	4.38	4.59	2.03	1.47	3.31

- Energy resolution at higher energy (~20 MeV) is important.
- It can be seen with 40% P.C. cannot with 14% P.C..
- ~300 events/ 5Mt・years (>17MeV)

Summary

✓ When core-collapse supernova happens in or nearby our galaxy, Hyper-K has many interesting physics potential.

✓ Hyper-K is possible to perform a precise measurement of SRN, especially spectrum.

✓ Solar neutrinos; neutrino oscillation, solar model, etc. are possible to be studied very precisely.

Summary

A meeting “Astrophysics neutrino observation at Hyper-Kamiokande” was held on 15th May, 2015, at Kobe University.

Many researchers also outside neutrino community are interested in and support Hyper-K.