Detection of supernova neutrinos in Super-Kamiokande

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for Super-K collaboration

2014,6,26@IHEP2014,Protvino

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Super-Kamiokande collaboration

PRL 112, 091805 (2014) PHYSICAL REVIEW LETTERS week ending 7 MARCH 2014

First Indication of Terrestrial Matter Effects on Solar Neutrino Oscillation

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(The Super-Kamiokande Collaboration)

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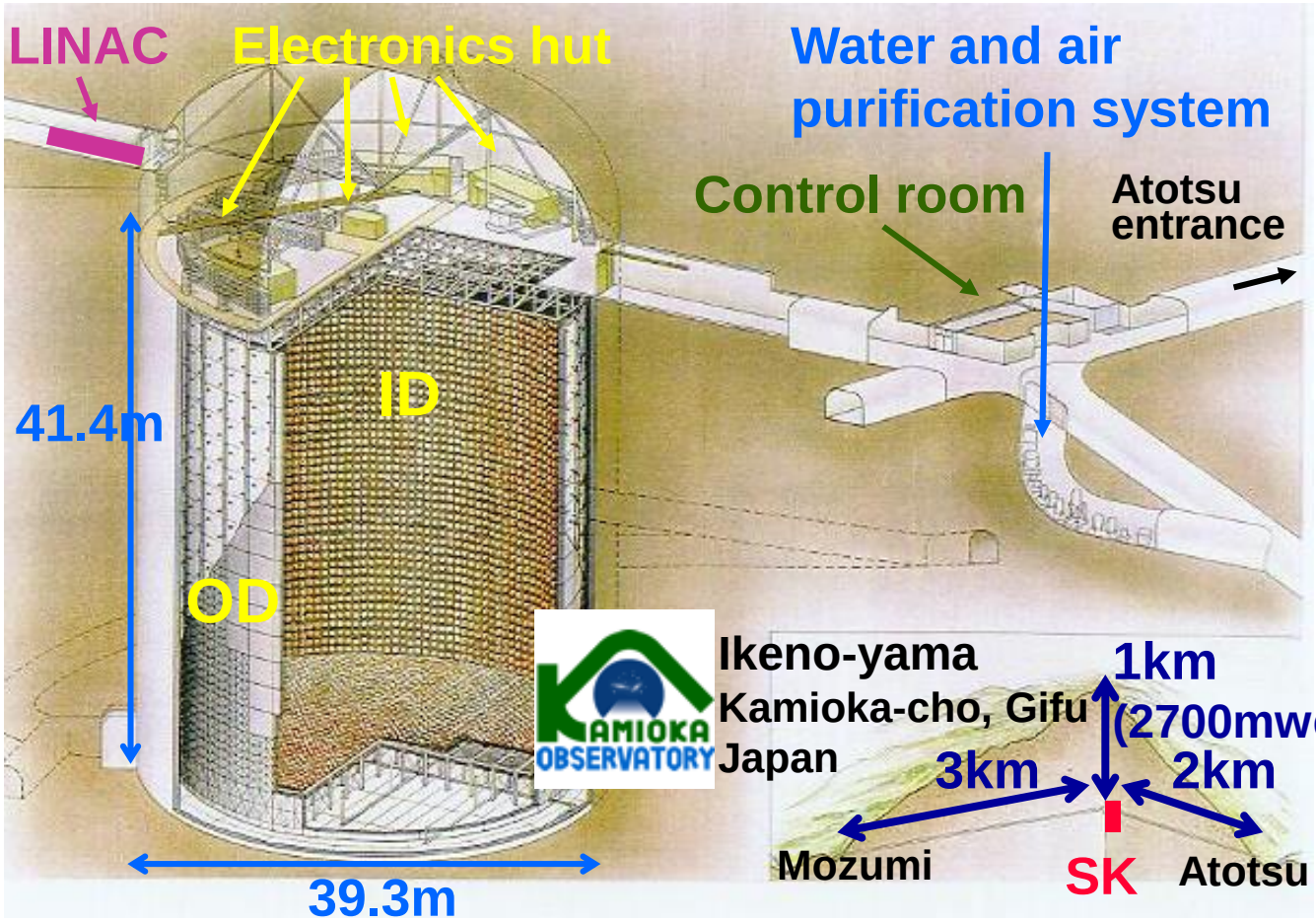
12 Gifu University, Japan
25 Shizuoka University of Welfare, Japan
13 GIST College, Korea
26 Sungkyunkwan University, Korea
14 University of Hawaii, USA
27 Tokai University, Japan
28 University of Tokyo, Japan

~120 collaborators
35 institutions
7 countries

Super-Kamiokande detector



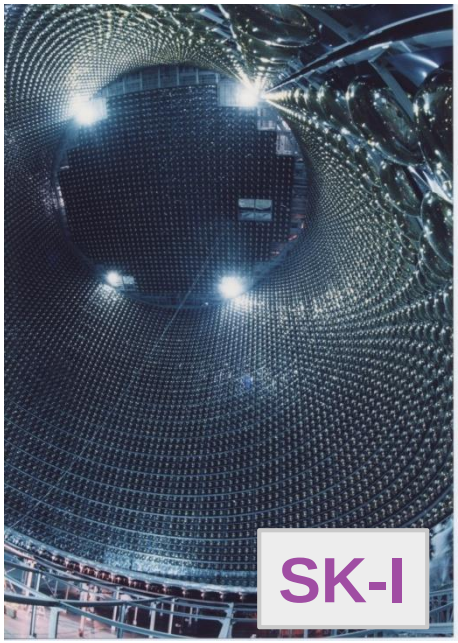
- 50kton water
- ~2m OD viewed by 8-inch PMTs
- 32kt ID viewed by 20-inch PMTs
- 22.5kt fid. vol. (2m from wall)
- ~4.5MeV energy threshold
- SK-I: April 1996~
- SK-IV is running

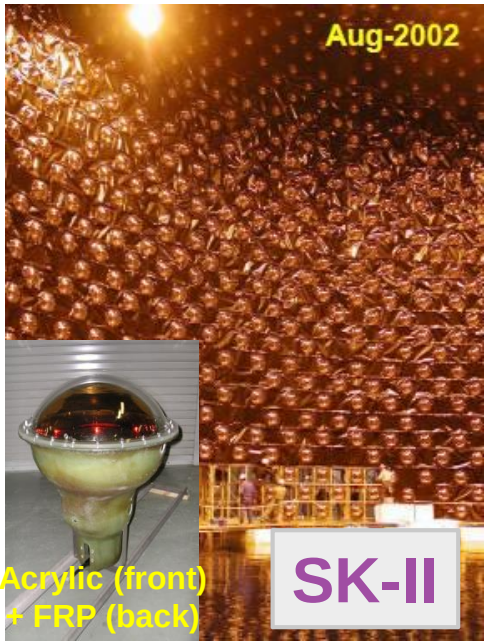
Inner Detector (ID) PMT: ~11100 (SK-I,III,IV), ~5200 (SK-II)
Outer Detector (OD) PMT: 1885

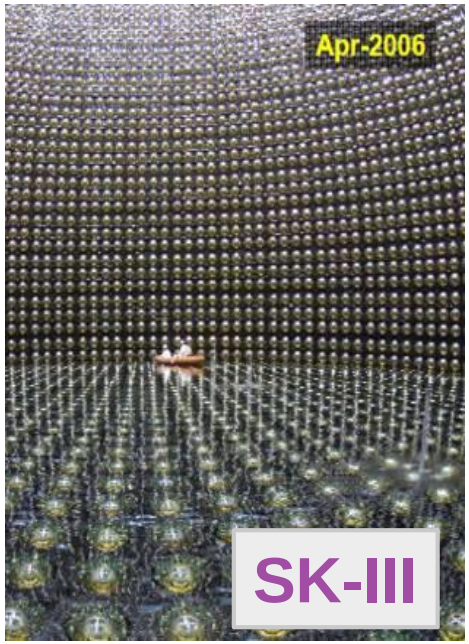
History of Super-Kamiokande

96 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14

SK-I SK-II SK-III SK-IV







	SK-I	SK-II	SK-III	SK-IV	
	11146 ID PMTs (40% coverage)	5182 ID PMTs (19% coverage)	11129 ID PMTs (40% coverage)	Electronics Upgrade	
Energy Threshold (Total energy)	5.0 MeV	7.0 MeV	5.0 MeV	~4.5 MeV	< 4.0 MeV
(Kinetic energy)	~4.5 MeV	~6.5 MeV	~4.5 MeV	~4.0 MeV	<~3.5 MeV
				Current	Target

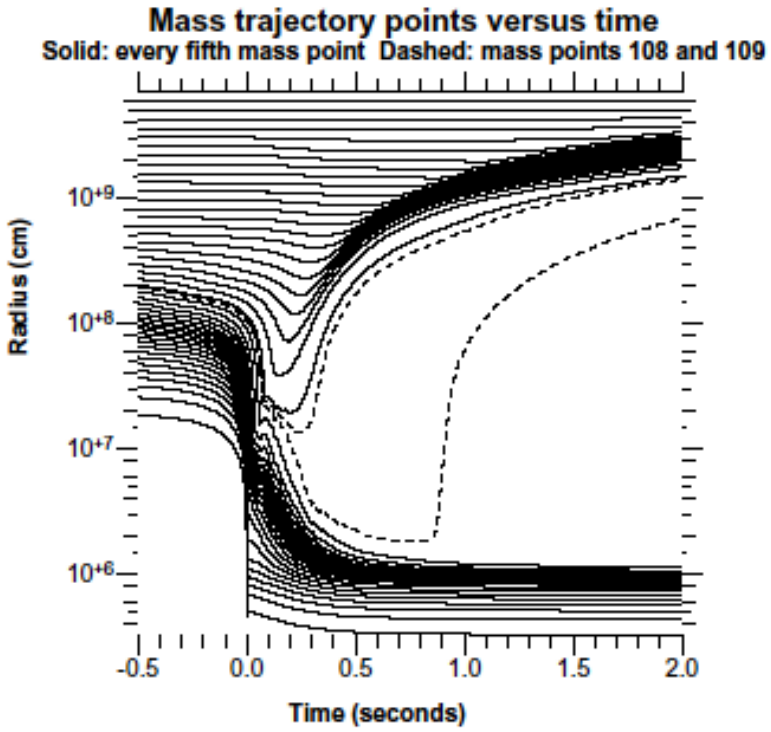
Neutrinos from Supernova

Released gravitational energy: ~3x10^{53} erg

Neutrinos carry almost all (99%) of the energy.

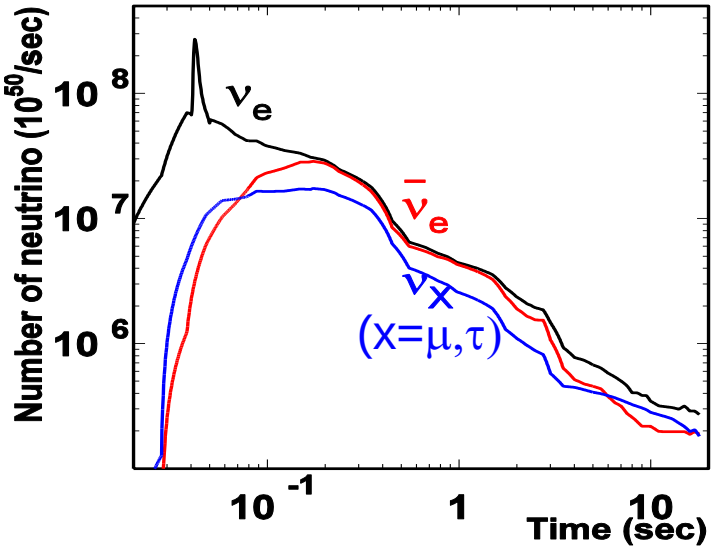
Energy for explosion and optical emission is only ~1%(~10^{51}erg).

Livermore simulation

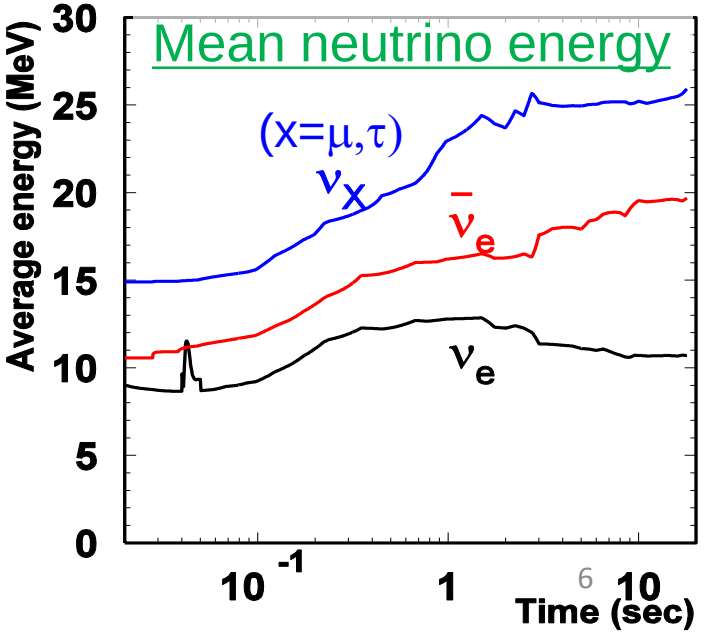


T.Totani, K.Sato, H.E.Dalhed and J.R.Wilson, ApJ.496,216(1998)

Expected time profile

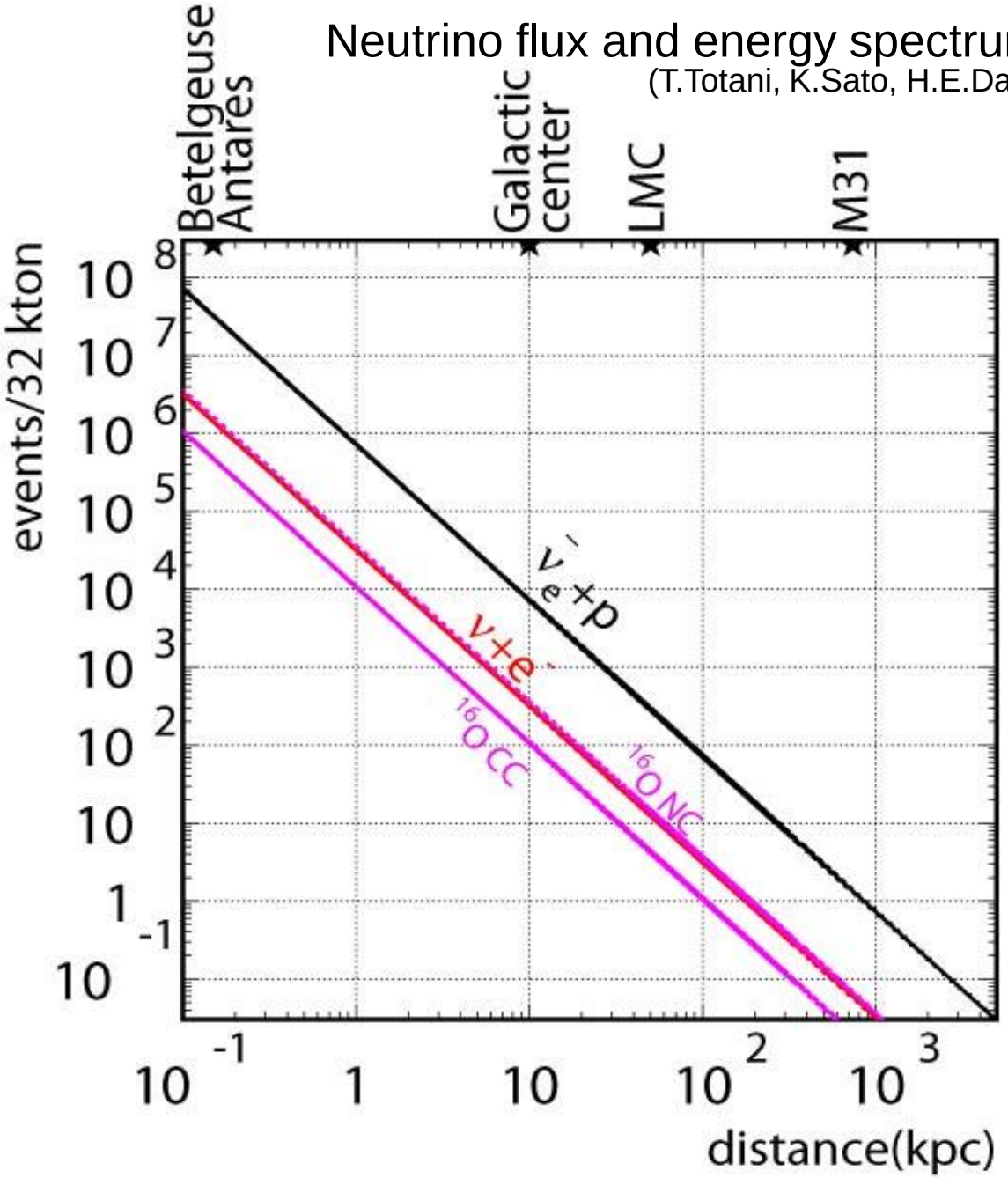


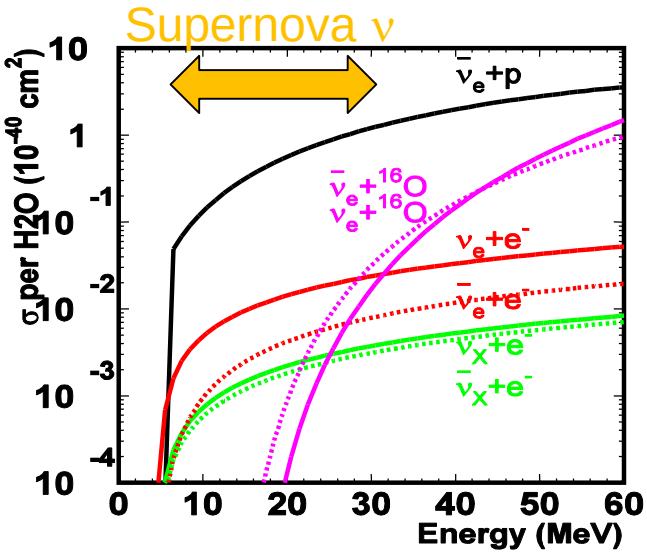
Mean neutrino energy



SN burst detection at SK

Neutrino flux and energy spectrum from Livermore simulation
(T.Totani, K.Sato, H.E.Dalhed and J.R.Wilson, ApJ.496,216(1998))



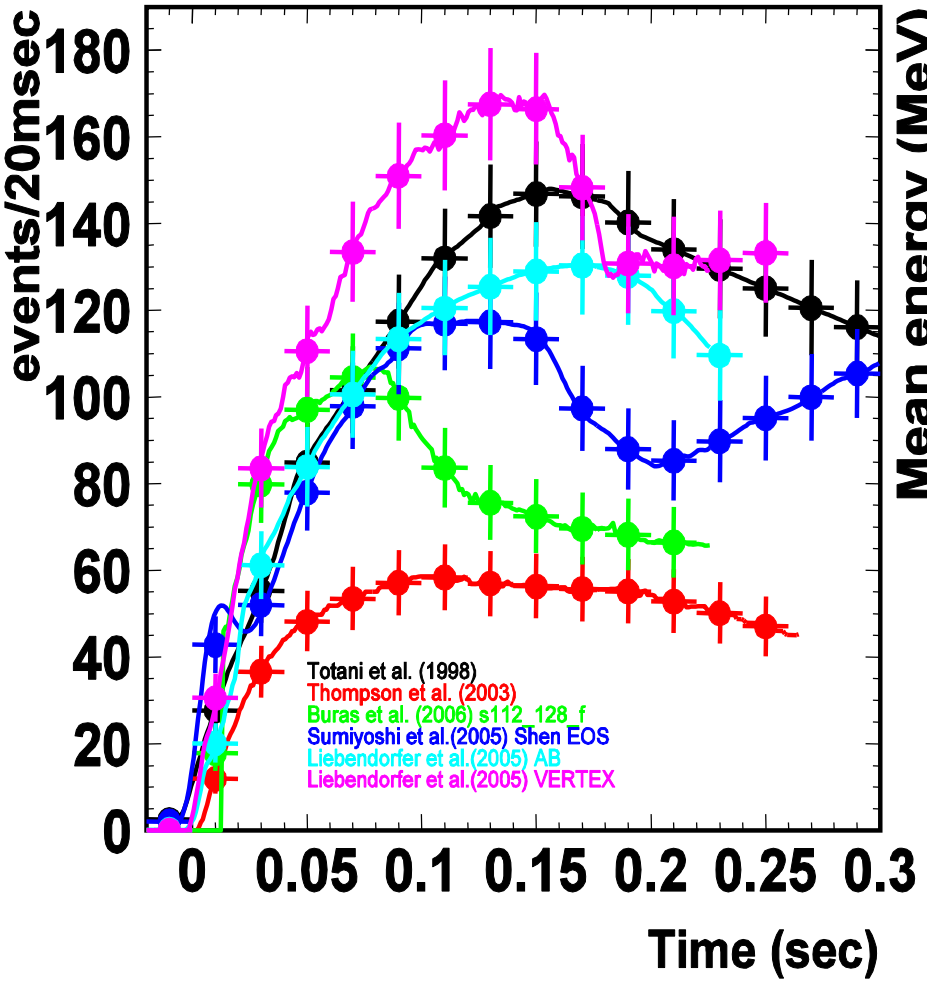


~7,300 $\bar{\nu}_e$+p events
~300 ν+e events
~360 ^{16}O NC γ events
~100 ^{16}O CC events
(with 5MeV thr.)
for 10 kpc supernova

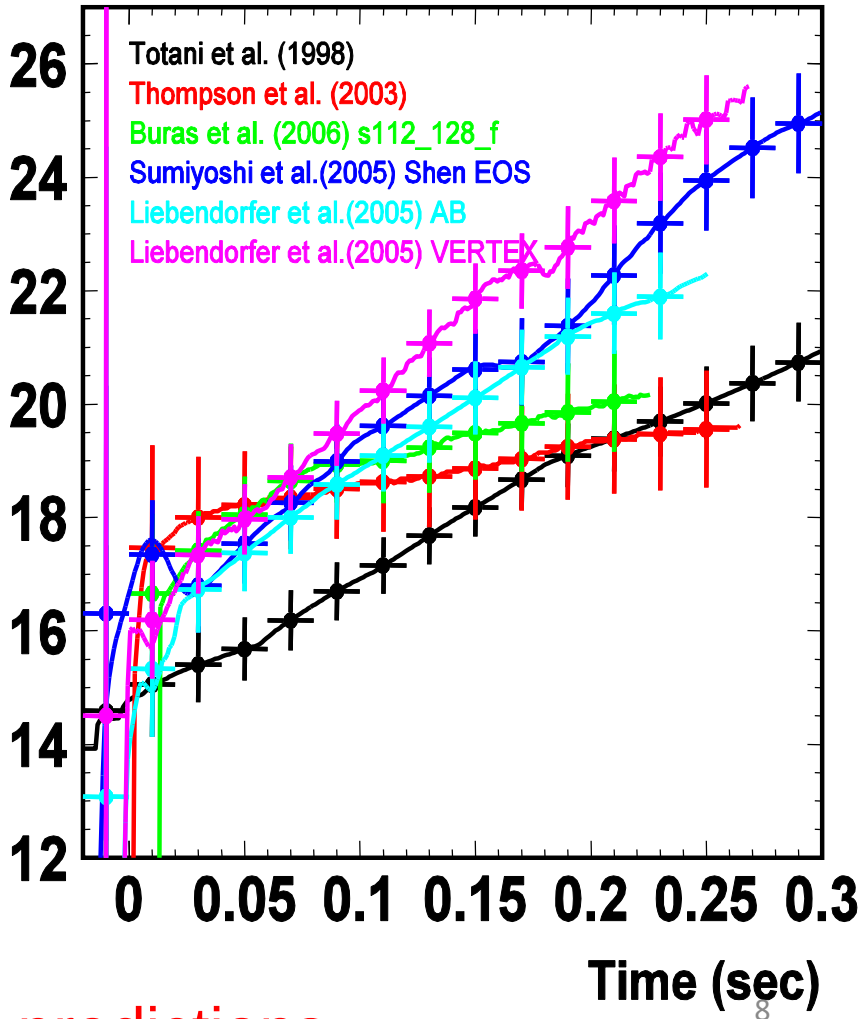
Super-K: Time variation measurement by $\bar{\nu}_e$+p

Assuming a supernova at 10kpc.
$\bar{\nu}_e p \rightarrow e^+ n$ events give direct energy information ($E_e = E_\nu - 1.3\text{MeV}$).

Time variation of event rate

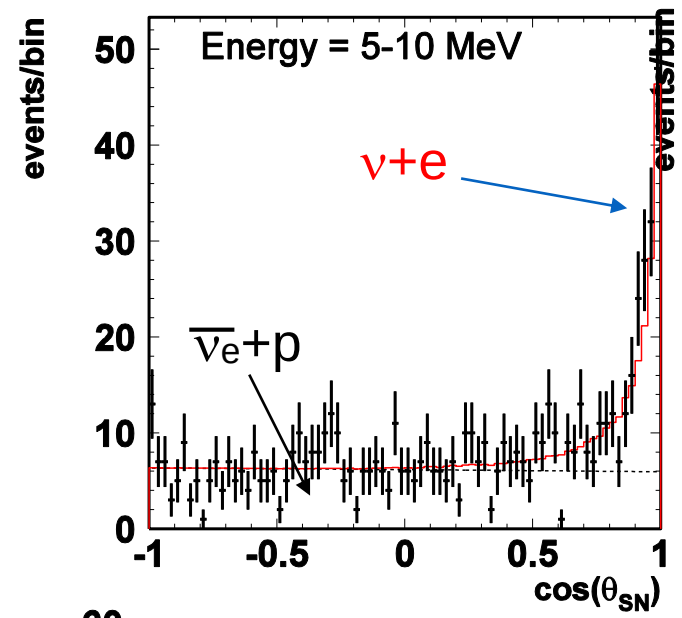


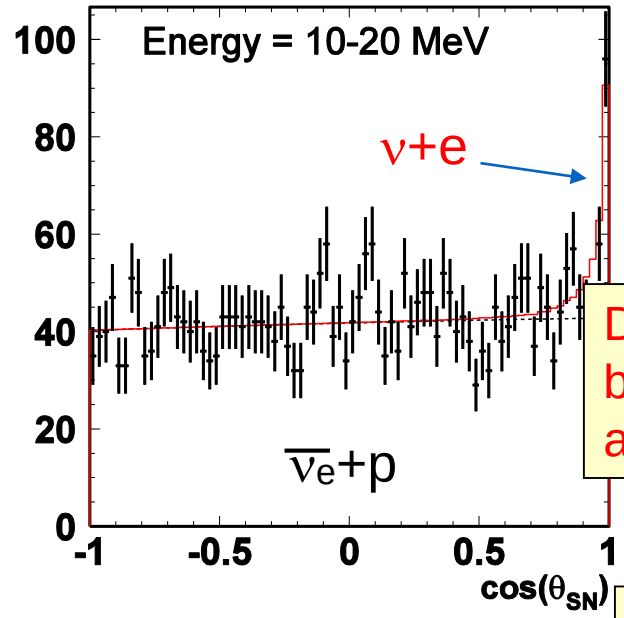
Time variation of mean energy

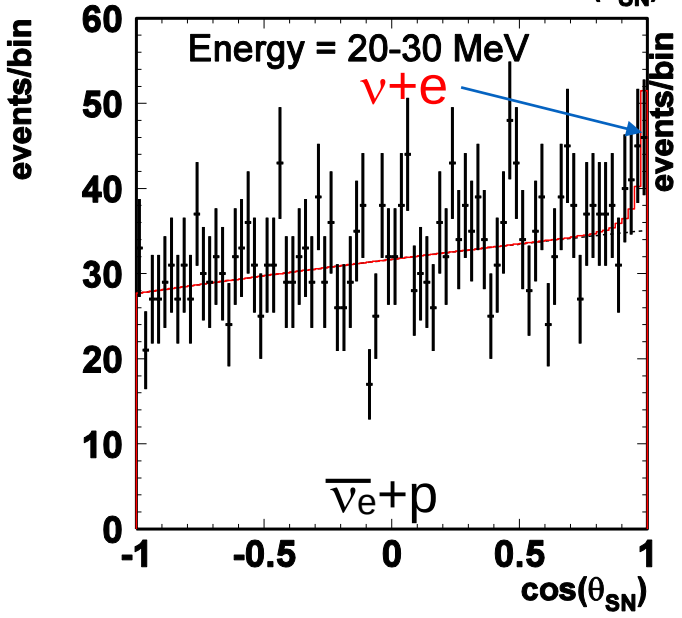


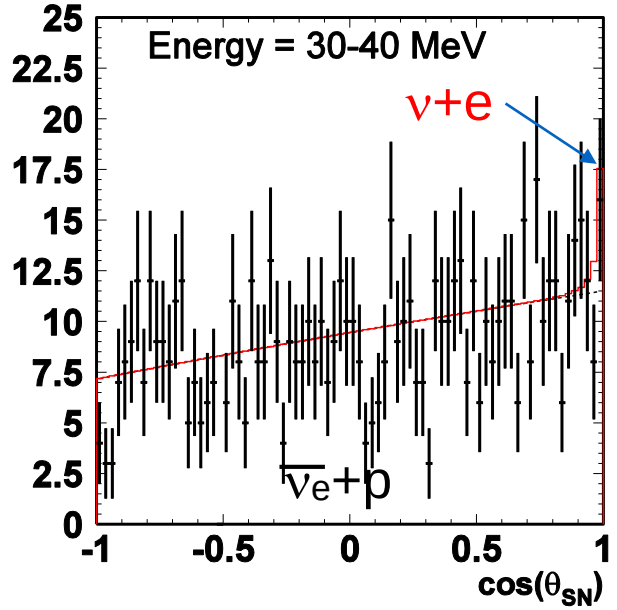
Enough statistics to discuss model predictions

Super-K: simulation of angular distribution









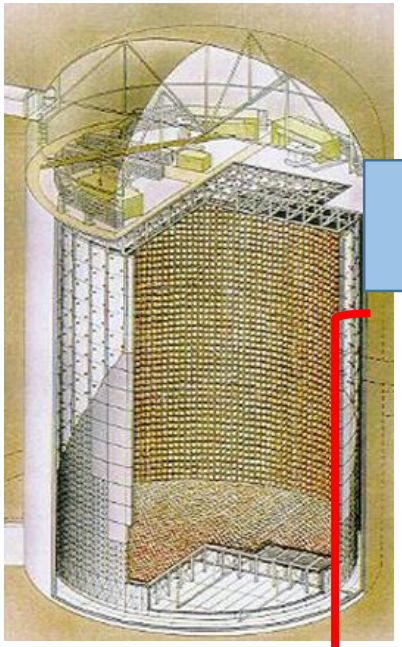
SN at 10kpc

Direction of supernova can be determined with an accuracy of ~5 degree.

Spectrum of ν+e events can be statistically extracted using the direction to supernova.

Neutrino flux and spectrum from Livermore simulation

Supernova monitor



DAQ system

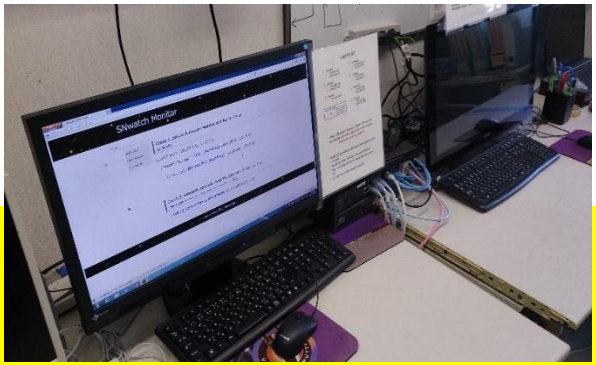
Real time process

Offline analysis

Independent system is running for SN monitor.

SN monitor process

- Reformat Process
- Event Reconstruction
- Combine all data and fit SN direction

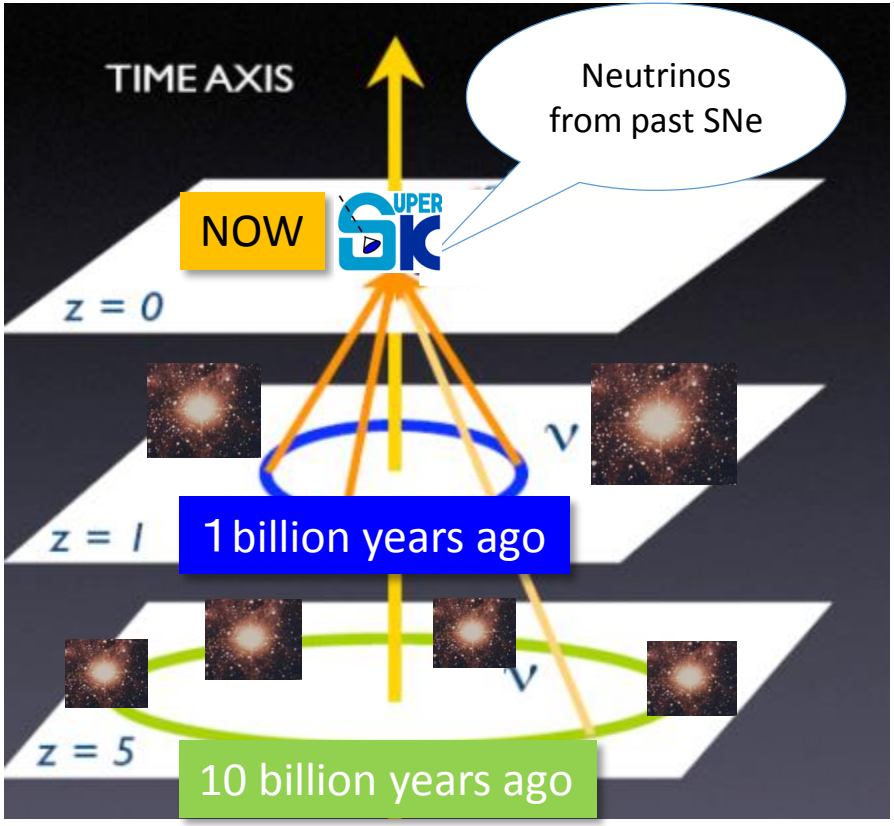


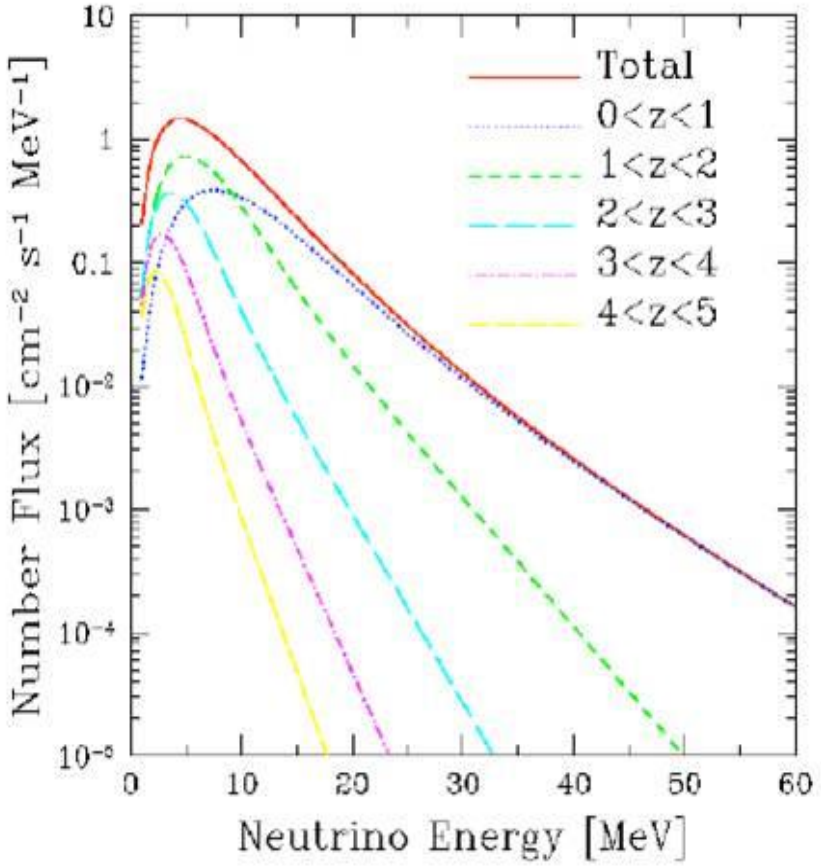
Within 15min!

SN alarm

- Alert for SK shift
- Call and send email to experts
  - Vertex distribution, energy, time profile and direction etc.

Supernova Relic Neutrino





S.Ando, Astrophys.J. 607, 20(2004)

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

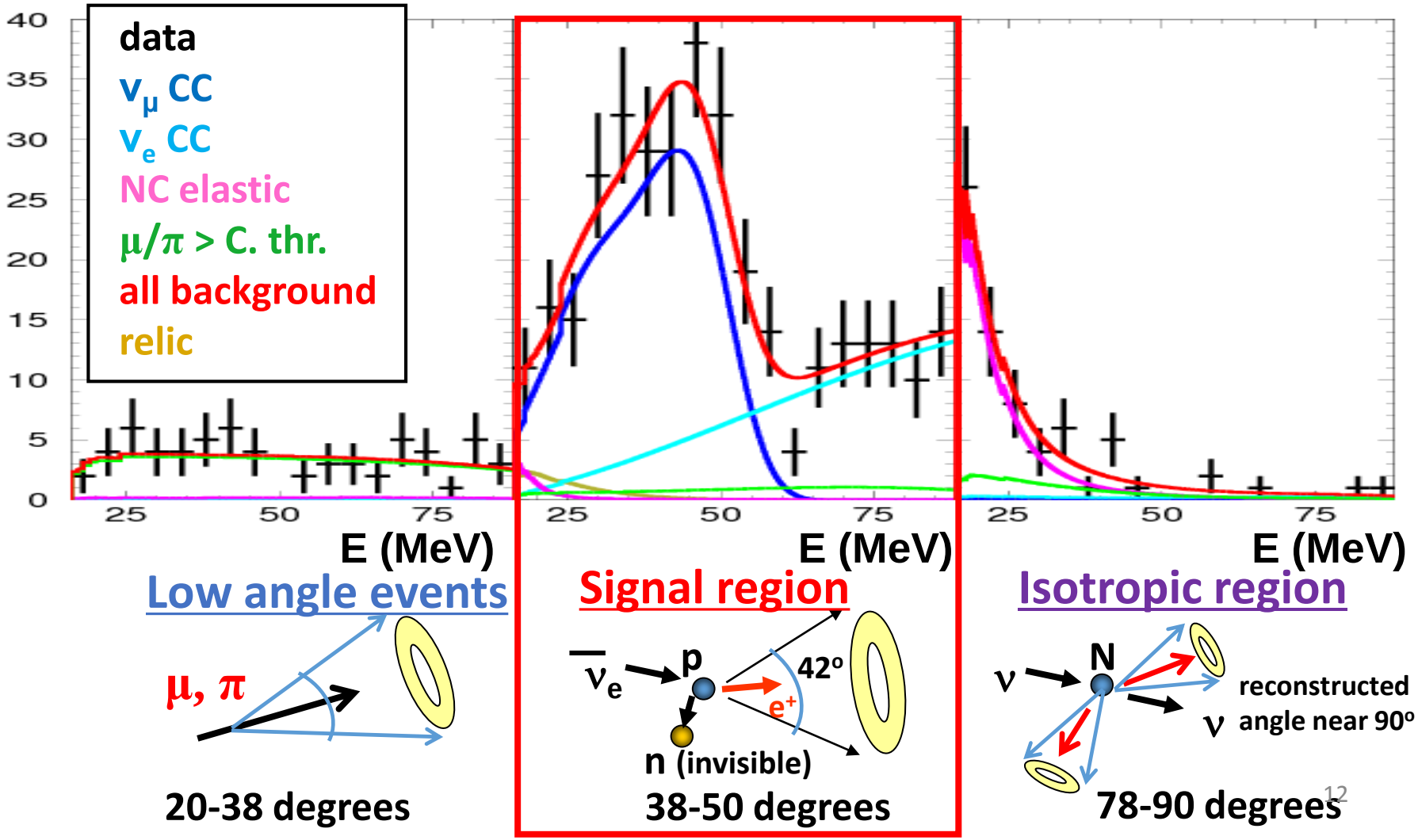
SRN upper limit from SK

PRD 85, 052007 (2012)

SK combined 90% C.L. (SK4 is not included yet)

< 5.1 ev / yr / 22.5 ktons = **< 2.7 /cm²/s (>16 MeV)**

(using LMA model spectrum (Ando et.al, 2005)



Future plan

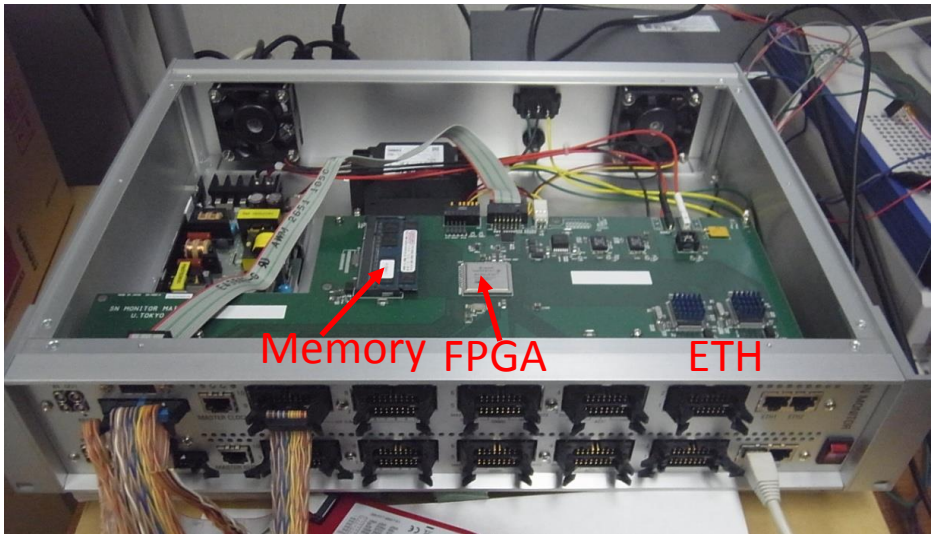
- New electronics for close SN
- Gd project
- Hyper-Kamiokande

New electronics for very close SN

- In case of very close SN(ex. Betelgeuse : 0.2kpc)
- Expected event rate $> 10^7$ events / 10 sec
- Current DAQ limitation : 6×10^6 events/ 10 sec

New electronics only for very close SN is under development.

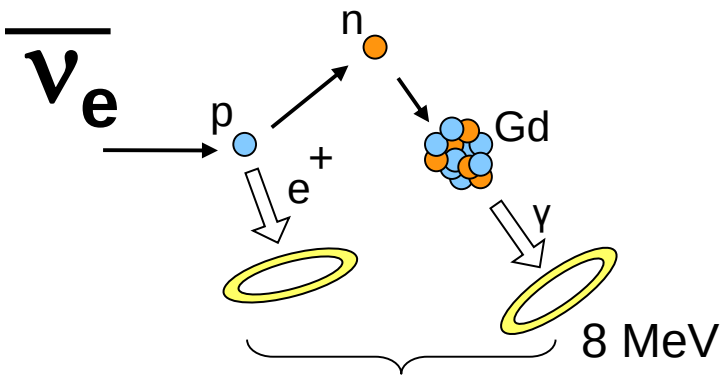
-Additional module to current elec.
-Save only number of hits every 16ns
→ Energy × Flux
-No dead time
-Will be installed in this year



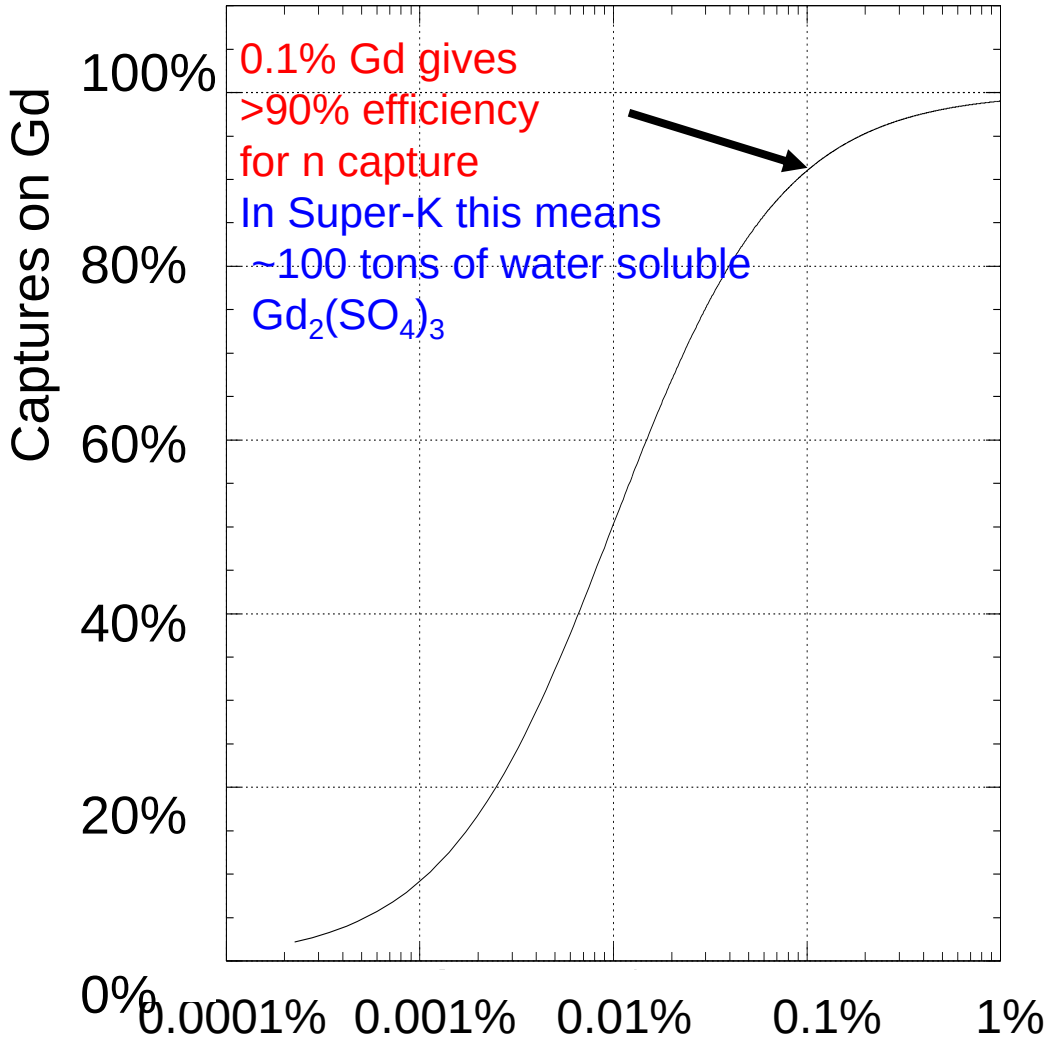
Gd project in SK (GADZOOKS!)

Identify $\overline{\nu}_e p$ events by neutron tagging with Gadolinium.

Gadolinium has large neutron capture cross section and emit 8MeV gamma cascade.



ΔT~20μs
Vertices within 50cm



EGADS

Evaluating Gadolinium's
Action on Detector Systems

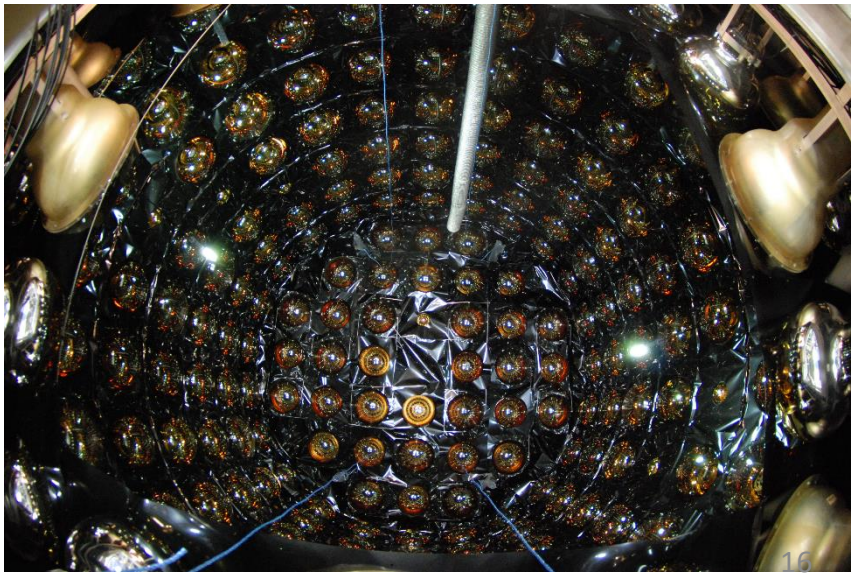
- Effect to water transparency
  - Confirmed to be OK w/o PMT
  - Test with PMTs is ongoing
- Water purification system
  - Design for SK is on going
- Material effect
- Ambient neutron level

Summarize the results within a year.

→ Make decision among collaborators.

→Construction +test (~2year)

→Start observation

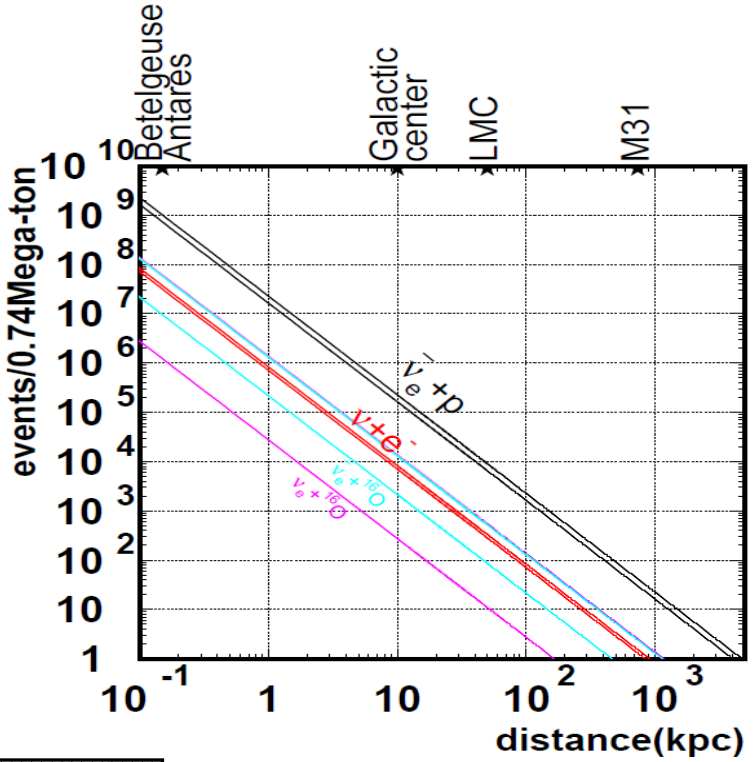


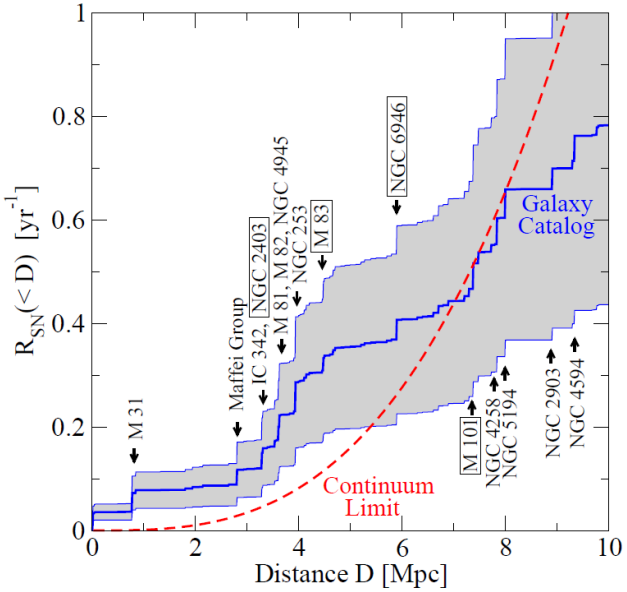
Hyper-Kamiokande

Fiducial volume of HK is 20 times larger than that of SK:

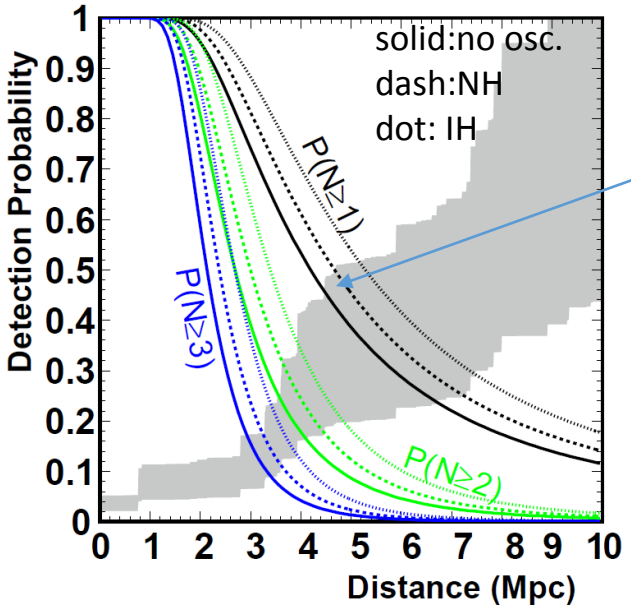
~200,000 events from SN@G.C.

This will give us some sensitivity for SNe in nearby galaxies.





S. Ando et al PRL 95, 171101 (2005)

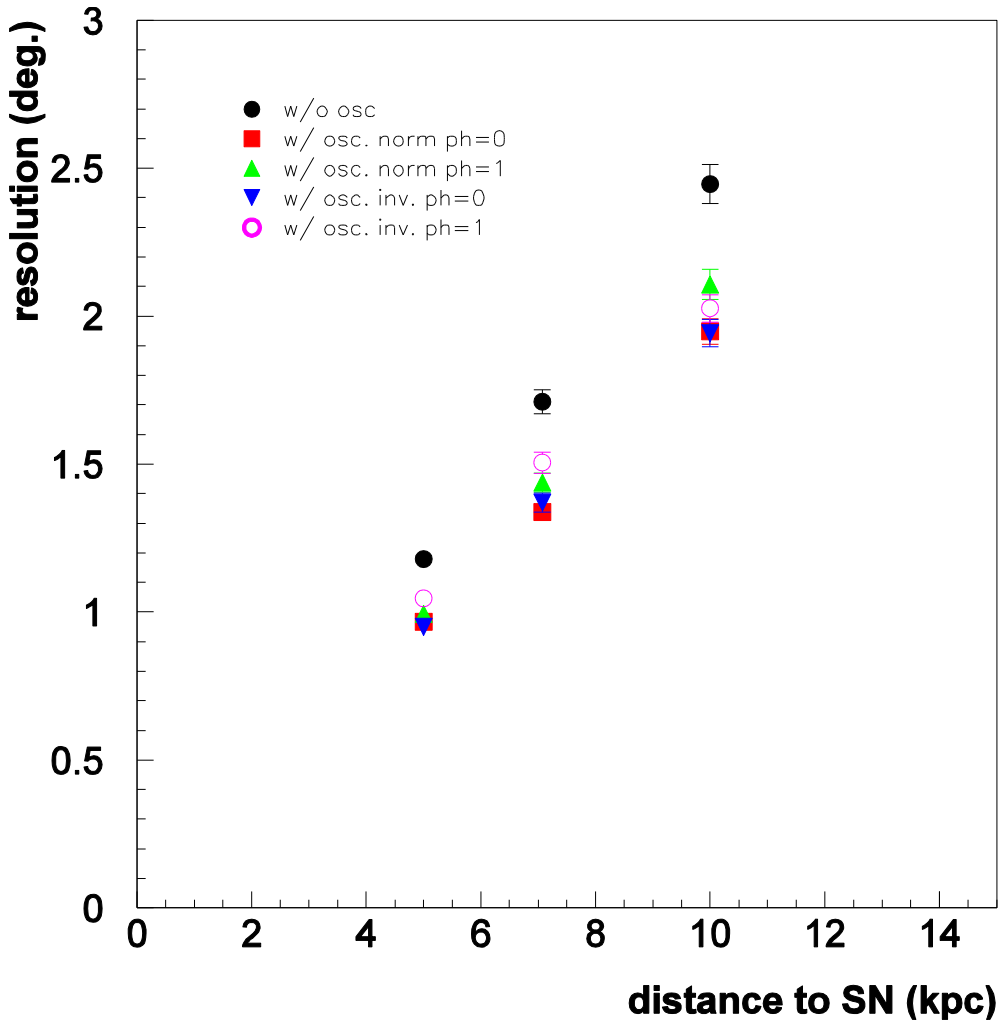


If we can take coincidence with other experiments (ex. GW), even single event can be identified as SN neutrino.

Summary

- Super-K has been ready for SN for ~15years.
  - If SN happens in near G.C., ~10000 events will be detected.
  - This will give a important information to understand the mechanism of the supernova mechanism.
  - SRN limit is close to theoretical prediction.
- Future plan
  - New electronics for very close SNe
  - Study of SRN with Gd is on going
  - HK has potential to detect SN@nearby galaxy
- Please wish SN in our galaxy while SK/HK is ON!

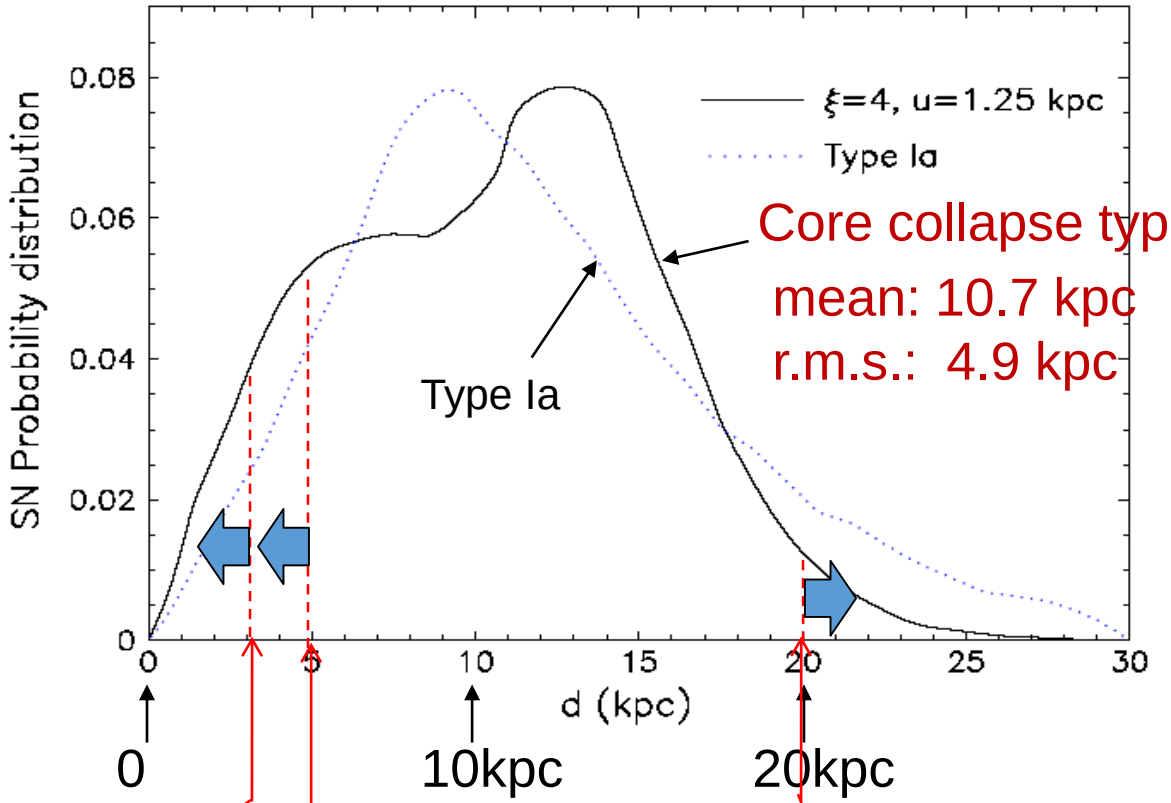
Angular resolution vs. distance



Distance to Galactic supernova

Mirizzi, Raffelt and Serpico, JCAP 0605,012(2006), astro-ph/0604300

Based on birth location of neutron stars

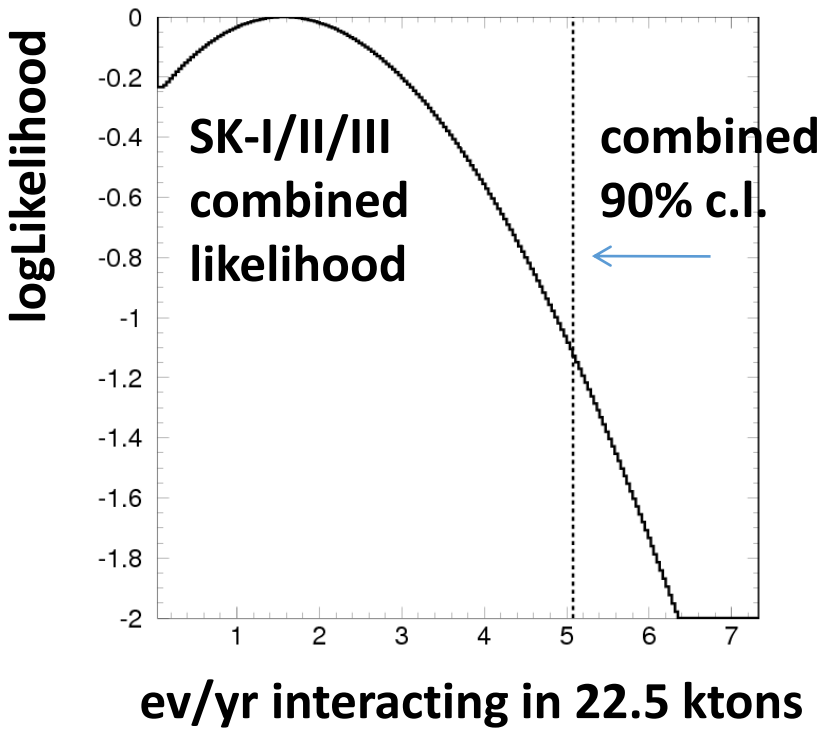


7% probability
< 3.16 kpc
> x10 statistics

16% probability
< 5 kpc
> x 4 statistics

3% probability
> 20 kpc
< 1/4 statistics

Upper limit from SK



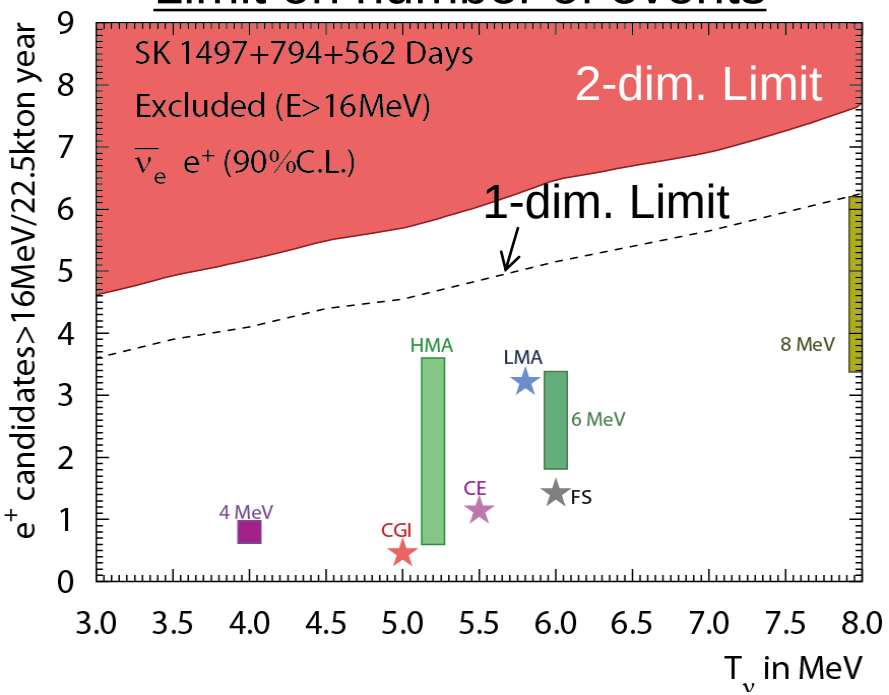
combined 90% c.l.:

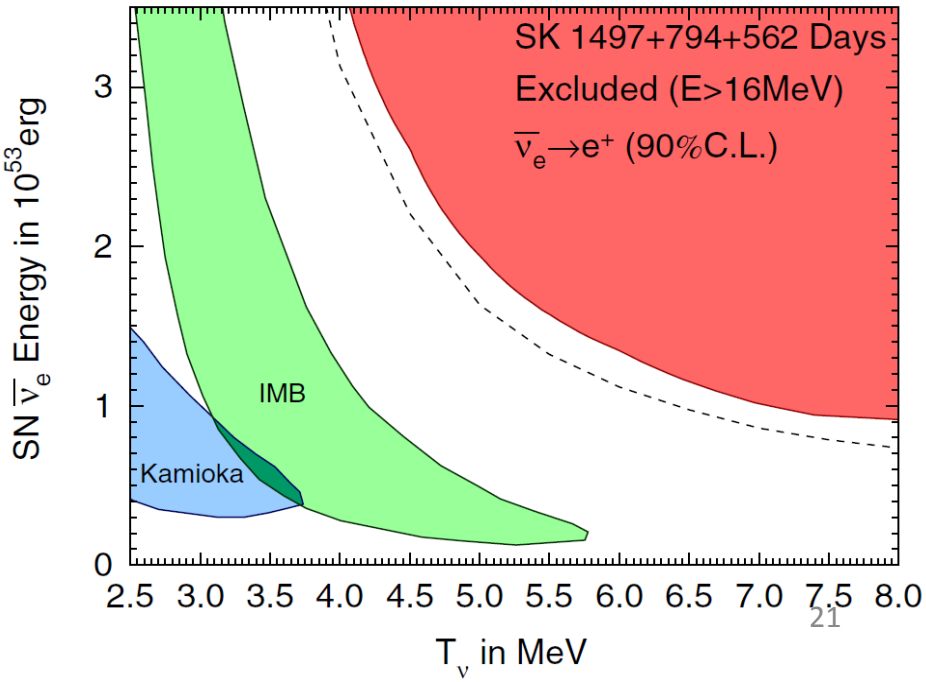
< 5.1 ev / yr / 22.5 ktons

< 2.7 /cm²/s (>16 MeV)

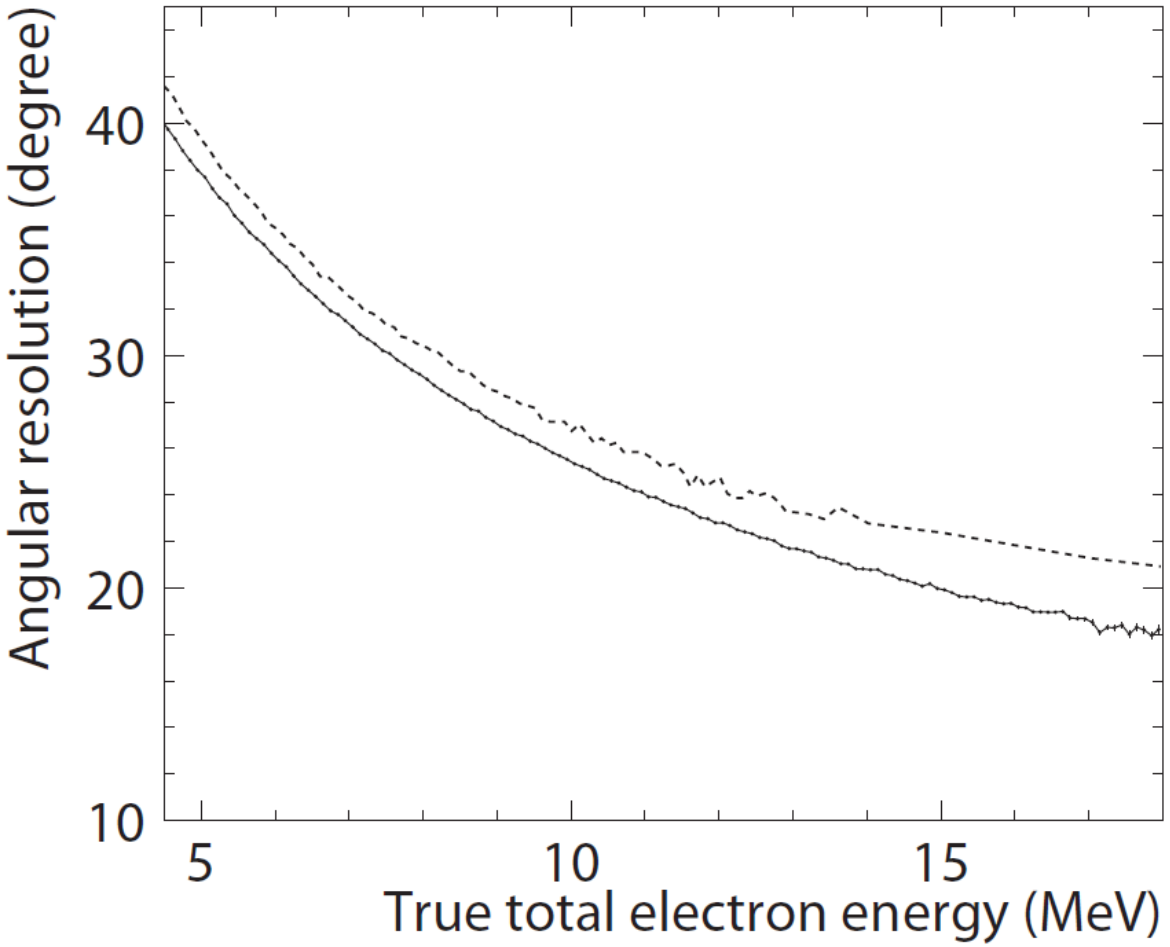
(using LMA model prediction (Ando et.al, 2005)

Limit on number of events



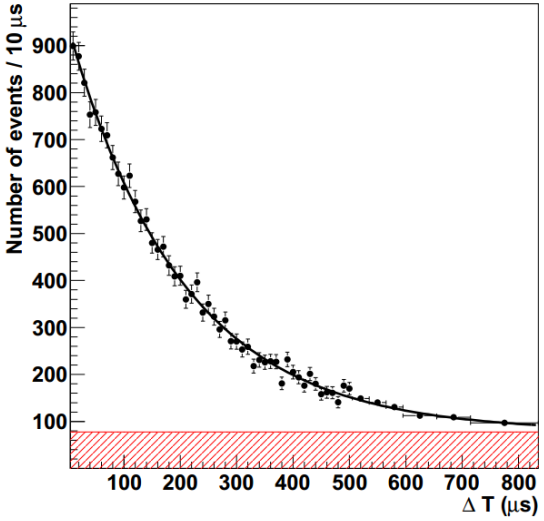


Angular resolution of SK (e-scat.)

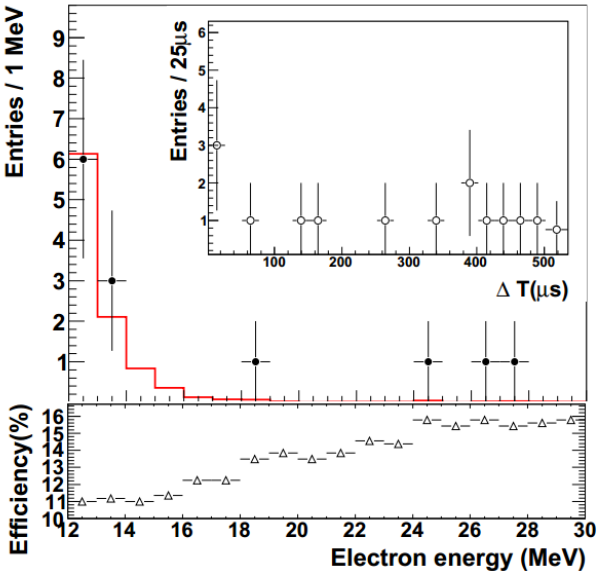


SRN with n capture by p

SK-4 960 days



Am/Be calibration



Physics run

Flux upper limit