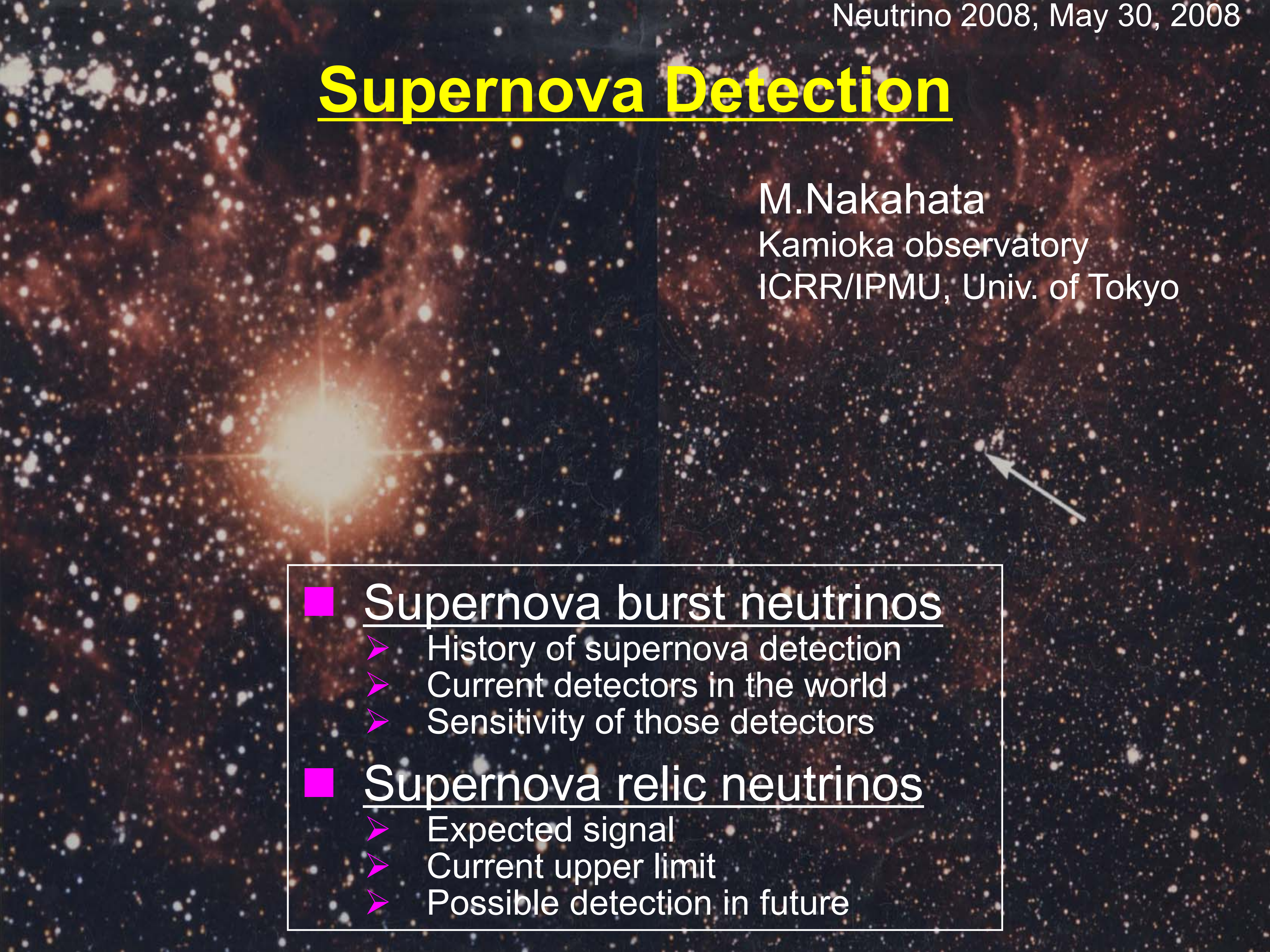


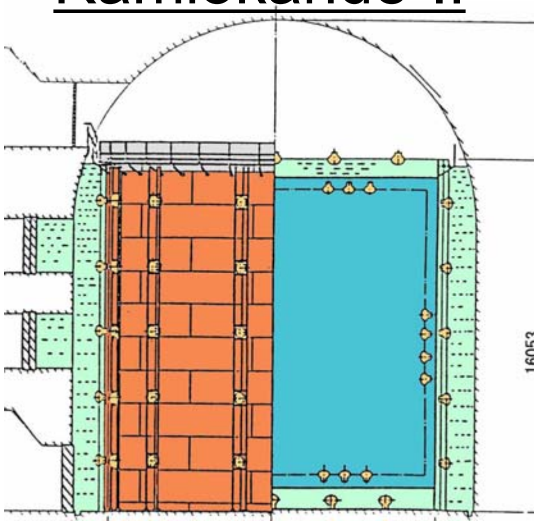
Supernova Detection

M.Nakahata
Kamioka observatory
ICRR/IPMU, Univ. of Tokyo

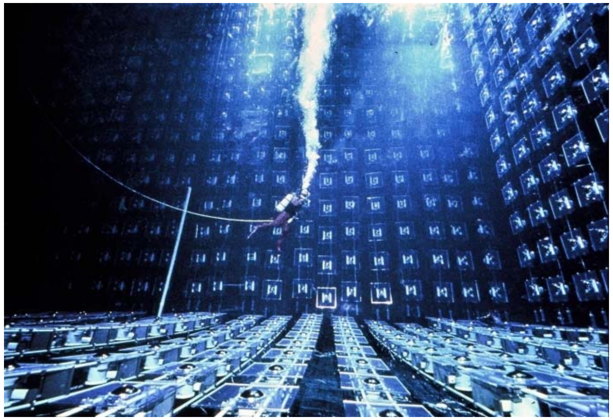
- **Supernova burst neutrinos**
  - History of supernova detection
  - Current detectors in the world
  - Sensitivity of those detectors
- **Supernova relic neutrinos**
  - Expected signal
  - Current upper limit
  - Possible detection in future

SN1987A: supernova at LMC(50kpc)

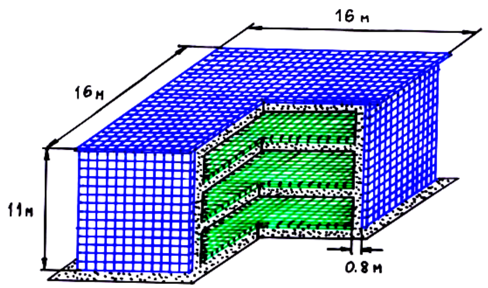
Kamiokande-II



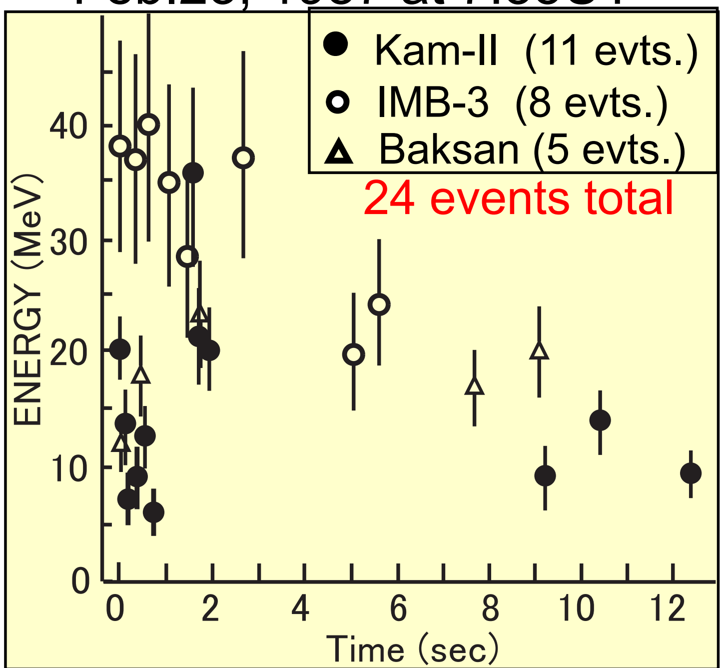
IMB-3

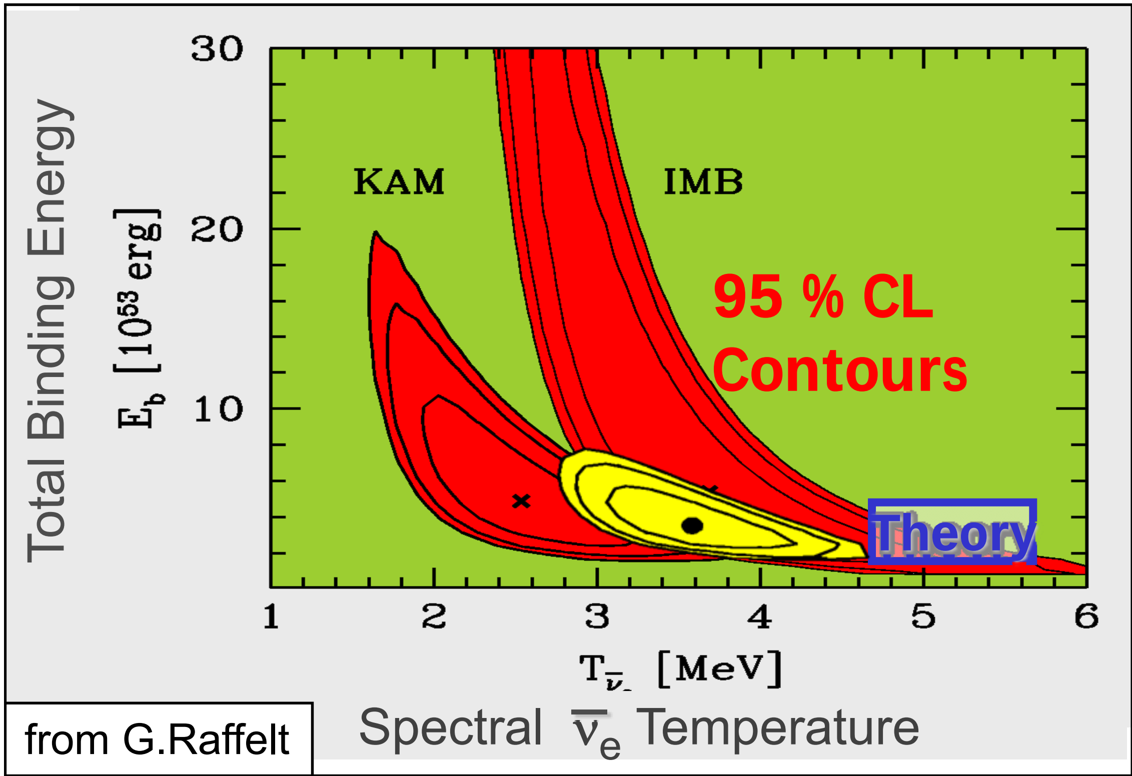


BAKSAN



Feb.23, 1987 at 7:35UT





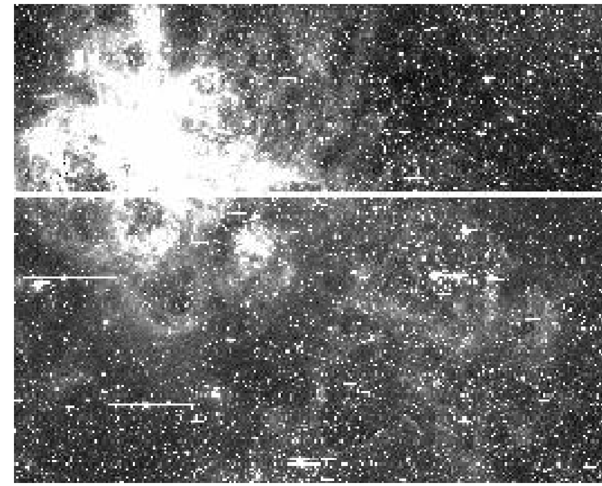
Have you seen Large Magellanic Cloud(LMC)?

I visited Mt. John Observatory yesterday, and saw LMC with the naked eye. (Thanks to Prof.Itow (Nagoya Univ.)).

We are here.
Mt. John Observatory

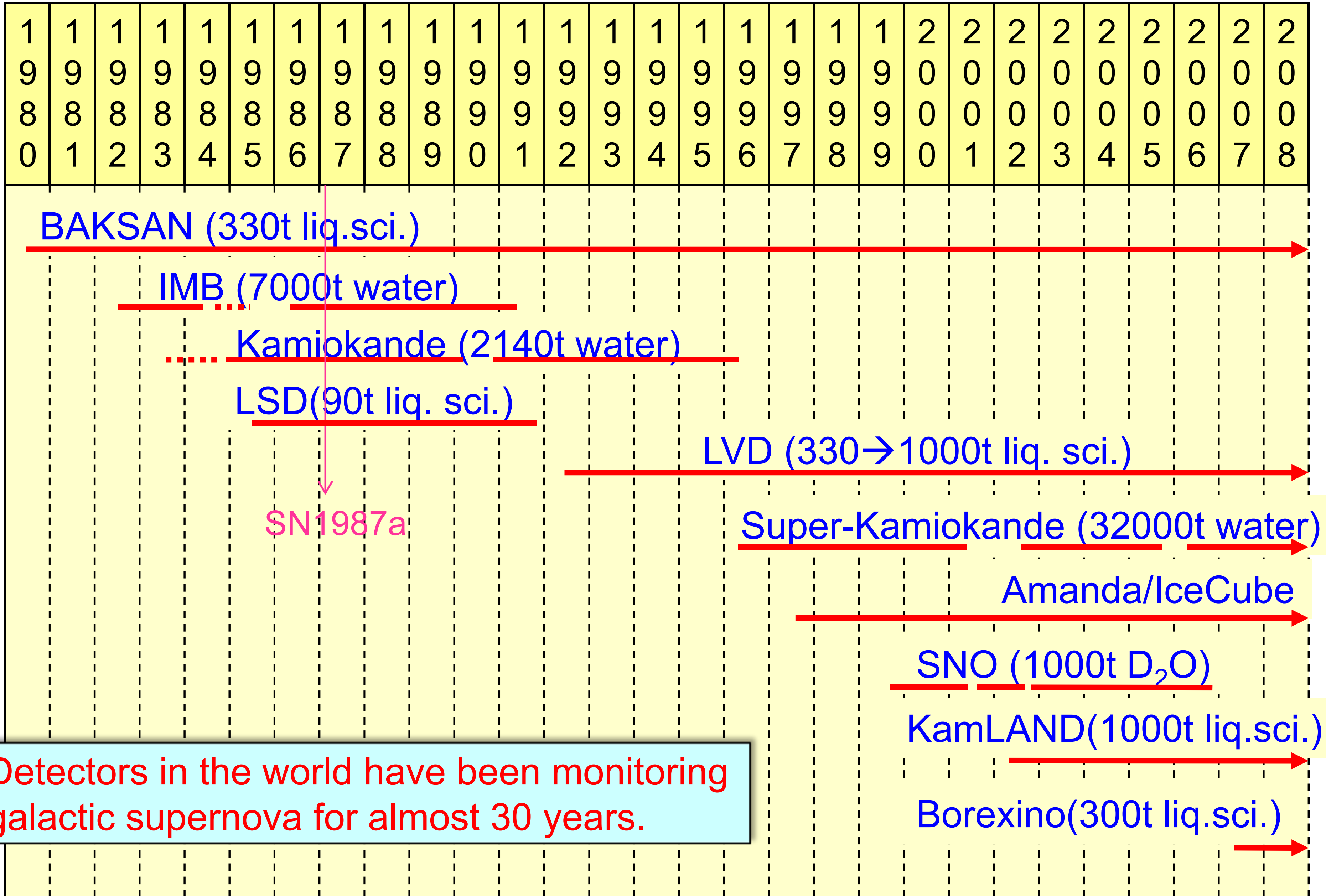
MOA 1.8m telescope
（Microlensing Observation in Astrophysics)

Tarantula Nebula by MOA on May 28, 2008



In 1987 by AAO

History of supernova detectors

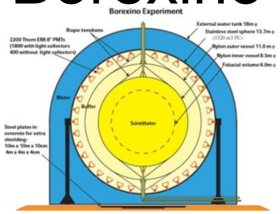


Detectors in the world have been monitoring galactic supernova for almost 30 years.

Supernova detectors in the world

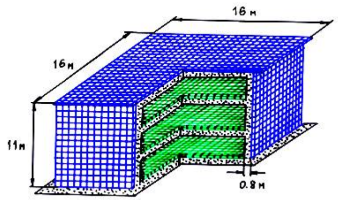
(running and near future experiments)

Borexino

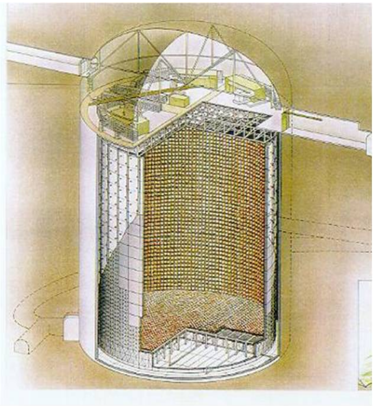


LVD

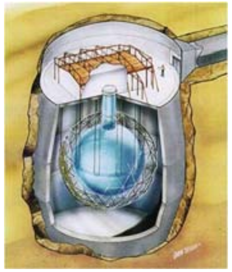
Baksan



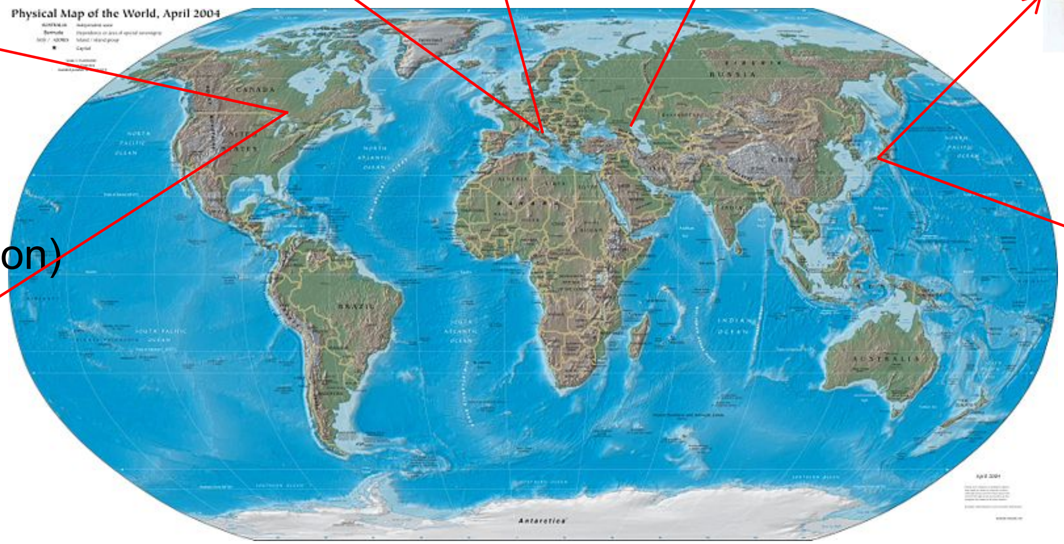
Super-K



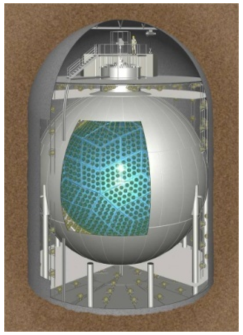
SNO+



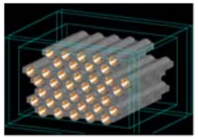
(beginning construction)



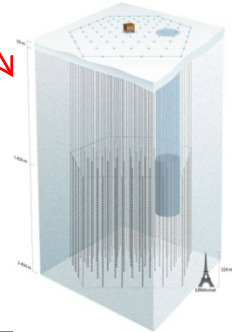
KamLAND



HALO



(proposed)

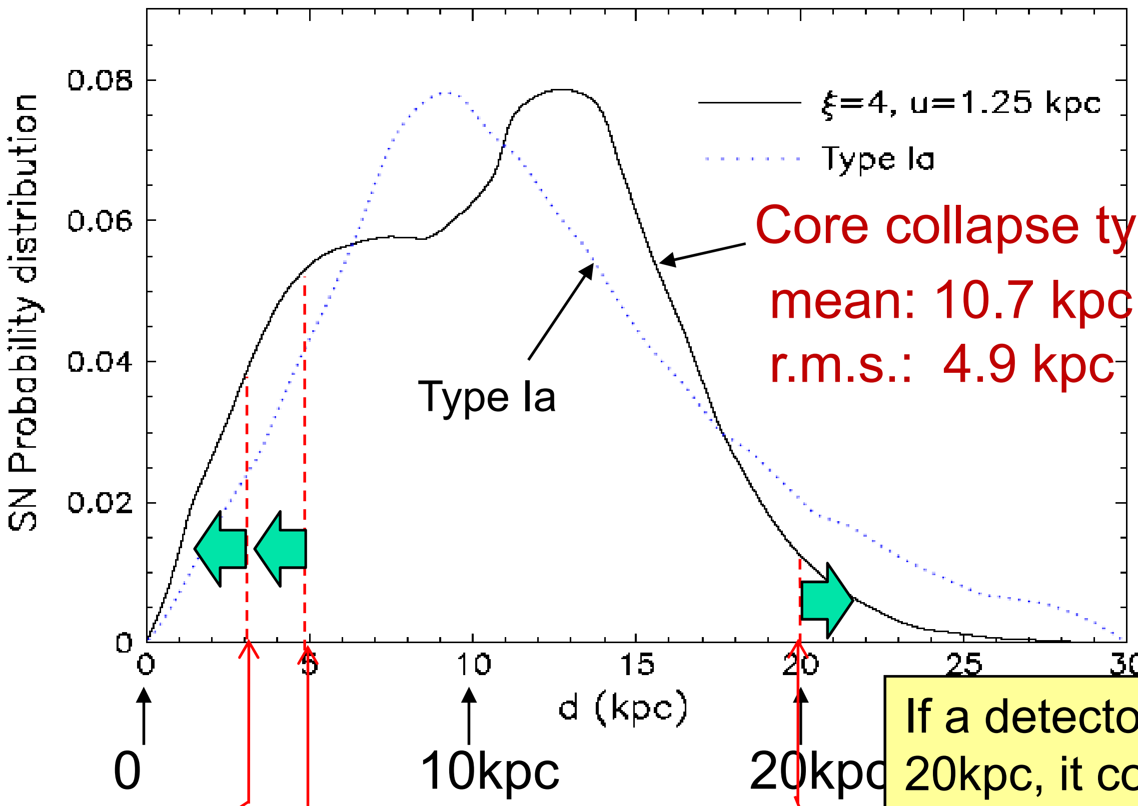


IceCube

Distance to Galactic supernova

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

Based on birth location of neutron stars



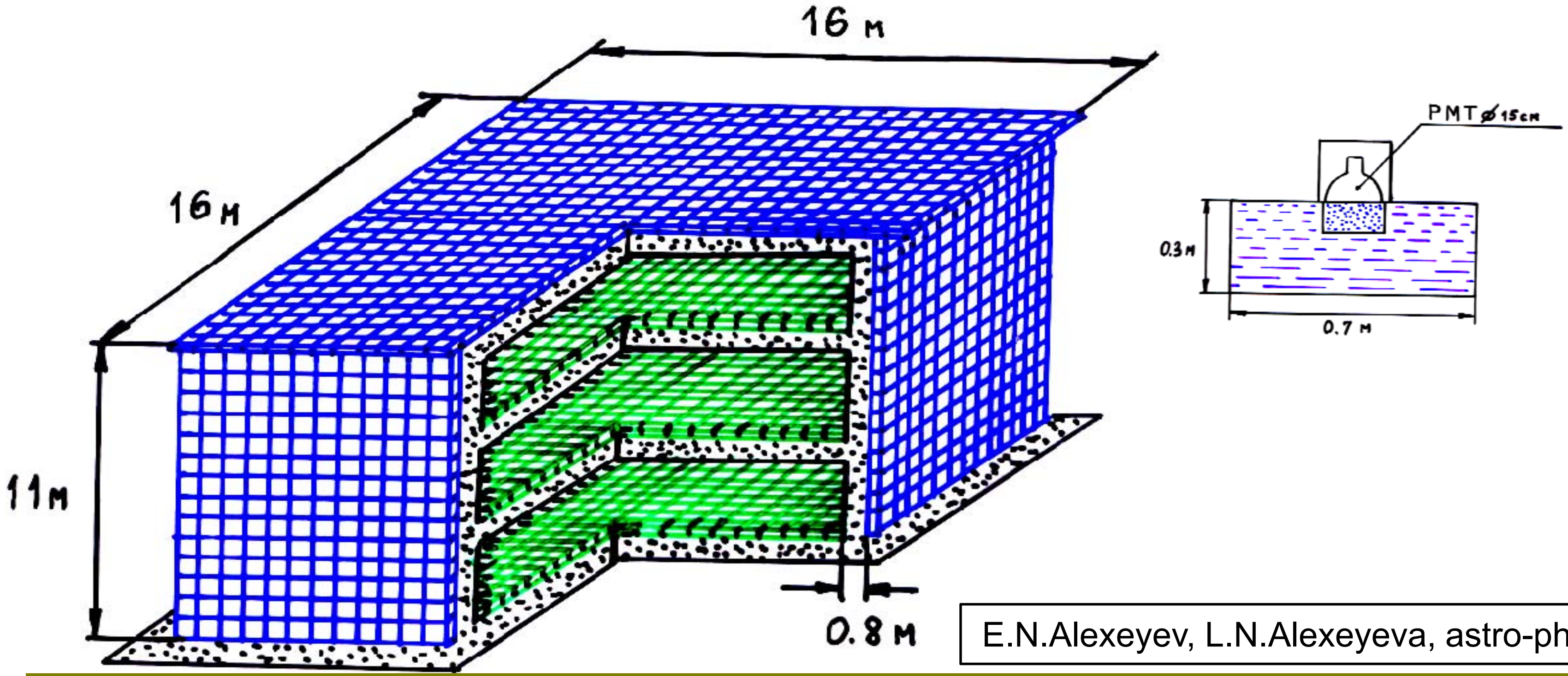
If a detector is sensitive up to 20kpc, it covers 97% of our galaxy.

7% probability
< 3.16 kpc
> x10 statistics

16% probability
< 5 kpc
> x 4 statistics

3% probability
> 20 kpc
< 1/4 statistics

The Baksan underground scintillation telescope



E.N.Alexeyev, L.N.Alexeyeva, astro-ph/0212499

Total number of standard detectors..............3150
Total target mass..............................330 tons of oil-based scintillator

~100 $\overline{\nu}_e p \rightarrow e^+ n$ events expected for 10 kpc SN.
Running since 1980 with ~90% live time.

Criteria of serious candidate: ≥ 9 events/20sec in inner 130ton detectors. (sensitive up to ~20kpc)

No signal (except for SN1987A) over the 28 calender years

LVD detector

LVD consists of an array of 840 counters, 1.5 m^3 each.

Total target:
1000 t of C_nH_{2n}
900 t of Fe

4MeV threshold

With <1MeV threshold for delayed signal (neutron tagging efficiency of 50 +- 10 %)

E resolution: 13%(1σ) at 15MeV

~300 $\bar{\nu}_e p \rightarrow e^+ n$ events expected for 10 kpc SN.

W.Fulgione, poster #90

At Gran Sasso Lab.

W.Fulgione, poster #90

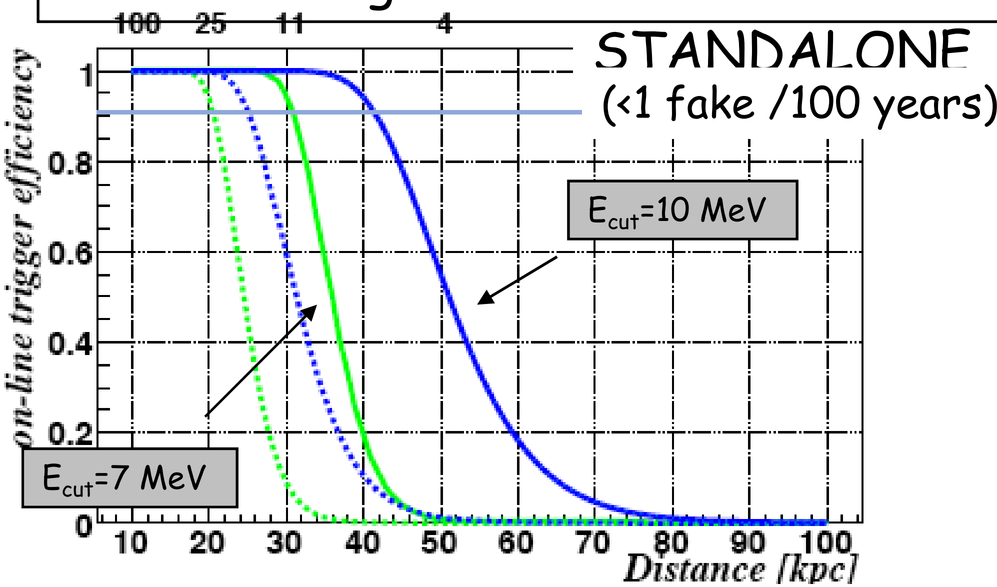
LVD on-line sensitivity

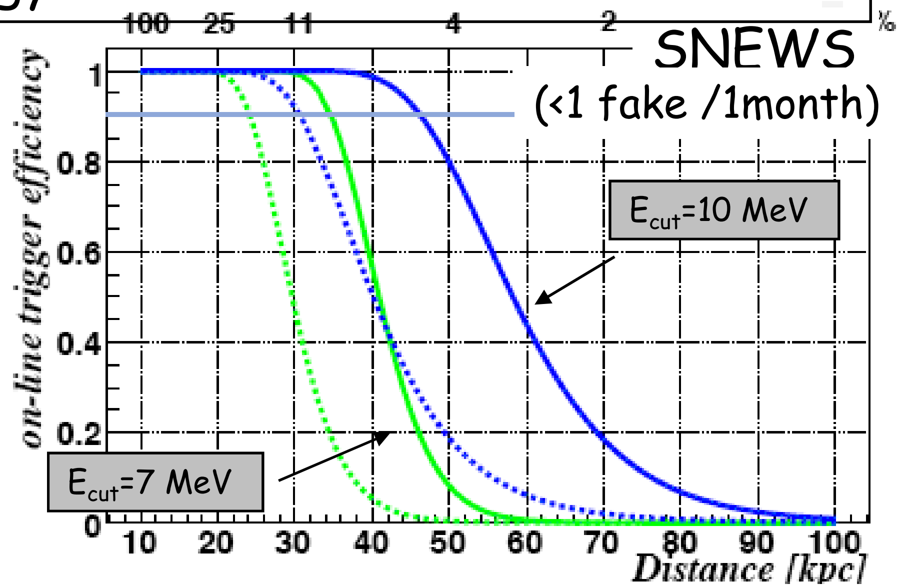
LVD can select burst candidates

- *on-line,*
- *with low model-dependence and*
- *with severe noise rejection factors.*

N.Yu. Agafonova et al. Astroparticle Physics, Vol 28/6 pp 516-522 -in press-

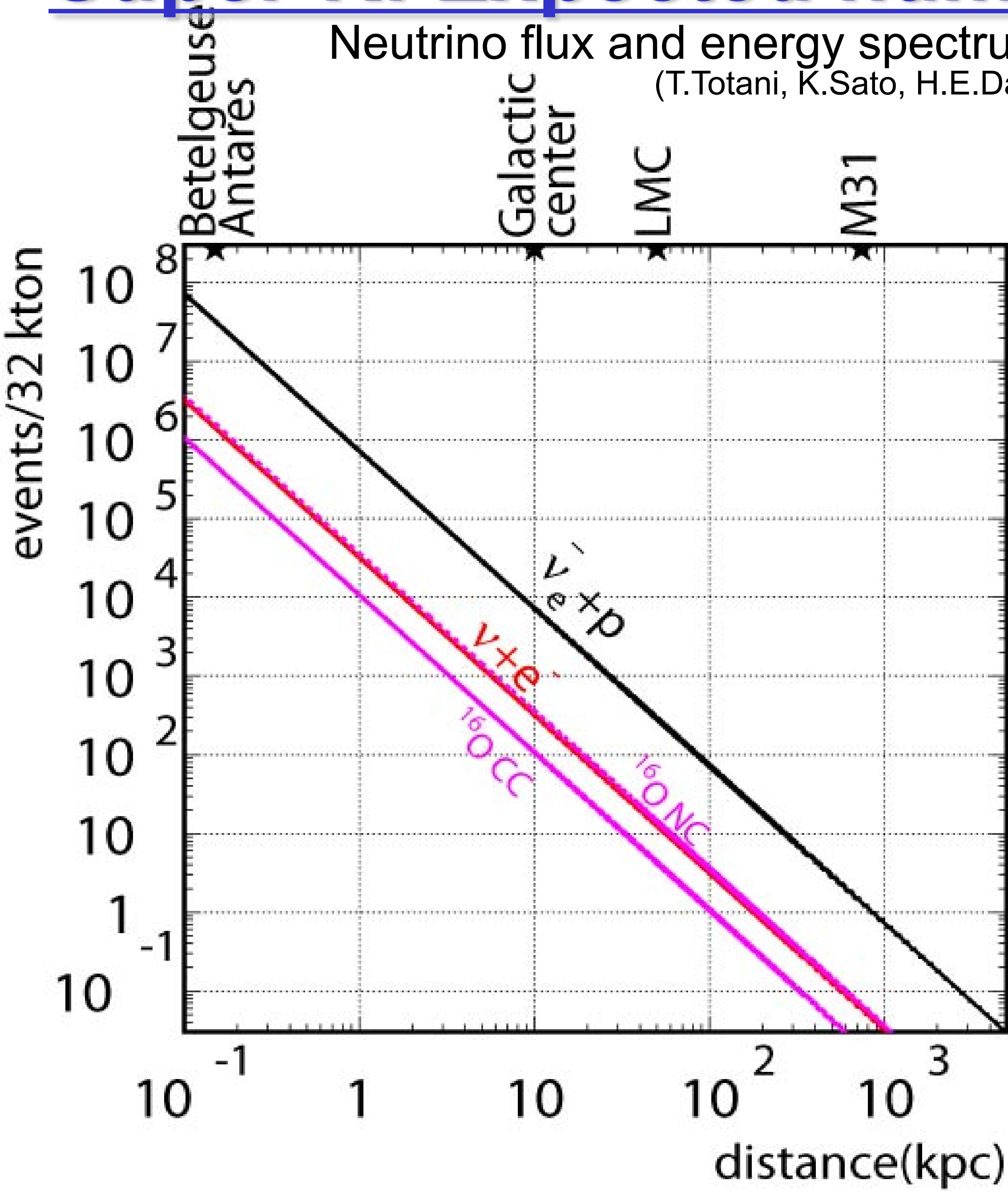
- LVD can identify, on-line, ν-bursts occurring in the whole Galaxy (D<20 kpc) with efficiency > 90%. Such a sensitivity is preserved even if the detector is running with only 1/3 of its total mass and stand-alone, with a severe noise rejection factor (<1 fake event/100 years).
- The on-line trigger efficiency can be extended up to 50 kpc by introducing a cut on the visible energy at 10 MeV.

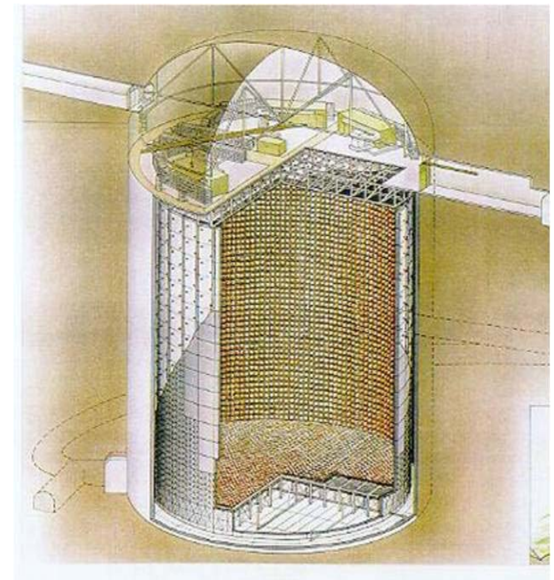




Super-K: Expected number of events

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





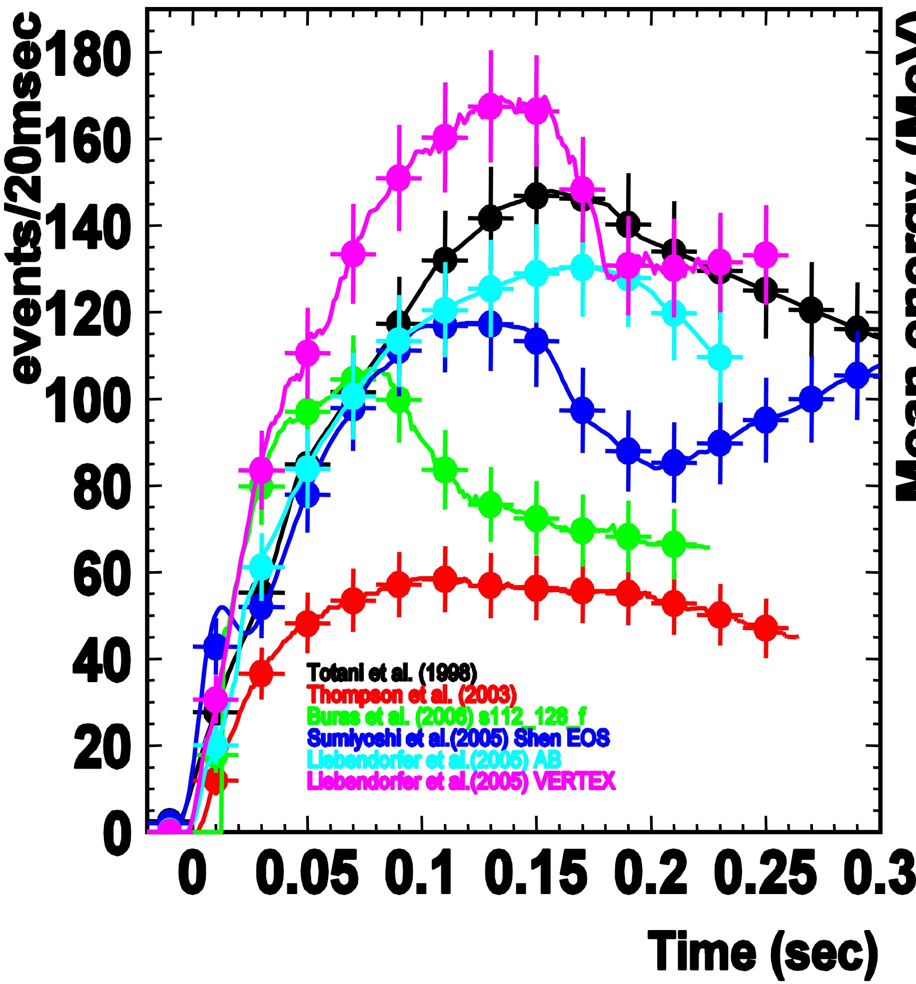
~7,300 $\overline{\nu}_e$+p events
~300 ν+e events
~360 ^{16}O NC γ events
~100 ^{16}O CC events
(with 5MeV thr.)
for 10 kpc supernova

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

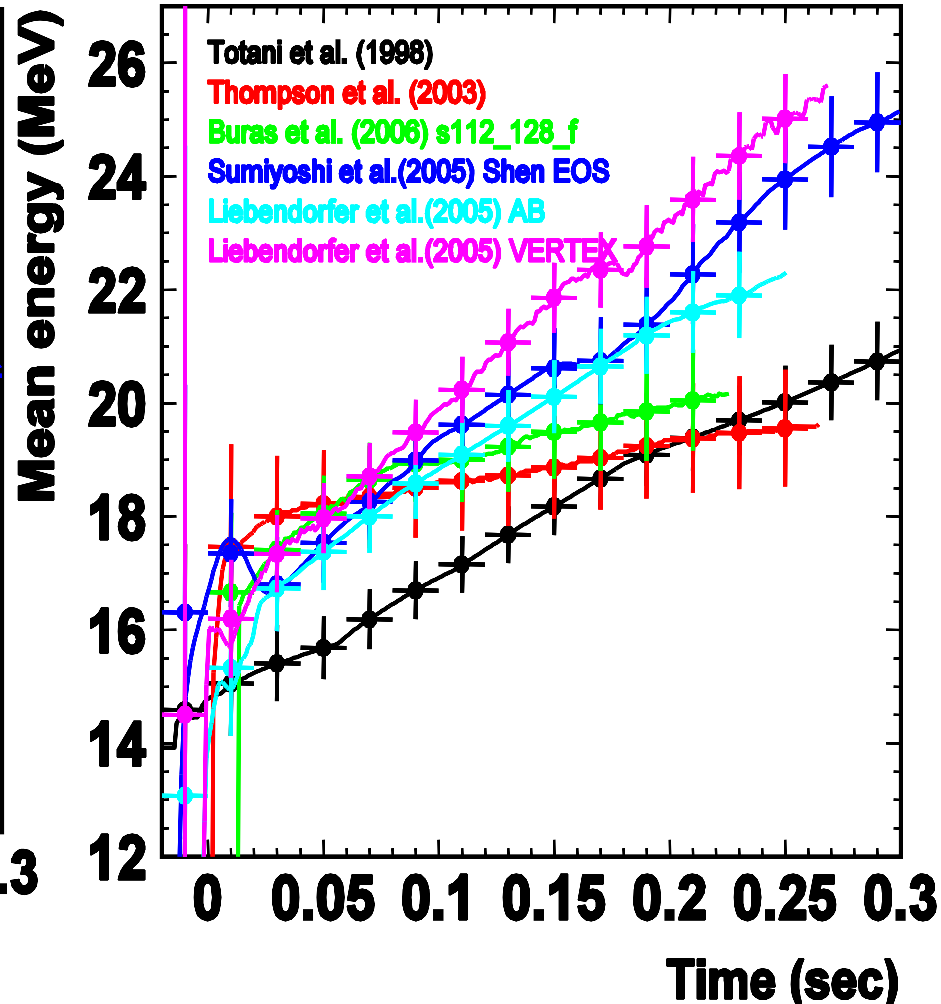
Assuming a supernova at 10kpc.

$\overline{\nu}_e p \rightarrow e^+ n$ events give direct energy information ($E_e = E_\nu - 1.3$MeV).

Time variation of event rate

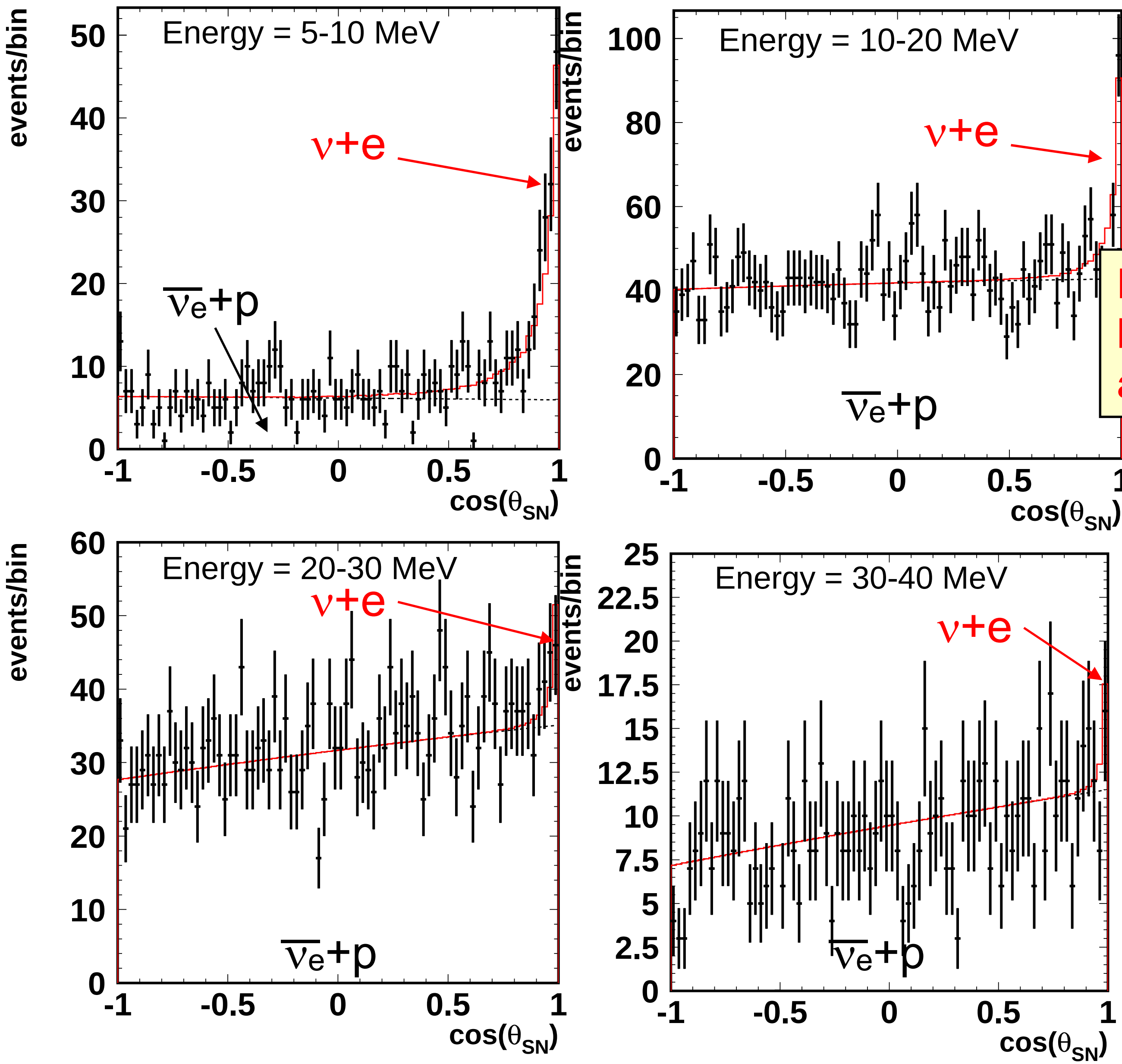


Time variation of mean energy



Enough statistics to discuss model predictions

Super-K: ν+e scattering events



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.

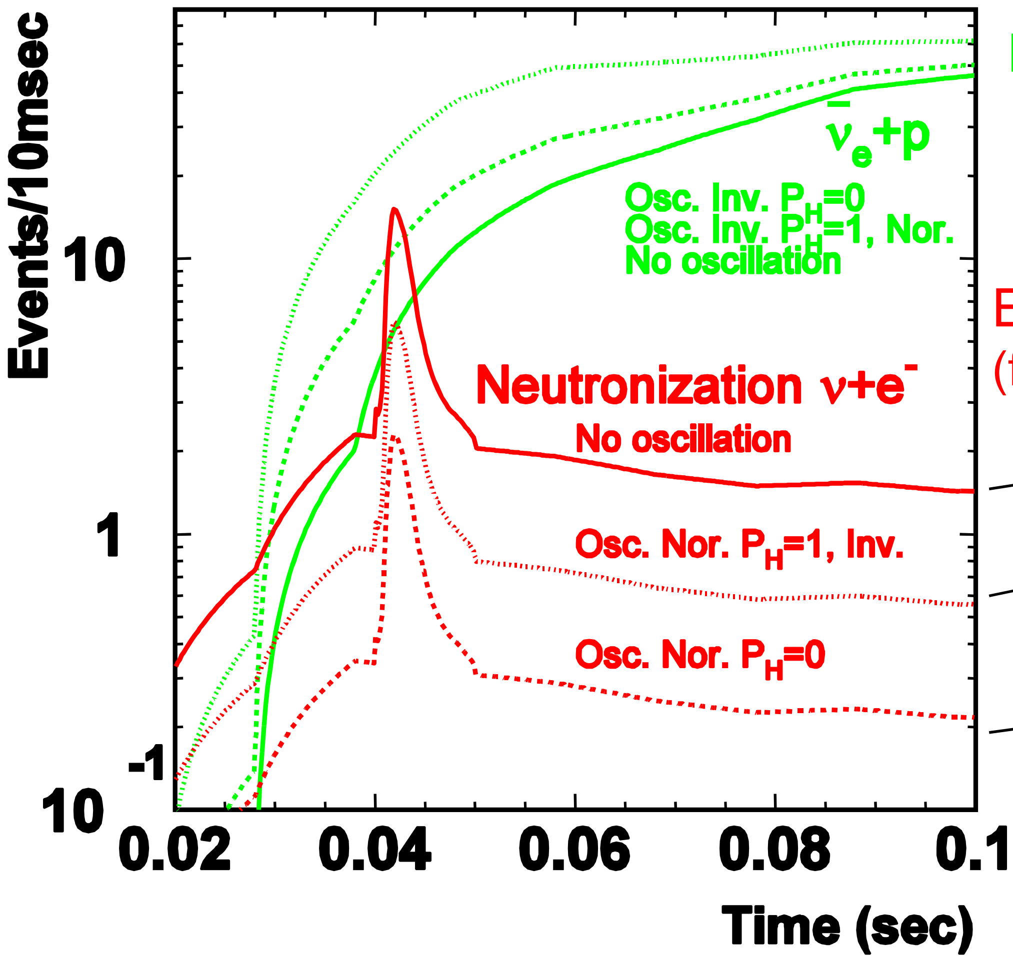
Neutrino flux and spectrum from Livermore simulation

Super-K: Neutronization burst

($e^- + p \rightarrow n + \nu_e$)

SN at 10kpc

Neutrino flux and spectrum from Livermore simulation



Event rate of $\bar{\nu}_e$+p events

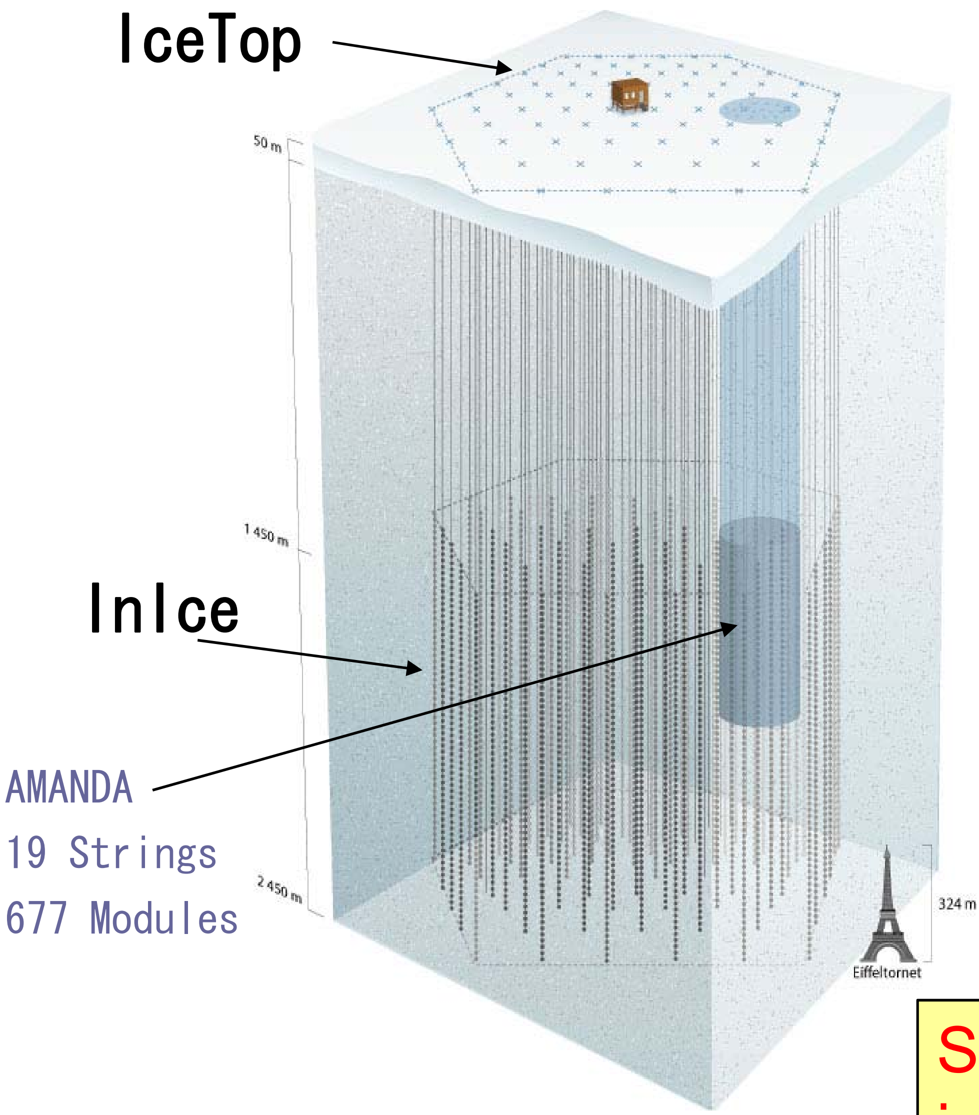
Event rate of neutronization burst
(forward peaked ν+e scattering events)

- No oscillation
- Normal P_H=1 or Inverted hierarchy
- Normal hierarchy P_H=0

P_H: crossing probability at H resonance
(P_H=0: adiabatic)

Number of events from neutronization burst is 0.9~6 events for SN@10kpc.
$\bar{\nu}_e$p events during this 10msec is about 8 - 30 events.
N.H. +adiamacitc case: neutronization=0.9ev., $\bar{\nu}_e$p = 14 ev.(1.4 for SN direction).

IceCube: The Giga-ton Detector Array



Design Specifications

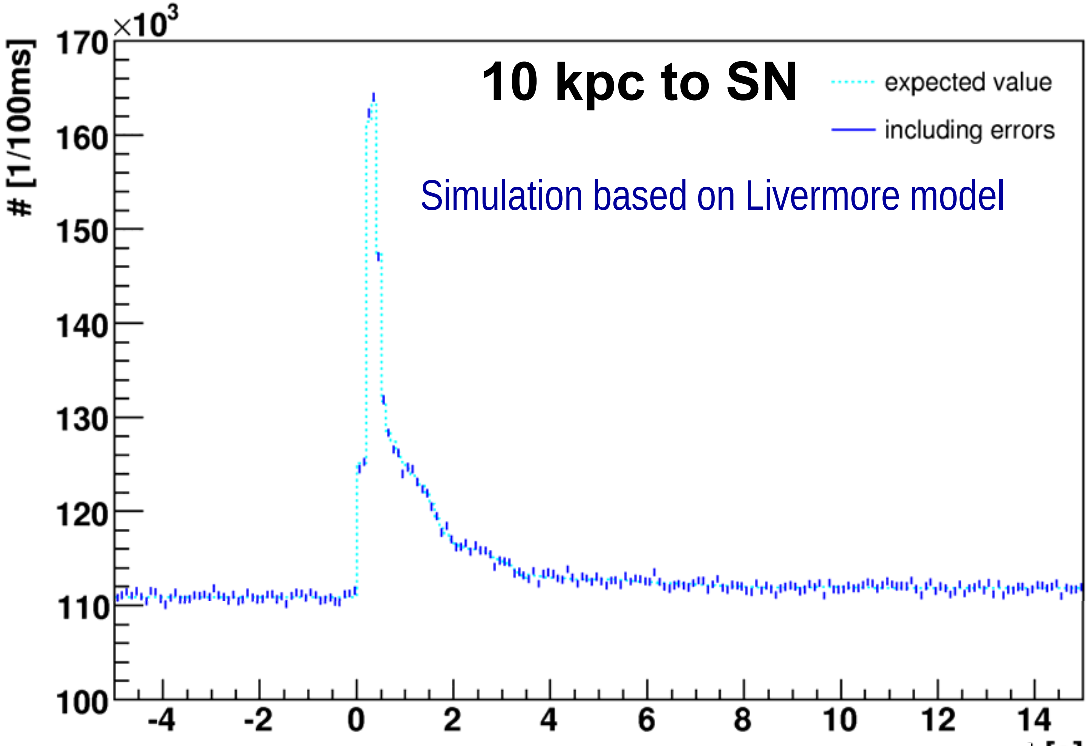
- Fully digital detector concept
- Number of strings – 75
- Number of surface tanks – 160
- Number of DOMs – 4820
- Instrumented volume – 1 km^3
- Angular resolution < 1.0°

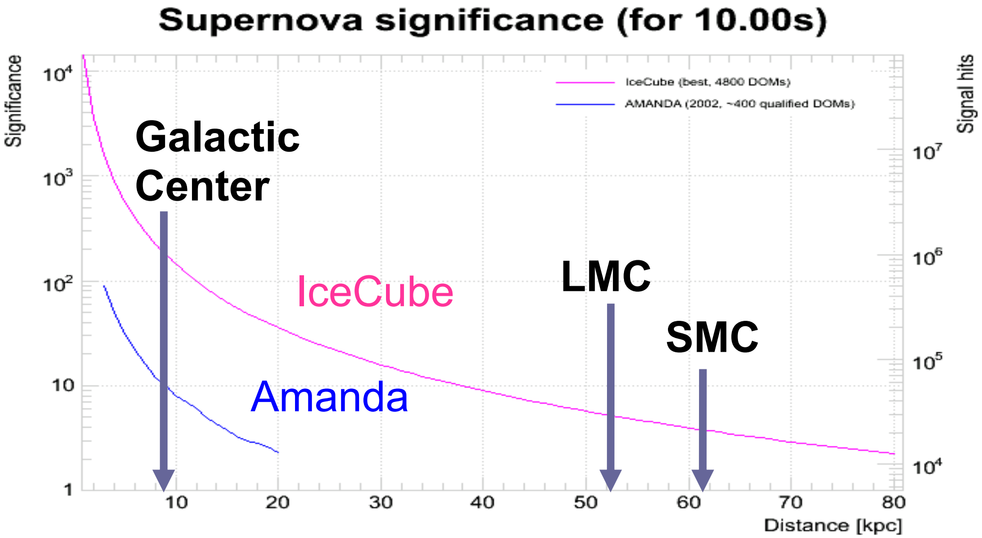
total of 40 strings were deployed so far.

Supernova neutrinos coherently increase the PMT signal rate.

AMANDA construction: 1997 - 2000
IceCube construction: 2005 - 2011

IceCube as MeV ν detector





Advantage:
- ☞ high statistics
  (0.75% stat. error
  @ 0.5s and 100ms bins)

Good for fine time structures (noise low)!

Disadvantage:
- ☞ no pointing
- ☞ no energy
- ☞ intrinsic noise

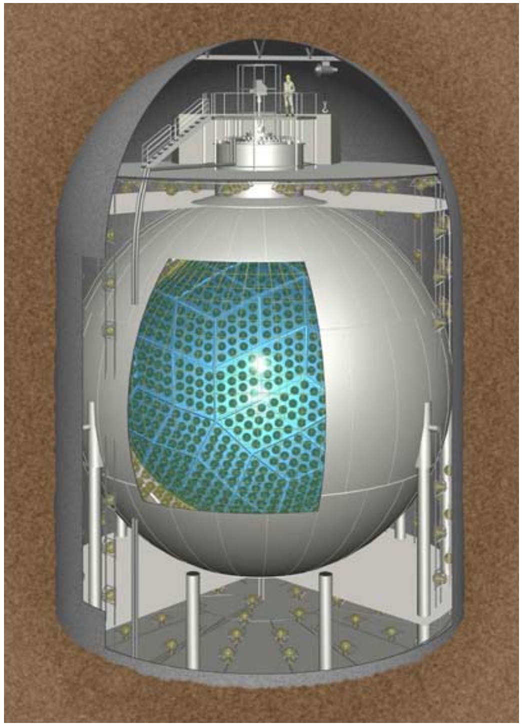
Significance:

Galactic center: ~200 σ
LMC : ~5 σ
SMC : ~4 σ

L.Koepke and A.Piegsa

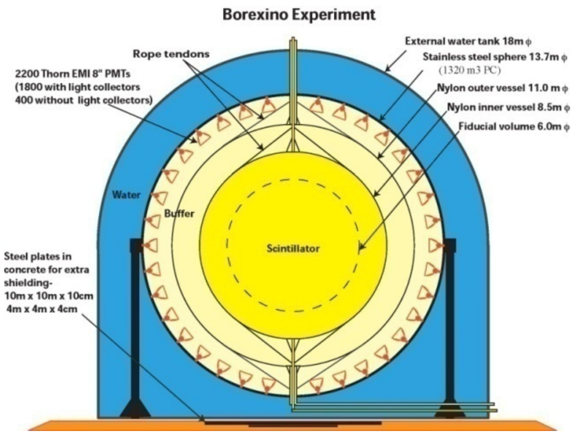
Single volume liq. scintillator detectors

KamLAND



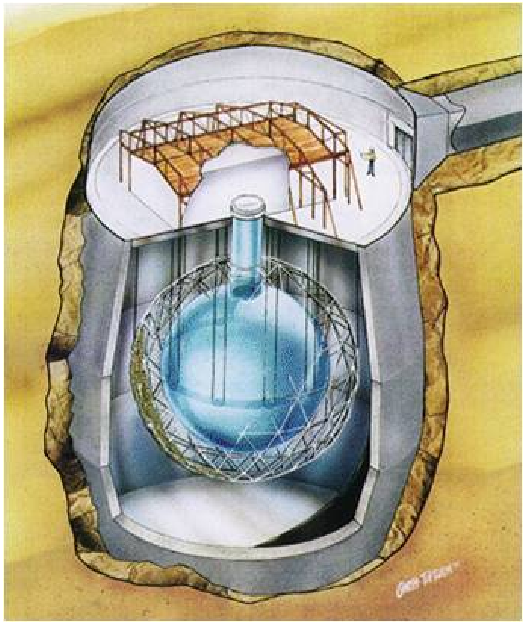
1000ton liq.sci.
Running since 2002.

Borexino



300ton liq.sci.
Running since 2007.

SNO+



1000ton liq.sci.
completing final design and beginning initial construction.

Liquid scinitillator detectors

Expected number of events(for 10kpc SN)

Events/1000 tons

- Inverse beta($\bar{\nu}_e + p \rightarrow e^+ + n$) : ～300 events

  Spectrum measurement with good energy resolution, e.g. for spectrum distortion of earth matter effect.

- CC on ^{12}C ($\nu_e + {}^{12}C \rightarrow e + {}^{12}N({}^{12}B)$) : ～30 events

  Tagged by $^{12}N(^{12}B)$ beta decay

- Electron scattering ($\nu + e^- \rightarrow \nu + e^-$) : ～20 events

- NC γ from ^{12}C ($\nu + {}^{12}C \rightarrow \nu + {}^{12}C + \gamma$): ～60 events

  Total neutrino flux, 15.11MeV mono-energetic gamma

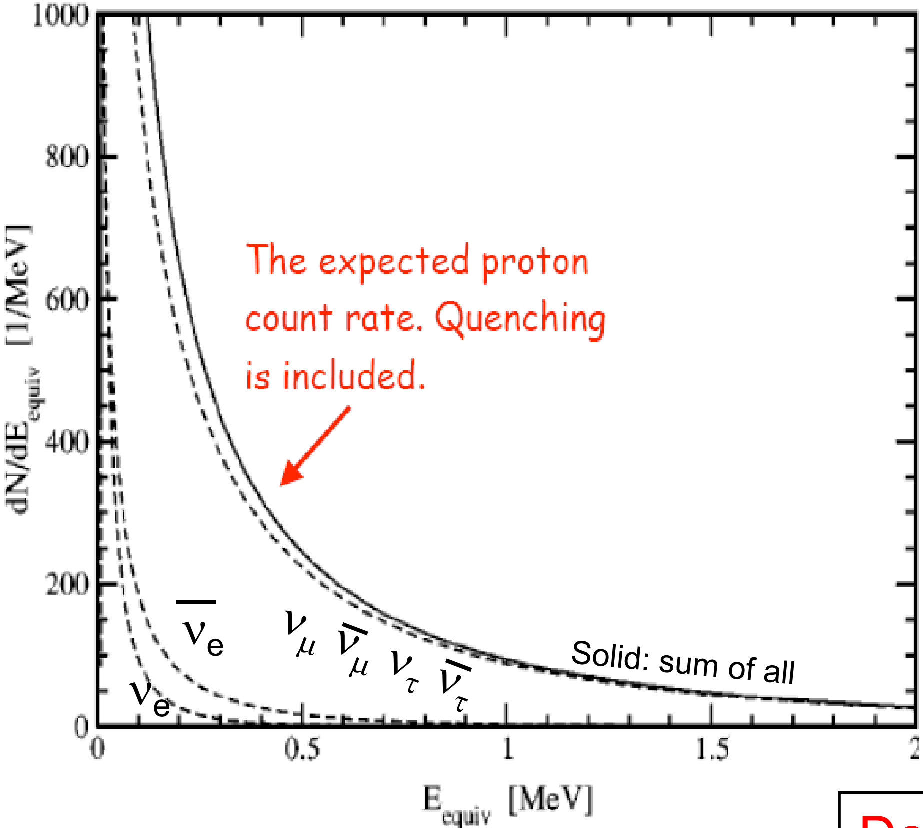
- ν+p scattering($\nu + p \rightarrow \nu + p$): ～300 events

  Spectrum measurement of higher energy component.
  Independent from neutrino oscillation.

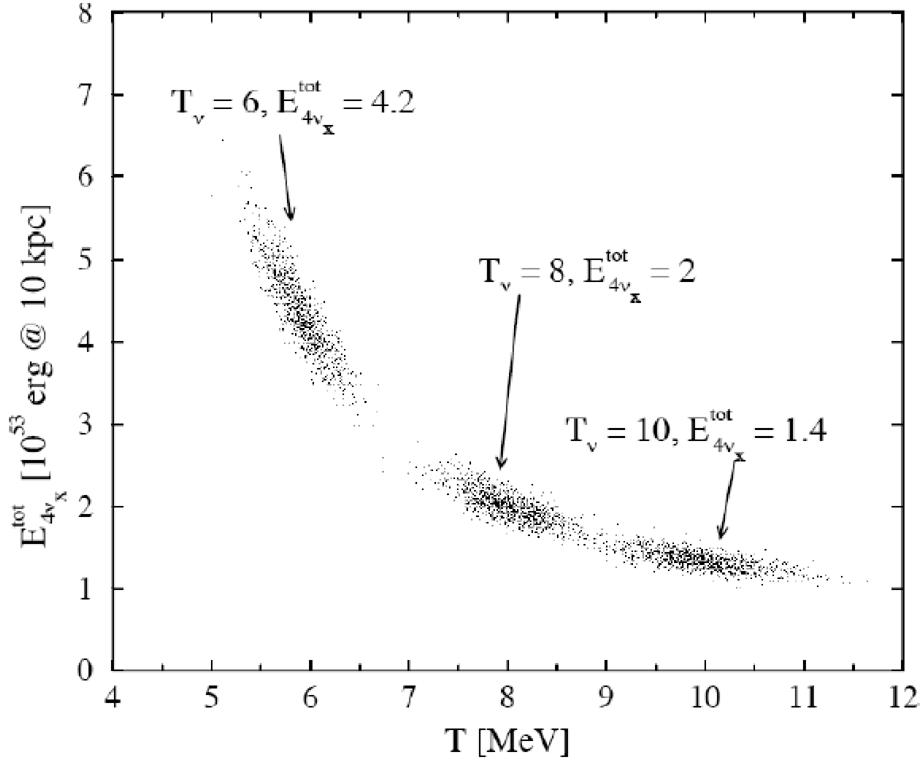
ν+p elastic signal（ν+p→ ν+p）at liq. Scintillator detectors

Beacom, Farr, and Vogel, PRD66, 033001(2002)

Expected spectrum



Sensitivity of temperature measurement



~300 events/kt above 200keV
~150 events/kt above 500keV

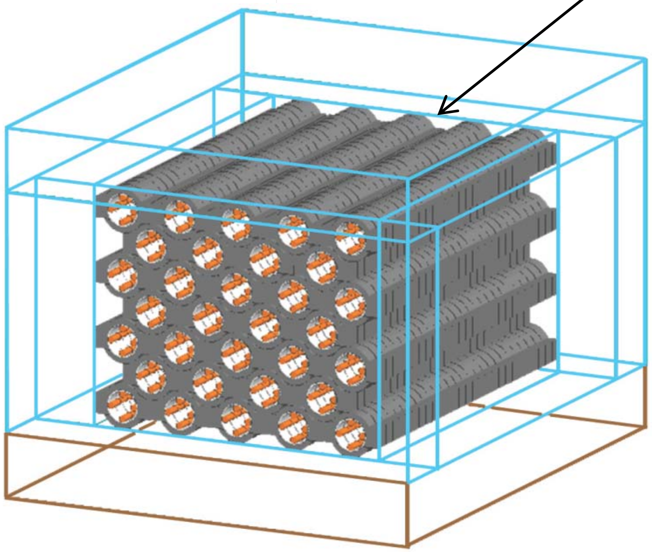
Determine original $\nu_\mu, \overline{\nu}_\mu, \nu_\tau, \overline{\nu}_\tau$ temperature with ~10% accuracy.
(free from neutrino oscillation.)

Current Borexino threshold: 200keV
Current KamLAND threshold: 600~700keV(will be lowered after 2008 distillation.)

HALO - a Helium and Lead Observatory

C.Virtue, poster #93

SNO ^{3}He neutron detectors with lead target



CC: $\nu_e + {}^{208}\mathrm{Pb} \rightarrow {}^{207}\mathrm{Bi} + n + e^-$

NC: $\nu_e + {}^{208}\mathrm{Pb} \rightarrow {}^{206}\mathrm{Bi} + 2n + e^-$

$\nu_x + {}^{208}\mathrm{Pb} \rightarrow {}^{207}\mathrm{Pb} + n$

$\nu_x + {}^{208}\mathrm{Pb} \rightarrow {}^{206}\mathrm{Pb} + 2n$

HALO-1 will use an available 76 tonnes of Pb

In HALO-1 for a SN @ 10kpc†,

- Assuming FD distribution with T=8 MeV for ν_μ's, ν_τ's.
- 65 neutrons through ν_e charged current channels
- 20 neutrons through ν_x neutral current channels

~ 85 neutrons liberated;
with ~50% of detection efficiency, ~40 events expected.

HALO-2 is a future kt-scale detector

SuperNova Early Warning System

snews.bnl.gov

K.Scholberg

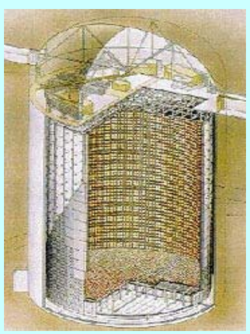
Details: arXiv:astro-ph/0406214

arXiv:0803.0531

Individual supernova-sensitive experiments send burst datagrams to SNEWS coincidence computer at Brookhaven National Lab(backup at U. of Bologna)

Email alert to astronomers if coincidence in 10 seconds

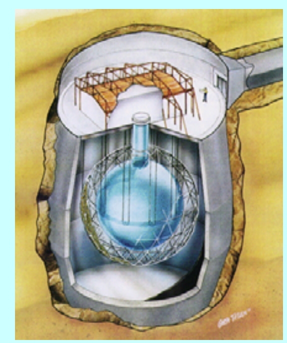
Participating experiments:



Super-Kamiokande (Japan)

Large Volume Detector (Italy)

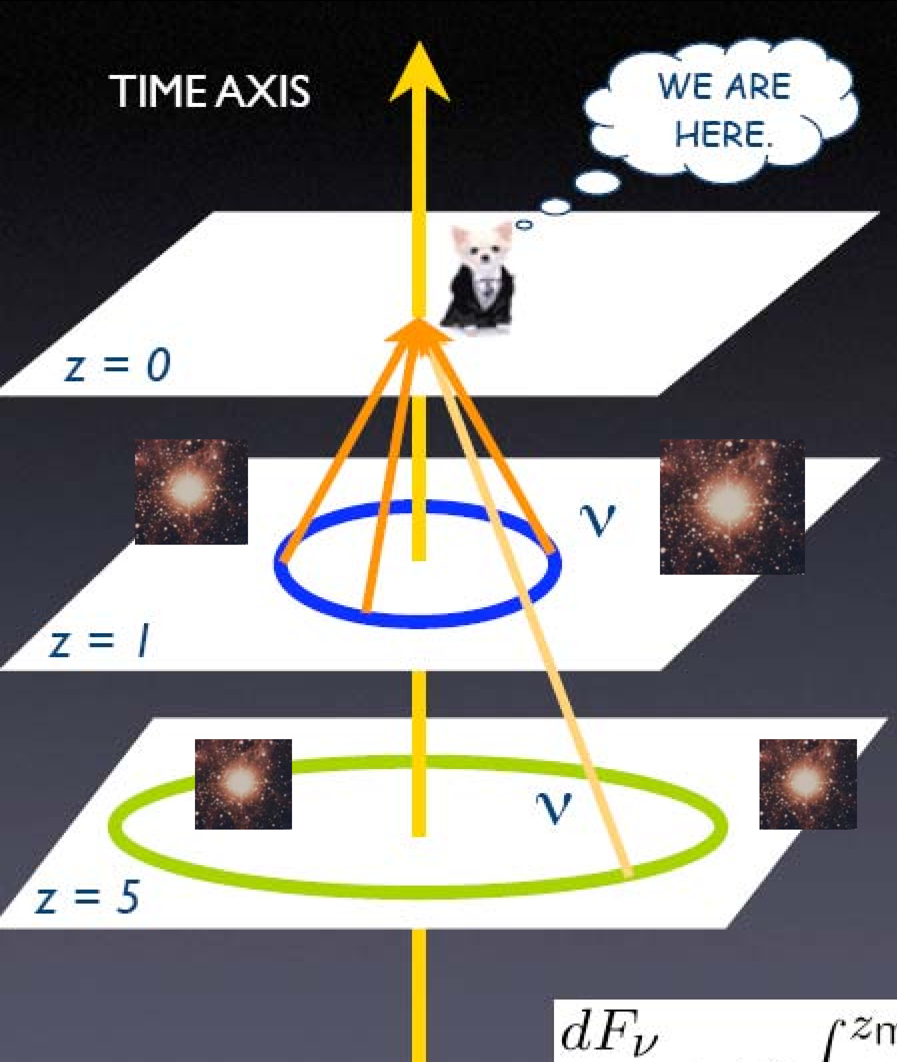
AMANDA/ IceCube (South Pole)

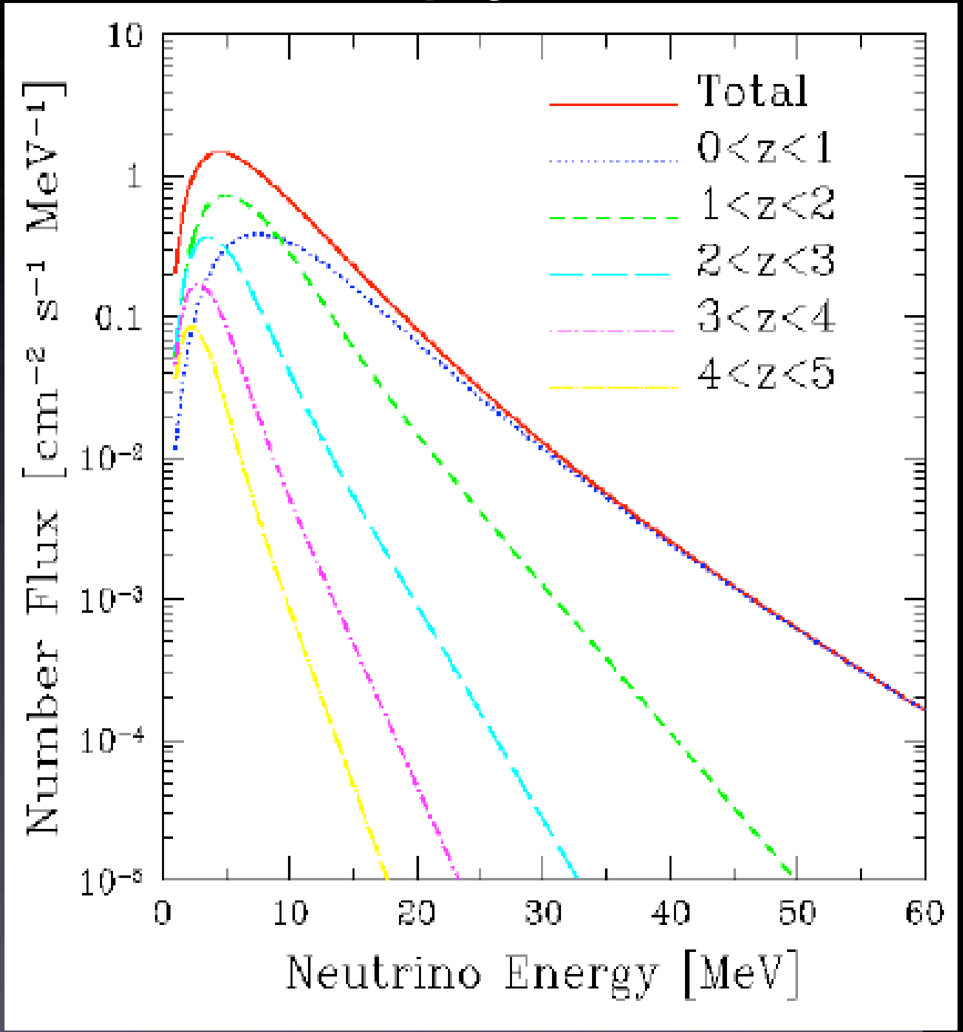


SNO (Canada) until end of 2006

Supernova Relic Neutrinos

S.Ando, Astrophys.J.607:20-31,2004.

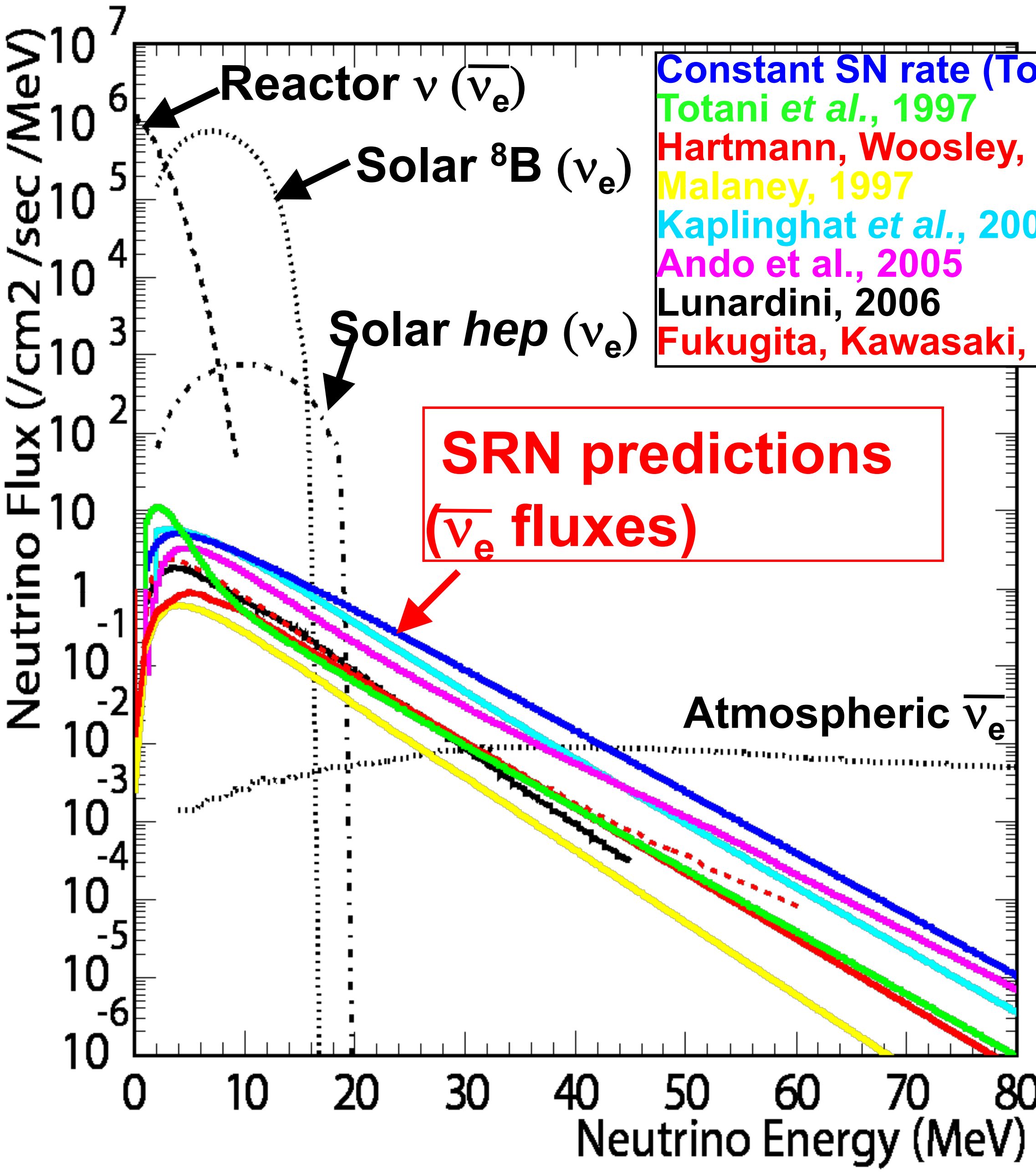




$$\frac{dF_\nu}{dE_\nu} = c\int_0^{z_{\max}} R_{\mathrm{SN}}(z)\frac{dN_\nu(E'_\nu)}{dE'_\nu}(1+z)\frac{dt}{dz}dz$$

S.Ando, NNN05

Supernova Relic Neutrinos



Expected number SRN events

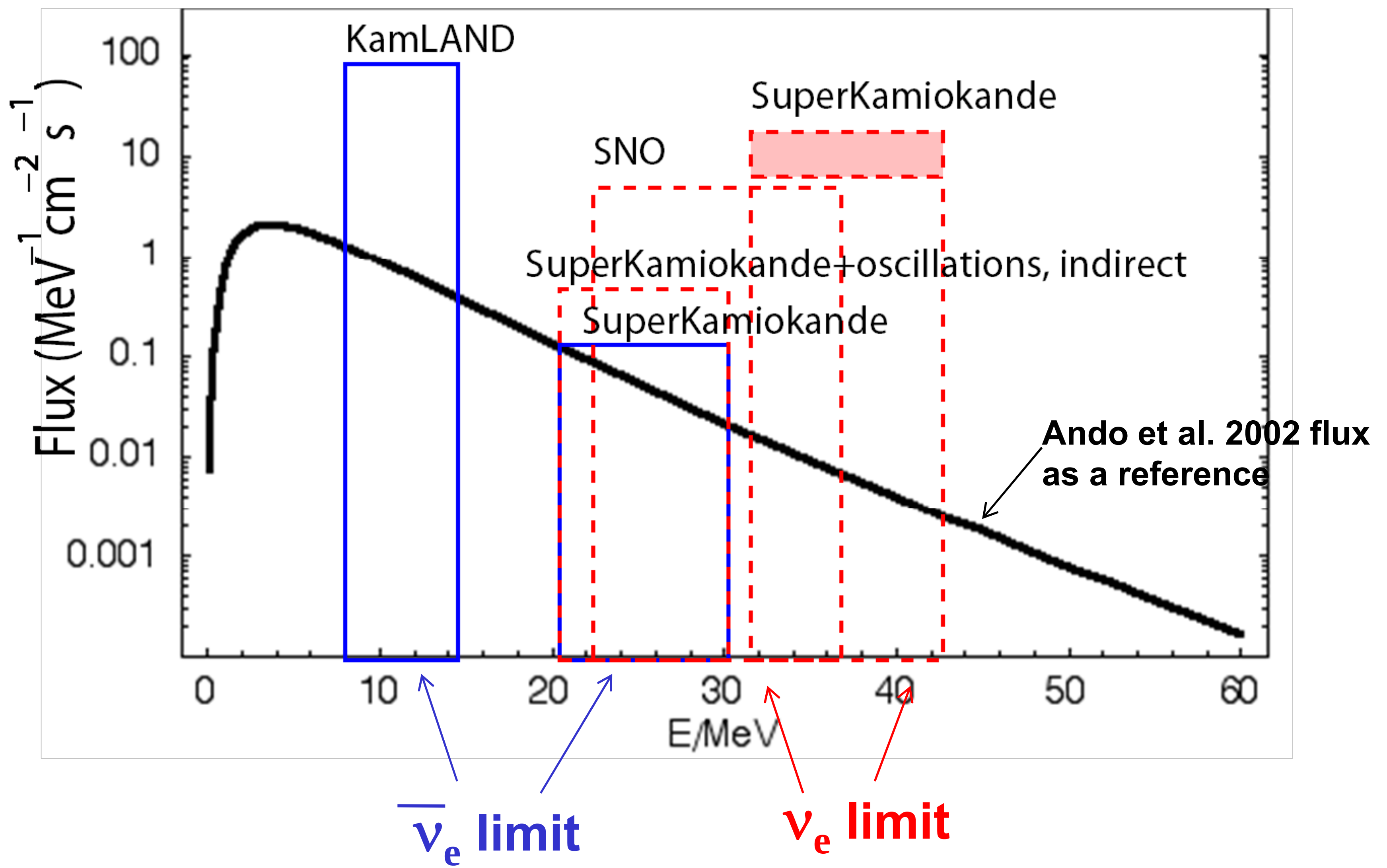
0.8 -5.0 events/year/22.5kton (10-30MeV)

0.3 -1.9 events/year/22.5kton (18-30MeV)

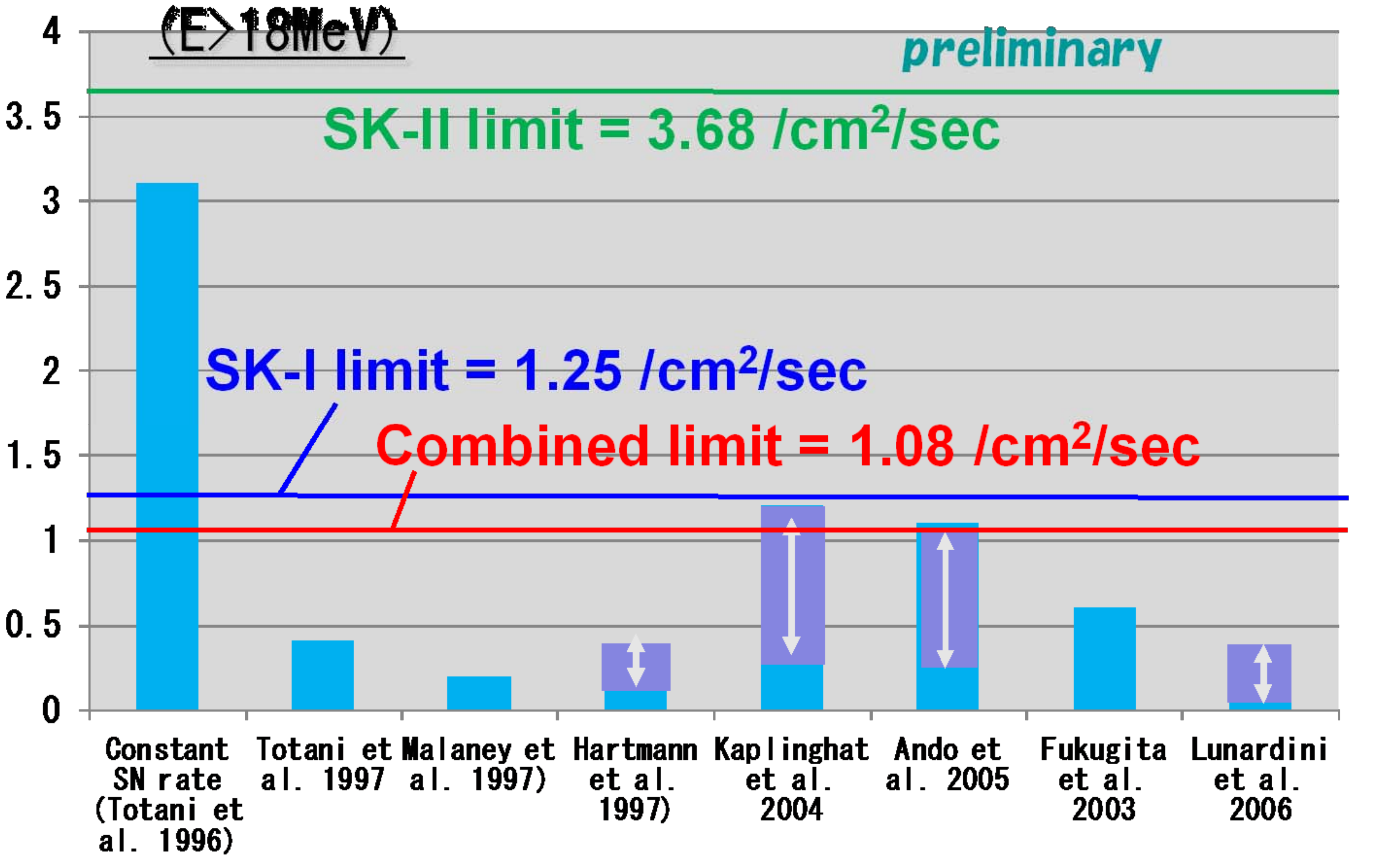
Large target mass and high background reduction are necessary.

SRN Flux upper limit so far

C. Lunardini, astro-ph/0610534

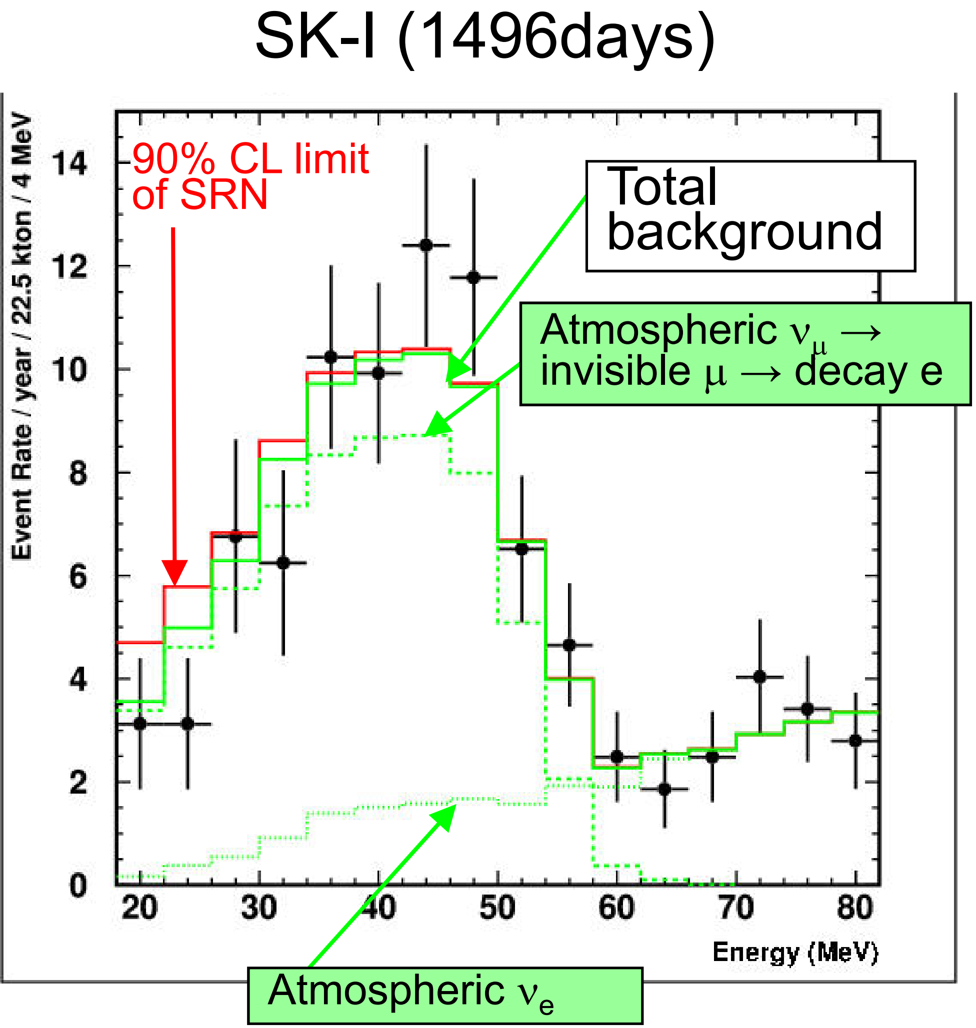


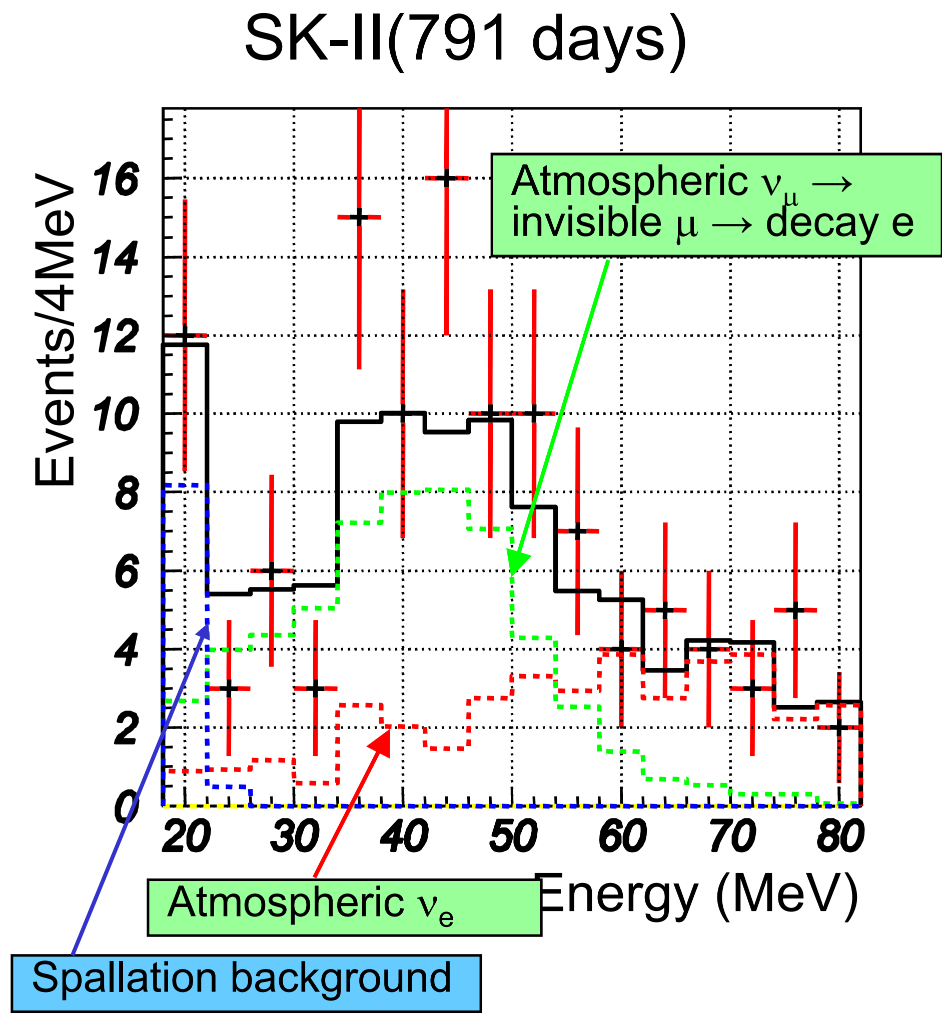
Super-K results so far
Flux limit VS predicted flux



T.iida, poster #90.5

Energy spectrum of SK-I and SK-II (>18MeV)

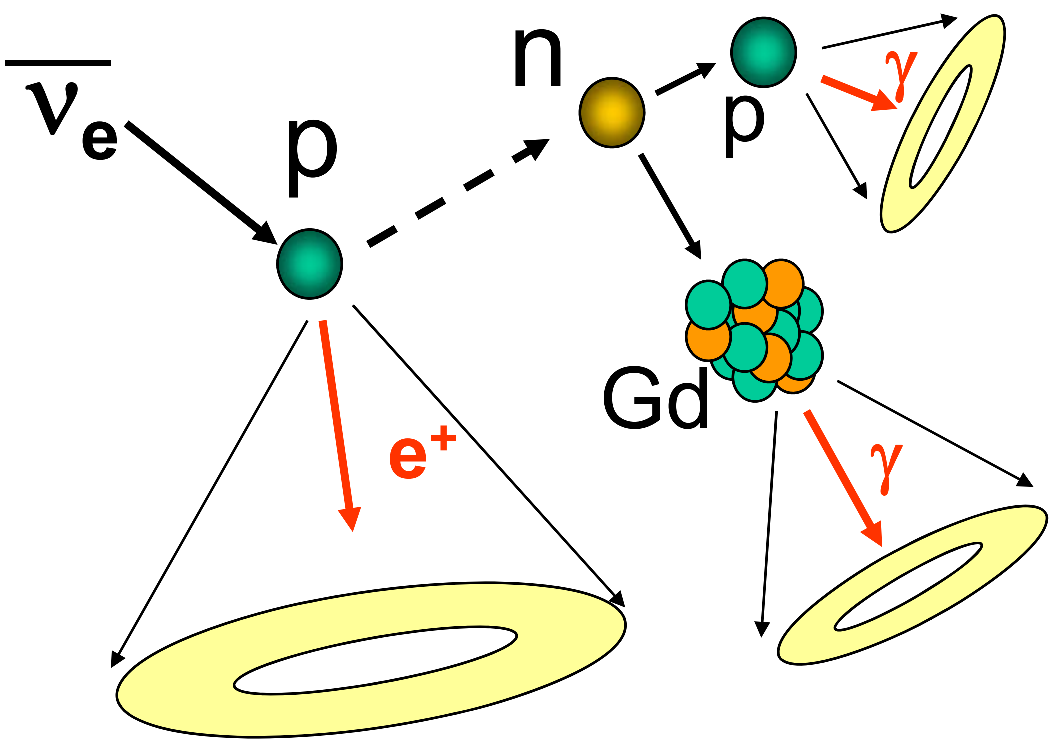




Observed spectrum is consistent with estimated background.
Search is limited by the invisible muon background.

T.iida, poster #90.5

Neutron tagging in water Cherenkov detector



Positron and gamma ray vertices are within ~50cm.

GADZOOKS!

n+Gd →~8MeV γ

ΔT = ~30 μsec

Add 0.2% $GdCl_3$ in water

(J.Beacom and M.Vagins)

Phys.Rev.Lett.93:171101,2004

Another possibility

n+p→d + γ

2.2MeV γ-ray

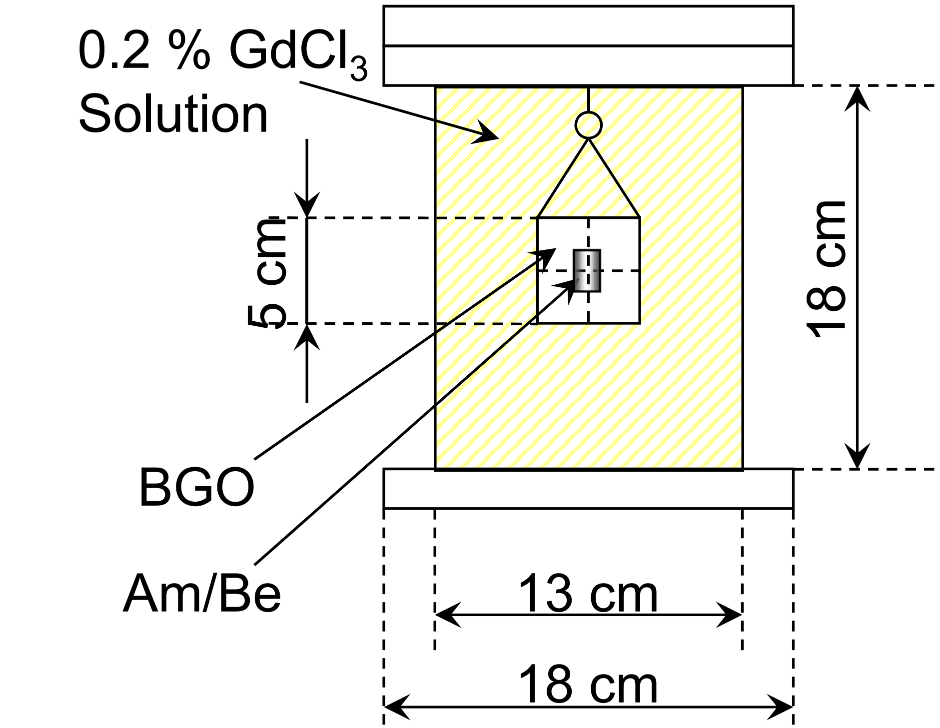
ΔT = ~ 200 μsec

Number of hit PMT is about 6 in SK-III

$\overline{\nu}_e$ can be identified by delayed coincidence.

Test neutron tagging at Super-K

$GdCl_3$ test vessel



This apparatus deployed in the SK tank.

BGO signal (prompt signal (large and long time pulse))

Look for Cherenkov signal (delayed signal)

$\alpha + {}^{9}Be \rightarrow {}^{12}C^{*} + n$

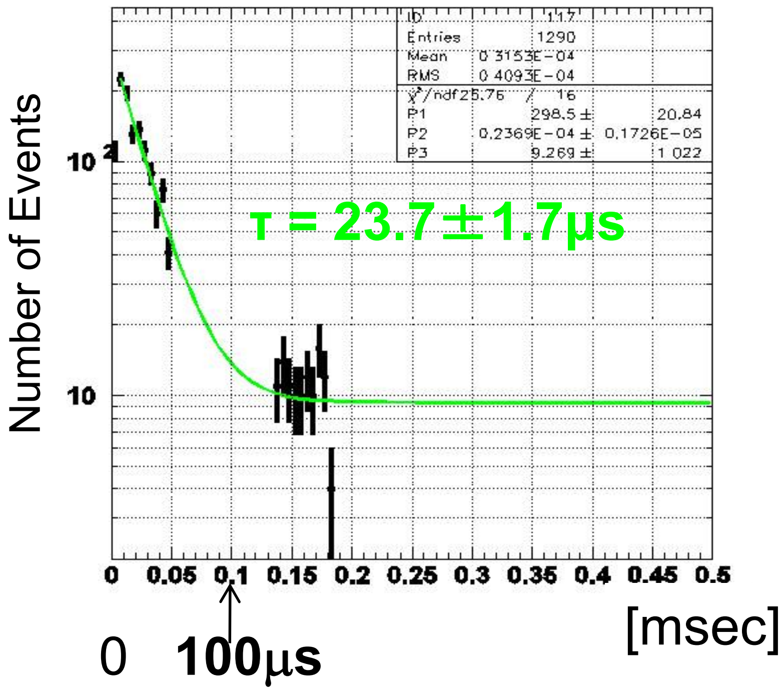
${}^{12}C^{*} \rightarrow {}^{12}C + \gamma(4.4\ MeV)$

$n + p \rightarrow \ldots\ldots \rightarrow n + Gd \rightarrow Gd + \gamma$ (totally 8 MeV)

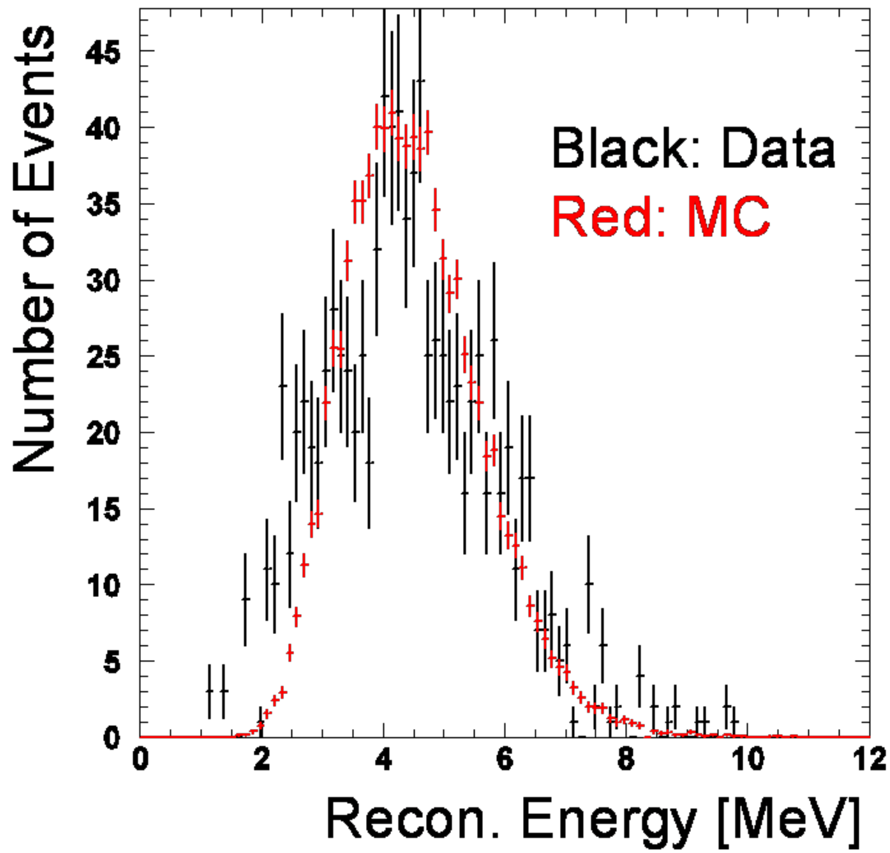
H.Watanaba, poster #94

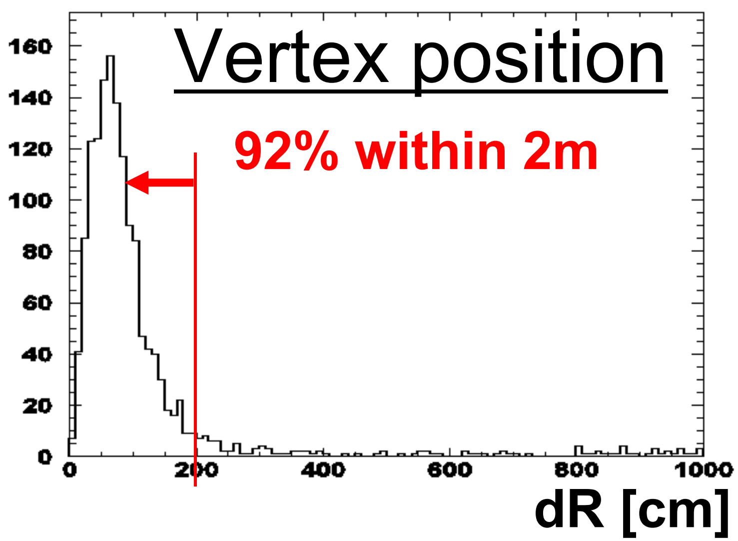
Cherenkov signal of Gd gamma rays

Time from prompt



Energy spectrum





Measured time, vertex and energy distributions are as expected from the MC simulation.

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Tagging efficiency and BG reduction

Selection criteria of delayed signal:

(1) Vertex position within 2m

(2) Energy of delayed signal > 3MeV

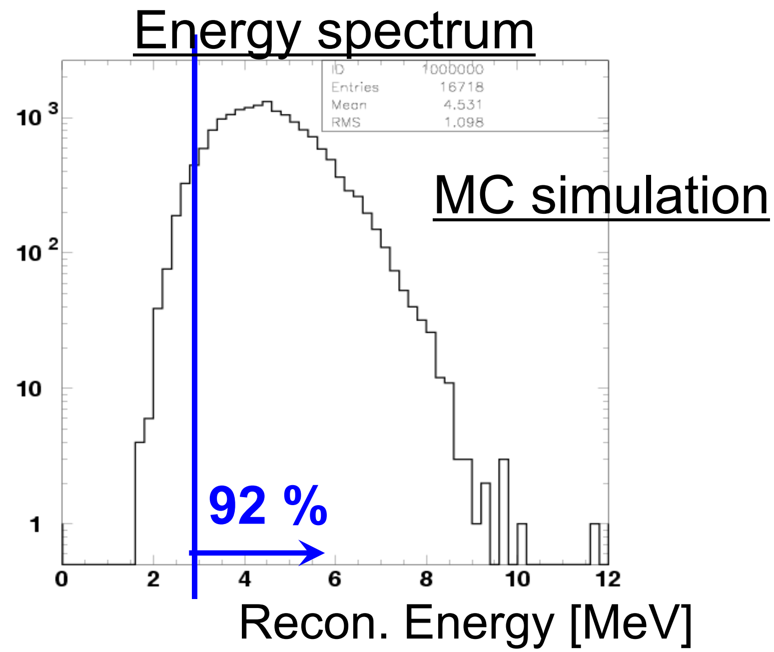
(3) Time after the prompt within 60μsec.

(4) Ring pattern cuts

Selection efficiency is ~74%.

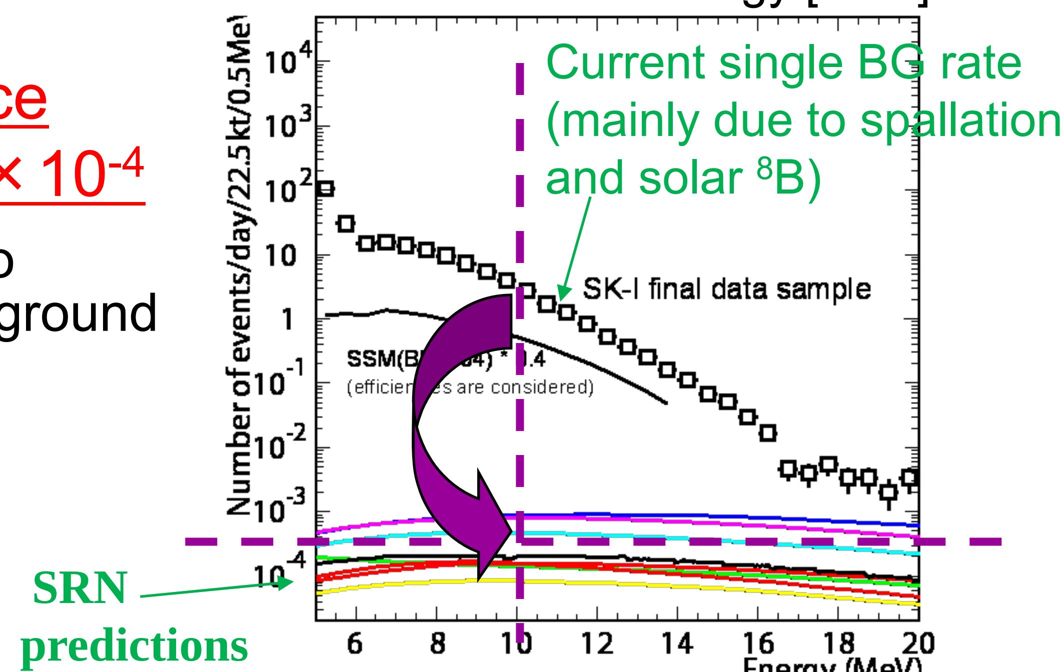
With 90% capture eff. by 0.2% Gd,

→ Tagging efficiency is 67%



While the chance coincidence prob. is estimated to be ~2×10^{-4}

It almost satisfy the requirement to remove remaining spallation background at 10 MeV.



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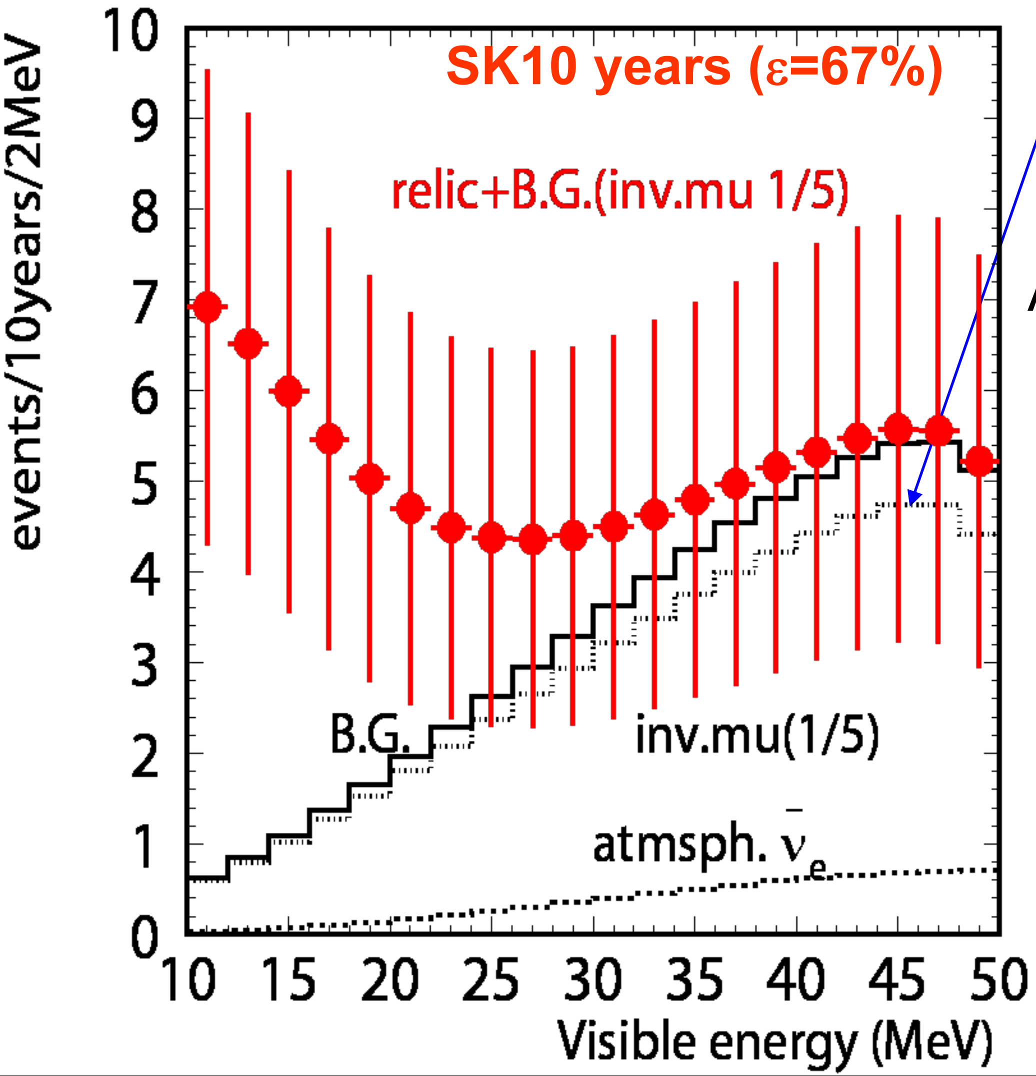
poster #94

Possibility of SRN detection

Relic model: S.Ando, K.Sato, and T.Totani, Astropart.Phys.18, 307(2003) with flux revise in NNN05.

If invisible muon background can be reduced by neutron tagging



Assuming invisible muon B.G. can be reduced by a factor of 5 by neutron tagging.

Assuming 67% detection efficiency.

By 10 yrs SK data,
Signal: 33, B.G. 27
(E_{vis} =10-30 MeV)

Items to be studied before introducing gadolinium to SK

- **Effect to water transparency**

  Water transparency should be long enough to do various physics at SK.

- **Water purification system**

  Current water purification system remove ions. So, it must be modified to purify water without removing gadolinium.

- **Material effects**

  Corrosion by gadolinium solution should be checked.

- **How to introduce/remove**

  How to mix gadolinium uniformly in the tank. How quickly/economically/completely can the Gd be removed?

- **Ambient neutron level in the tank**

  Does it cause significant increase singles in trigger rate[for solar analysis]?

In order to study those things, we will construct a test tank (6~10m size) in the Kamioka mine.

Conclusions

- Supernova burst neutrinos

  If a galactic supernova happens in near future,
  - Many $\overline{\nu}_e$ events are expected.
  - Various new types of signals (e.g. neutral current signals) are expected.
- Supernova relic neutrinos
  - Will give us star formation history.
  - Expected event rate is small and we need large volume detector at least as large as Super-K.
  - G&D for the gadolinium project is going on.

Acknowledgements to
L.Koeke, G.Bellini, P.Vogel, W.Fulgione, K.Inoue, S.Enomoto, M.Chen, S.Yen, C.Virtue, A.Piegsa, J.Heise, N.McCauley, E.Alexeyev, S.Yen, K.Scholberg, J.Learned, S.Dye, W.Kropp, M.Vagins, M.Smy, H.Watanabe, T.Iida, M.Ikeda