Supernova Neutrino Study with Hyper-Kamiokande

T. Yano

Kobe Univ.

28th Jan. 2015
6th Open Meeting for the Hyper-Kamiokande meeting

Introduction

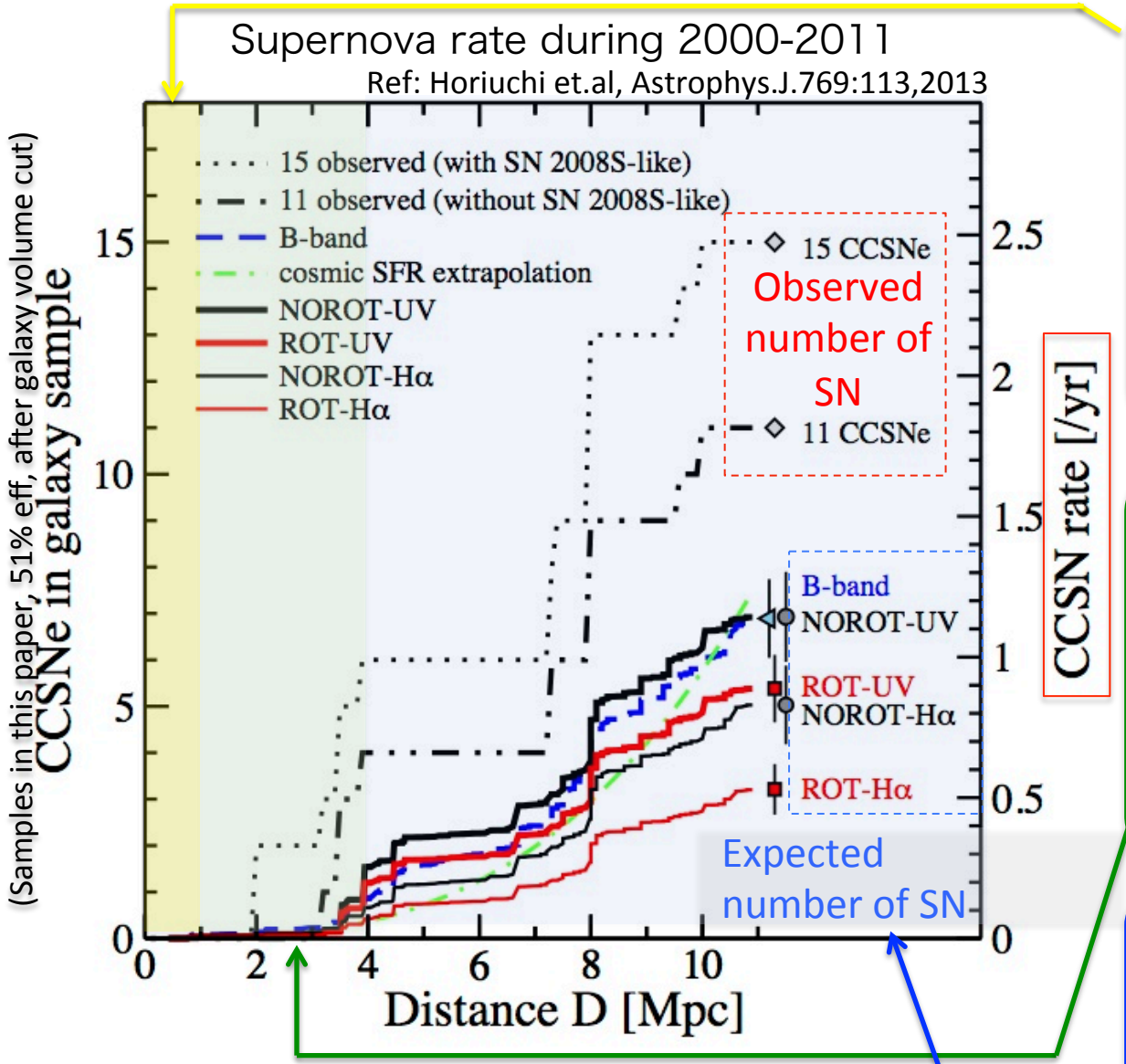
Supernova neutrino study with Hyper-K

- Several studies about SN neutrino physics prospects have been done for Hyper-K.
- In this presentation, studies for supernova neutrino and supernova relic neutrino are summarized and shown.

Physics motivation of Supernova neutrino study

- Neutrinos can bring out the information of inner part of supernova.
- It can provide the information for :
  - Inner structure of SN
  - SN explosion mechanism
  - Physics process in SN center
  - Nucleosynthesis inside SN
  - Black hole formation

Supernova Neutrino Study with HK



R < ~ 1 Mpc

- Detailed Observation.
- Supernova alarm.
- Coincident measurement with gravity wave.
- Frequency of galactic. supernova :
  Once per 200yrs.

R = 1 ~ 4 Mpc

- Supernova alarm.
- Observation with optical SN information.
- Frequency of SN at nearby galaxy :
  2 - 6 per 10yrs.

R >> 4 Mpc

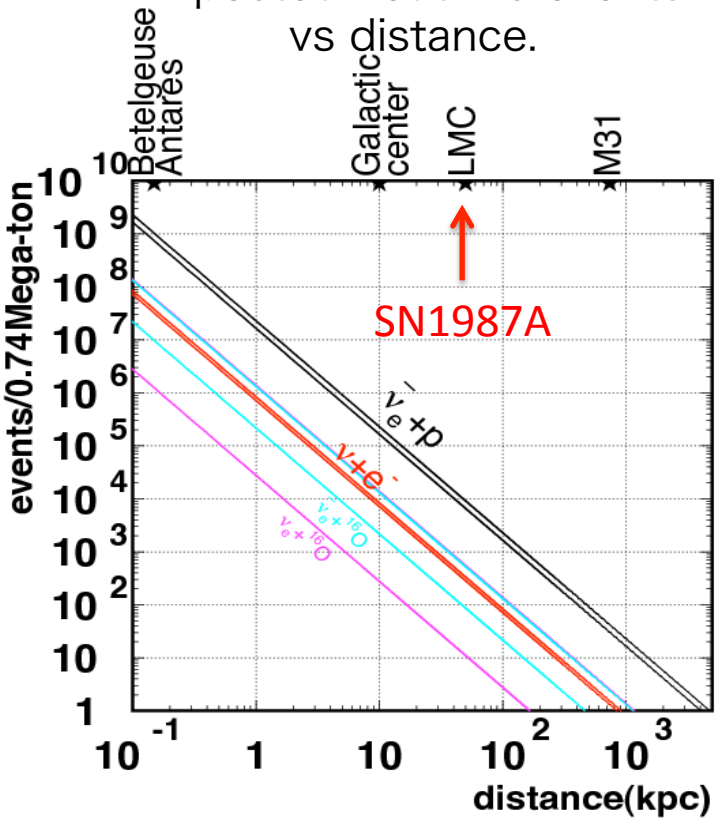
- Supernova relic neutrino search and observation
- Frequency : anytime

Supernova burst neutrinos at R < 1 Mpc

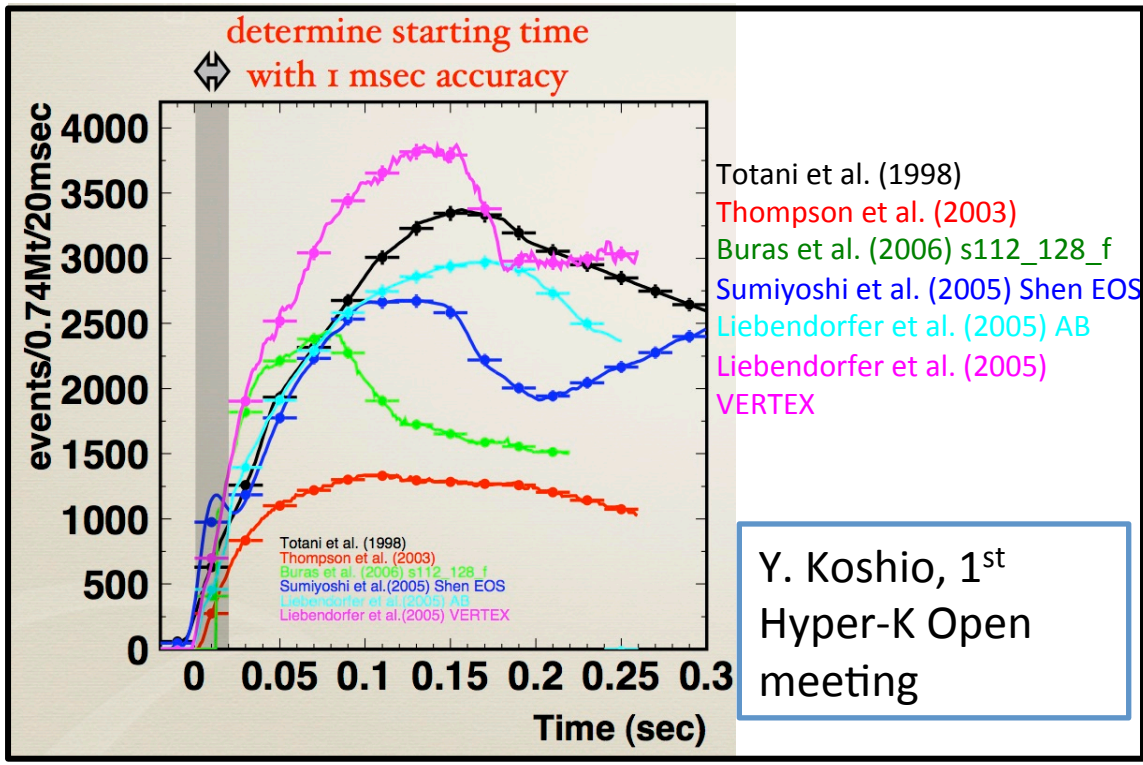
Very large statistics is expected for a galactic supernova.

- ~200k anti-ν_e events expected for 10kpc.
- Precise directionality for SN alarm
- Time and Energy profile is important inputs for SN theory and simulation.

Expected neutrino events vs distance.



Time spectrum of SN neutrinos at galactic center (10 kpc)

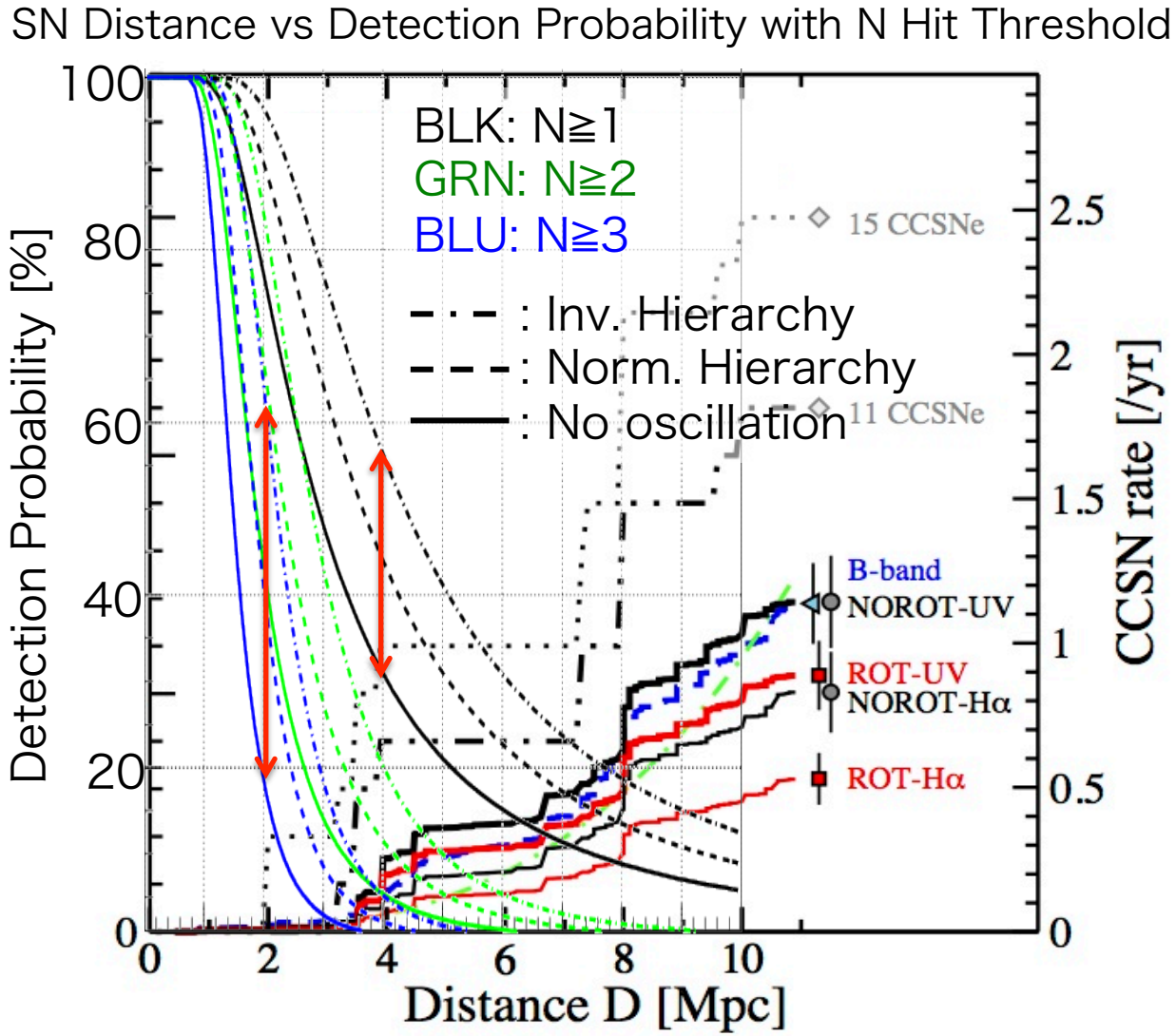


Totani et al. (1998)
Thompson et al. (2003)
Buras et al. (2006) s112_128_f
Sumiyoshi et al. (2005) Shen EOS
Liebendorfer et al. (2005) AB
Liebendorfer et al. (2005)
VERTEX

Y. Koshio, 1st Hyper-K Open meeting

SN burst neutrinos at R ~ 1 - 4 Mpc

Detection of burst neutrino from supernova at nearby galaxies is also possible at Hyper-K.



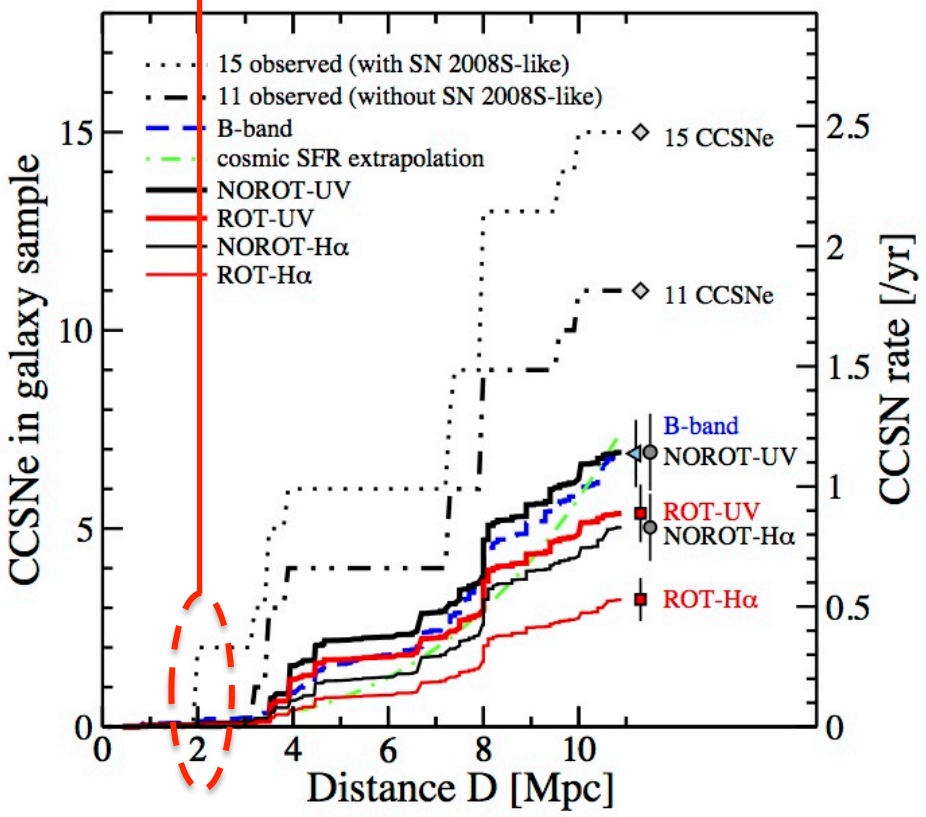
For SN at 2 Mpc, we will detect N≧3 events at 20-65% probability.

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

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

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

DIM supernova at R ~ 2 Mpc



2 dim supernovae were observed at 2 Mpc in 12 yrs.

- So called SN2008S-like.
- They are 2 ~ 3 times dimmer than usual core collapse SN.
- *Is it true CCSN or other type SN?*

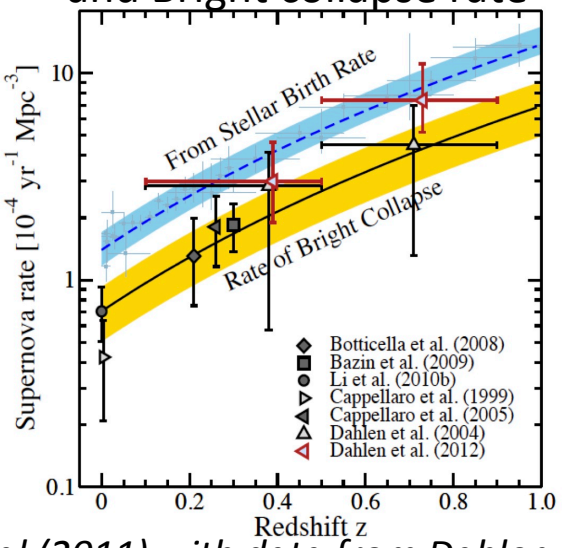
- Hyper-K will record N $\geqq$ 3 events with 18MeV energy threshold, for 2 Mpc CCSN. (20-60%)
- If they are true CCSN, we should have ν signals immediately.

Even if we don't have these signals, it will give a new information for the astrophysical process of these dim supernova.

Supernova Relic Neutrinos Search at R>>4Mpc

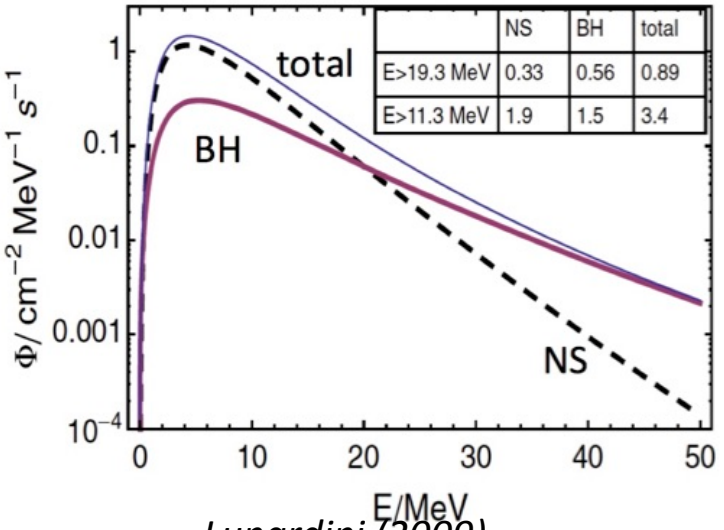
- SRN : diffused SN burst neutrinos from past Sne
  - SRN is continuously showering on us. If we have enough sensitivity, SRN is promising source of SN information.
  - The information for SN model, SN nucleosynthesis.
  - Information for discrepancy between expected core-collapse rate and observation of blight collapse.
    - DIM supernova or supernova forming black hole?

Stellar birth rate(=collapse rate) and Bright collapse rate



Horiuchi et.al (2011) with data from Dahlen et.al (2012)

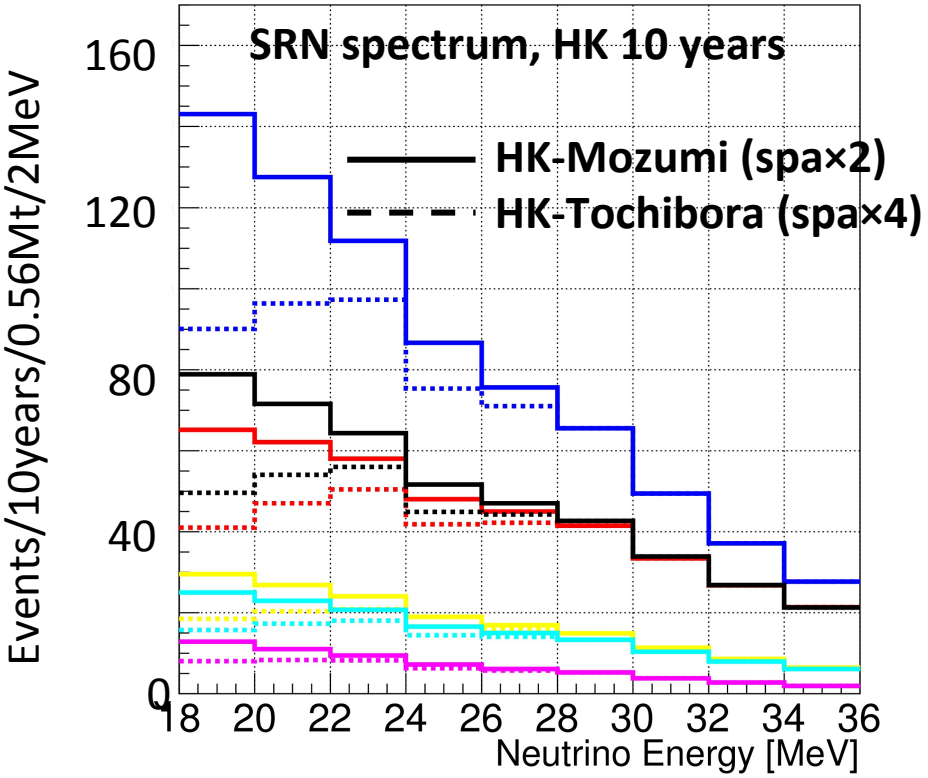
SRN spectrums for forming Neutron Star and Black Hole.



Lunardini (2009)

Supernova Relic Neutrinos Search with HK

- Measurement of SRN with energy threshold of 17.5 MeV will be possible at normal Hyper-K.
- Hyper-K will provide SRN spectrum information at higher energy. (17.5~30 MeV)



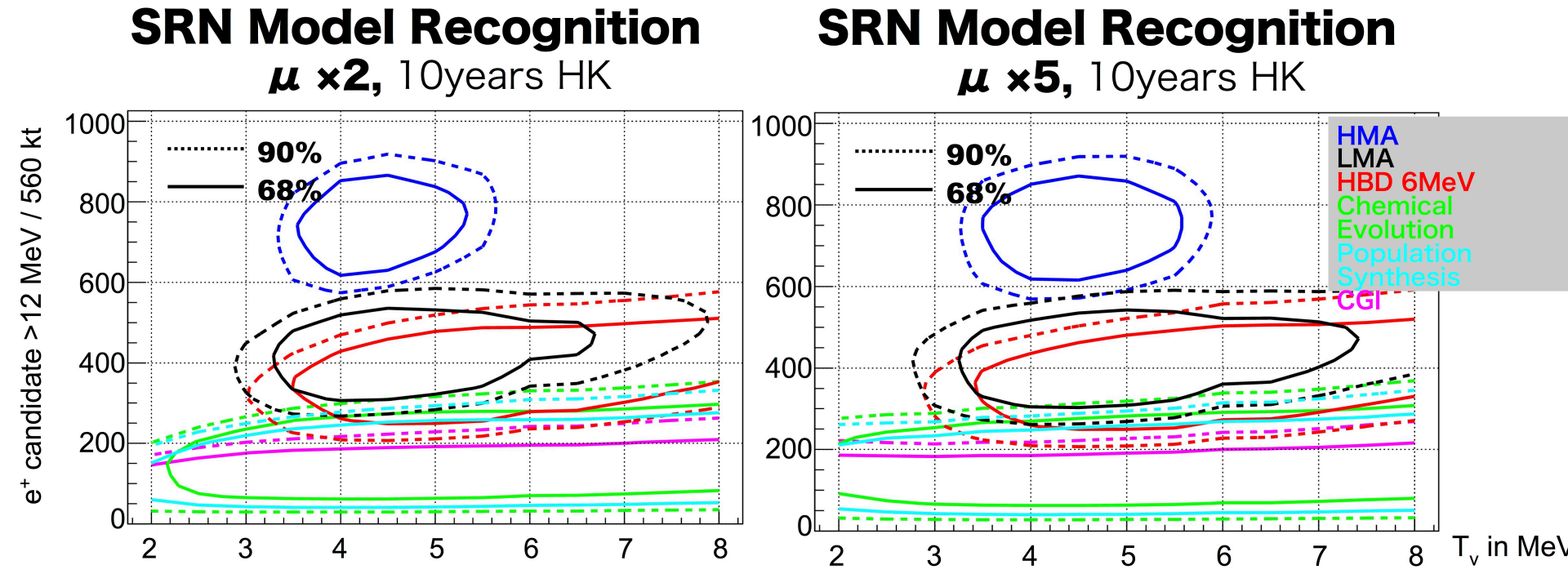
With HK 10 years,
240±40 ev. (20-30MeV, Mozumi)
215±40 ev. (20-30MeV, Tochibora)
will be extracted for LMA-model by fitting the spectrum with signal + BG.

SRN models

Kaplinghat, Steigman & Walker (2000)
Ando, Sato & Totani (2003)
Horiuchi, Beacom & Dwek (2009)
($T\nu$ = 6MeV)
Hartmann & Woosley (1997)
Totani et.al. (1996)
Malaney (1997)

Supernova Relic Neutrinos Study with HK+Gd

- Hyper-K and neutrino tagging with Gd was also studied.
- With HK +Gd, the energy threshold for SRN events can be lowered from 17.5MeV to 12 MeV (Mozumi) or 14 MeV (Tochibora).
- LMA or HBD model can be recognized from others.



Summary

- **Supernova burst neutrino**
  - Hyper-K will provide the high statistic data for galactic supernova. (200k events for 10kpc)
  - It is also possible to have events of supernova at nearby galaxies. (0.37-0.83 events at 4Mpc)
  - Dim supernova can be studied. (20-60% of N≧3 at 2Mpc)
- **Supernova relic neutrino**
  - SRN above 17.5 MeV can be measured with Hyper-K.
  - By adding Gd, the model recognition will be improved.
- **Over all for supernova neutrinos**
  - The information of SN neutrinos is only 1987A ever.
  - SN burst and SRN will provide new information for SN neutrinos.

Appendix

Supernovae in recent 12 years

TABLE 3
LOCAL CCSNE (IN BOLD, TOTAL 17) AND POSSIBLE CCSNE (IN ITALIC, TOTAL 5) WITHIN 11 MPC DURING 2000 TO 2011 INCLUSIVE

Ref: Horiuchi et.al, Astrophys.J.769:113,2013

SN	Galaxy	Type	D (Mpc)	R.A.	Decl.	b (deg)	11HUGS Full	11HUGS LVLcut	LVL
SN 2002ap	NGC 0628	IcPec	7.3	01 36 41.7	15 46 59	−45.7	Y	Y	Y
SN 2002bu	NGC 4242	SN?[1]	7.4	12 17 30.1	45 37 08	70.3	Y	Y	Y
SN 2002hh	NGC 6946	IIP	5.9	20 34 52.3	60 09 14	11.7	Y	-	-
SN 2003gd	NGC 0628	IIP	7.3	01 36 41.7	15 46 59	−45.7	Y	Y	Y
SN 2004am	NGC 3034 (M 82)	IIP	3.5	09 55 52.2	69 40 47	40.6	Y	Y	Y
SN 2004dj	NGC 2403	IIP	3.2	07 36 51.4	65 36 09	29.2	Y	Y	Y
SN 2004et	NGC 6946	IIP	5.9	20 34 52.3	60 09 14	11.7	Y	-	-
SN 2005af	NGC 4945	IIP	3.6	13 05 27.5	−49 28 06	13.3	Y	-	-
SN 2005at	NGC 6744	Ic	9.4	19 09 46.2	−63 51 25	−26.1	Y	-	-
SN 2005cs	NGC 5194 (M 51)	IIP	8.0	13 29 52.7	47 11 43	68.6	Y	Y	Y
SN 2007gr	NGC 1058	Ic	9.2	02 43 29.9	37 20 27	−20.4	Y	-	-
SN 2008S	NGC 6946	SN?[2]	5.9	20 34 52.3	60 09 14	11.7	Y	-	-
SN 2008ax	NGC 4490	IIb	8.0	12 30 36.1	41 38 34	74.9	Y	Y	Y
SN 2008bk	NGC 7793	IIP	3.9	23 57 49.7	−32 35 30	−77.2	Y	Y	Y
NGC300-OT	NGC 0300	SN?[3]	2.0	00 54 53.5	−37 41 00	−79.4	Y	Y	-
SN 2008iz	NGC 3034 (M 82)	II	3.5	09 55 52.2	69 40 47	40.6	Y	Y	Y
SN 2008jb	ESO 302-14	IIP	9.6	03 51 40.9	−38 27 08	−50.9	Y	Y	-
SN 2009hd	NGC 3627 (M 66)	IIP	10.1	11 20 15.0	12 59 30	64.4	Y	Y	Y
SN 2010da	NGC 0300	SN?[4]	2.0	00 54 53.5	−37 41 00	−79.4	Y	Y	-
SN 2011dh	NGC 5194 (M 51)	IIb	8.0	13 29 52.7	47 11 43	68.6	Y	Y	Y
PSN J12304185+4137498	NGC 4490	SN?[5]	8.0	12 30 36.1	41 38 34	74.9	Y	Y	Y
SN 2011ja	NGC 4945	IIP	3.6	13 05 27.5	−49 28 06	13.3	Y	-	-

NOTE. — [1]Thompson et al. (2009); Smith et al. (2011); Szczygieł et al. (2012b), [2]Prieto et al. (2008, 2009); Smith et al. (2009); Botticella et al. (2009); Pumo et al. (2009); Prieto et al. (2010); Szczygieł et al. (2012a), [3]Bond et al. (2009); Berger et al. (2009); Prieto et al. (2009); Kashi et al. (2010); Kochanek et al. (2012), [4]Elias-Rosa et al. (2010), [5]Cortini et al. (2011); Fraser et al. (2011); Magill et al. (2011)

In total, there were **22** supernovae in these 12 years and 11 Mpc, including 5 SN2008S-like supernova.
They are dimmer by 2-3 magnitude than usual and continuously discussed that *they are CCSN or not*.

Hyper-K can answer the question.

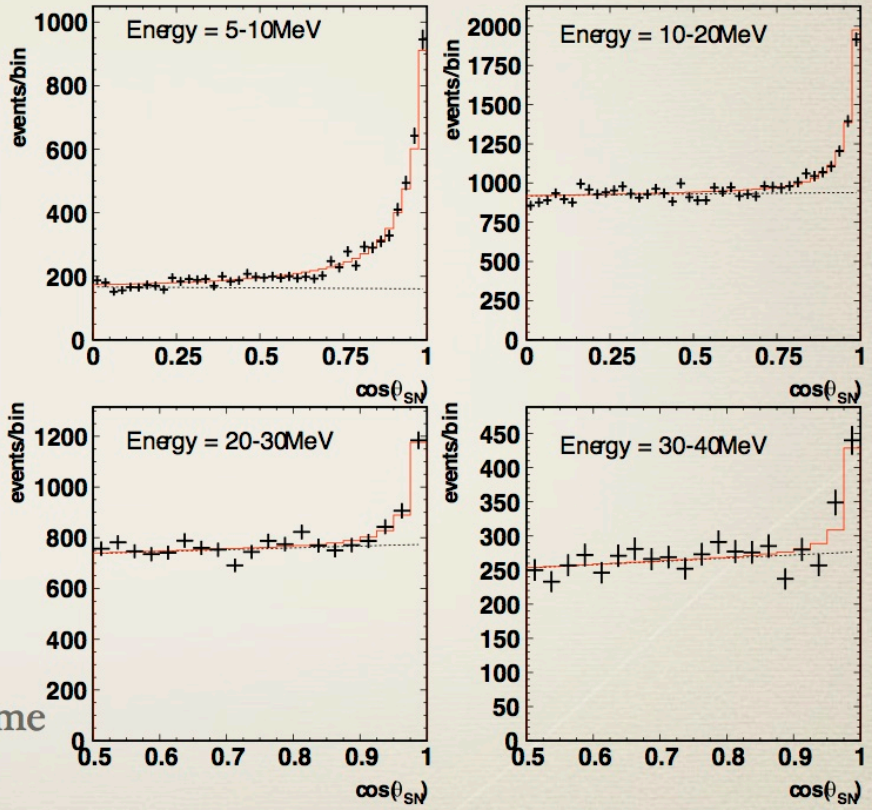
Galactic Supernova at Hyper-K

@ 10 kpc

Inverse beta ($\bar{\nu}_e + p \rightarrow e^+ + n$)	162,000~228,000
electron scattering ($\nu + e^- \rightarrow \nu + e^-$)	6,000~7,000
ν_e ^{16}O charged current	300~14,000
$\bar{\nu}_e$ ^{16}O charged current	2,000~13,000
total	170,000~260,000

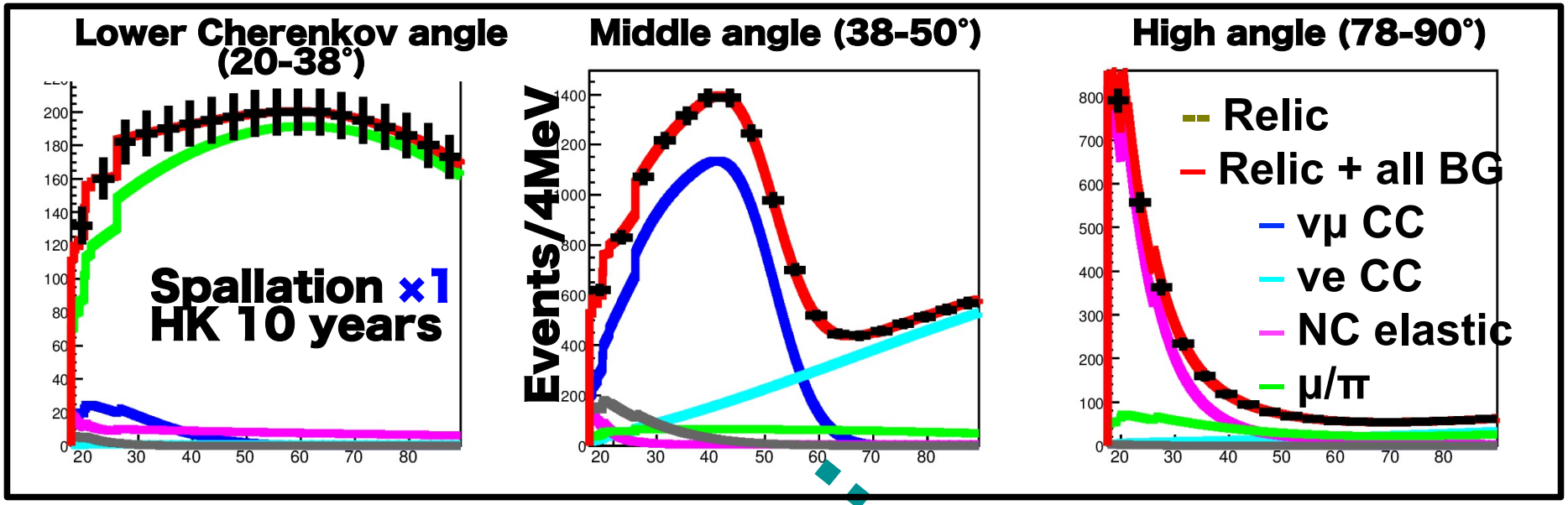
6.5MeV (kin.) energy threshold / 0.74Mton volume
No/NH/IH neutrino oscillation are assumed
spallation B.G. is ignorable.
(~20 events/0.74Mton/18sec.)

angular distributions



Y. Koshio, 1st Hyper-K Open meeting

Update : non-0 significance of SRN



1. Event samples are made from SK-II best fit **BG** spectrum and expected **SRN** spectrum (LMA model, Ando et al. 2003).
2. Signal efficiency of **relic spallation cut** and **other cuts (e.g. solar ν cut)** are considered. **(Updated)**
3. The event samples are fitted with **BG** and **LMA** spectra, using MINUIT2 (ROOT).