超新星ニュートリノの実験

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２０１５年3月１６日

新学術「地下素核研究」第一回超新星ニュートリノ研究会

東京理科大学

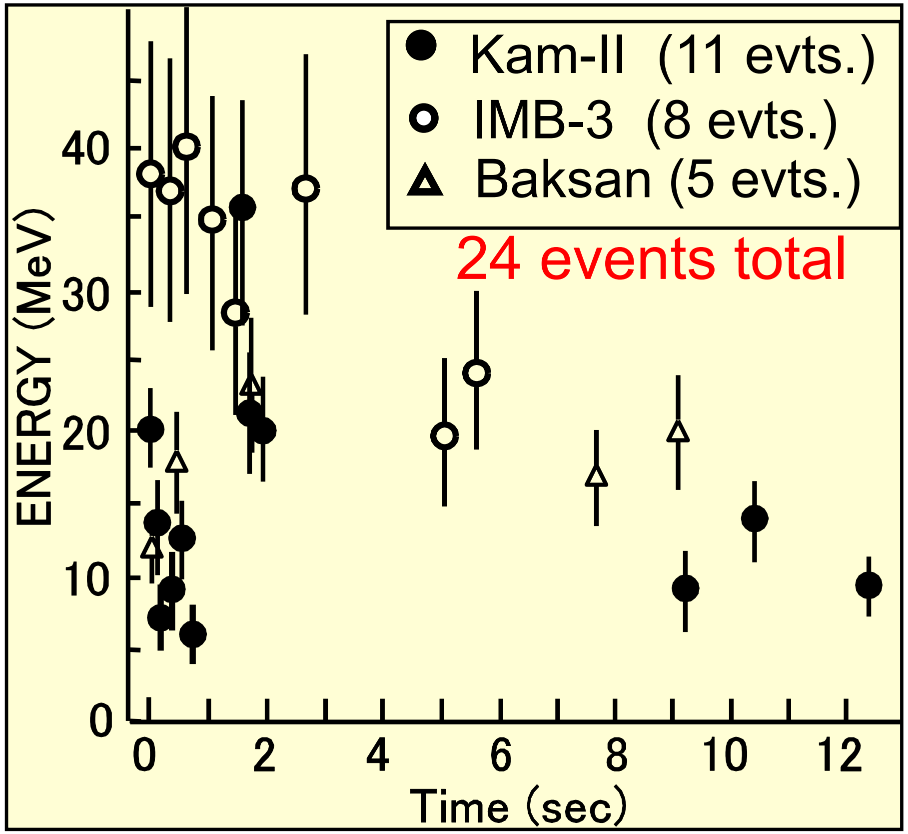
Outline

- ✓ Introduction
- ✓ Neutrino interaction for SN ν detection
  - Inverse beta decay
  - Charged Current interaction
  - Neutrino-electron elastic scattering
  - Neutral Current interaction
- ✓ Current supernova neutrino detectors
  - Water Cherenkov detector
  - Scintillation detector
  - Others
- ✓ Future prospects
- ✓ Summary


Introduction

Review of the SN1987A in LMC

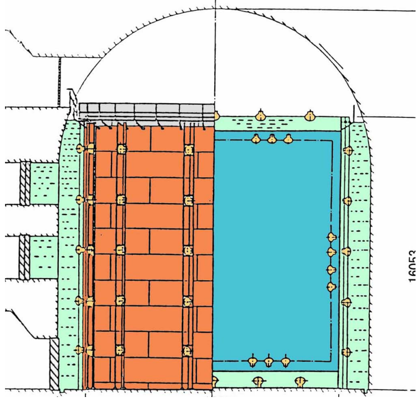
at 50kpc, ν's seen ~2.5 hours before first light



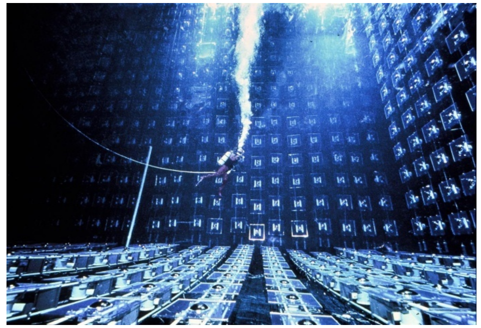
Most of them seems to $\overline{\nu_e}$ event

Water Cherenkov

Kamiokande-II



IMB-3

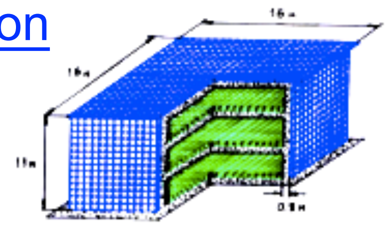


Strong directionality for ν_e event

Liquid Scintillator

Baksan

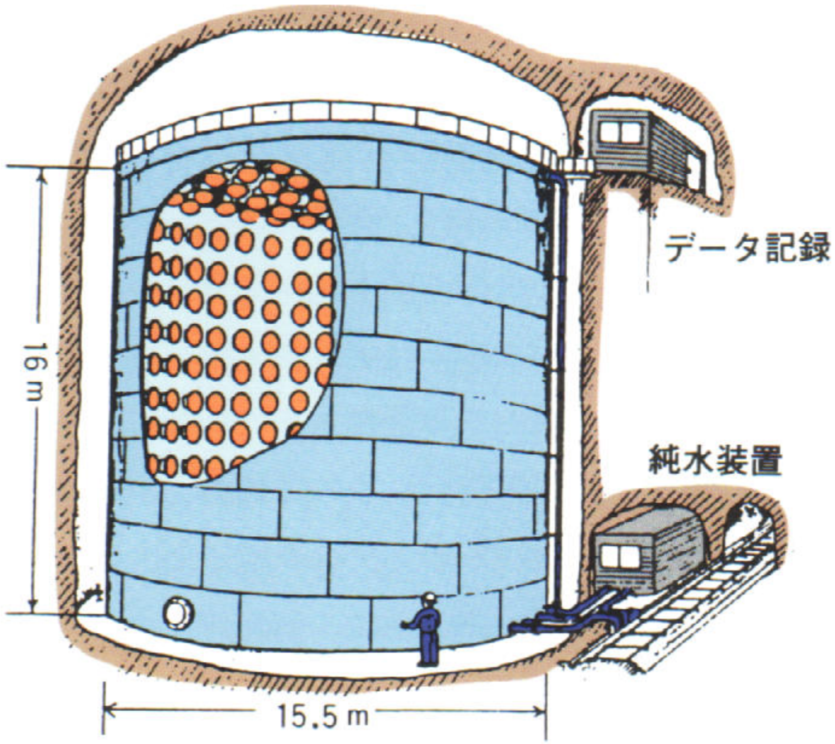
Good $\overline{\nu}_e$ event identification



Review of the SN1987A in LMC

Kamiokande (1983-1995)

kamioka mine (2700mwe)



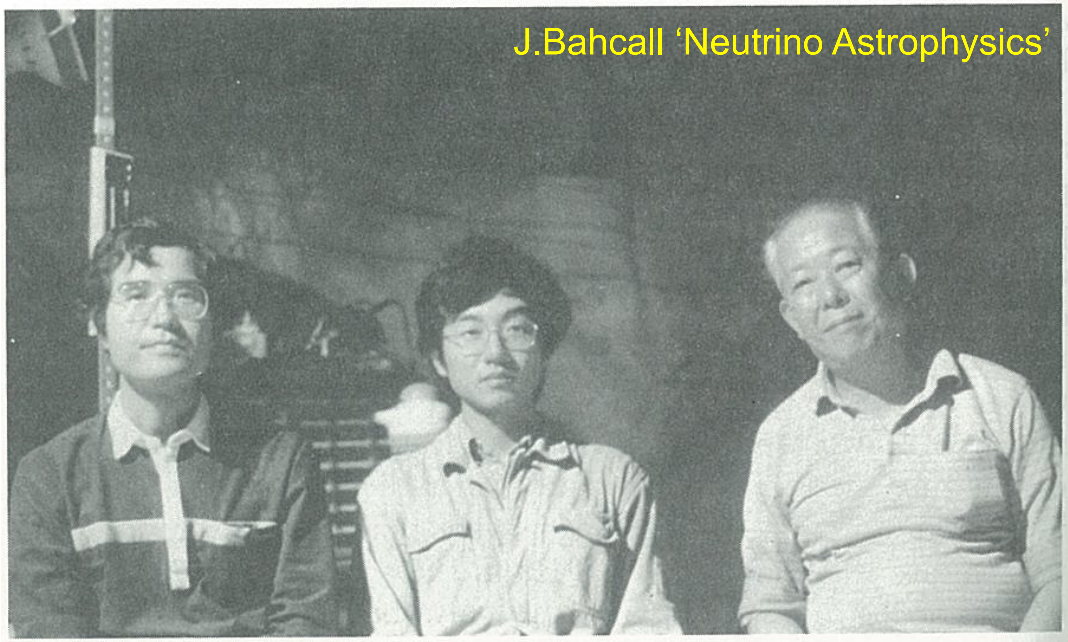
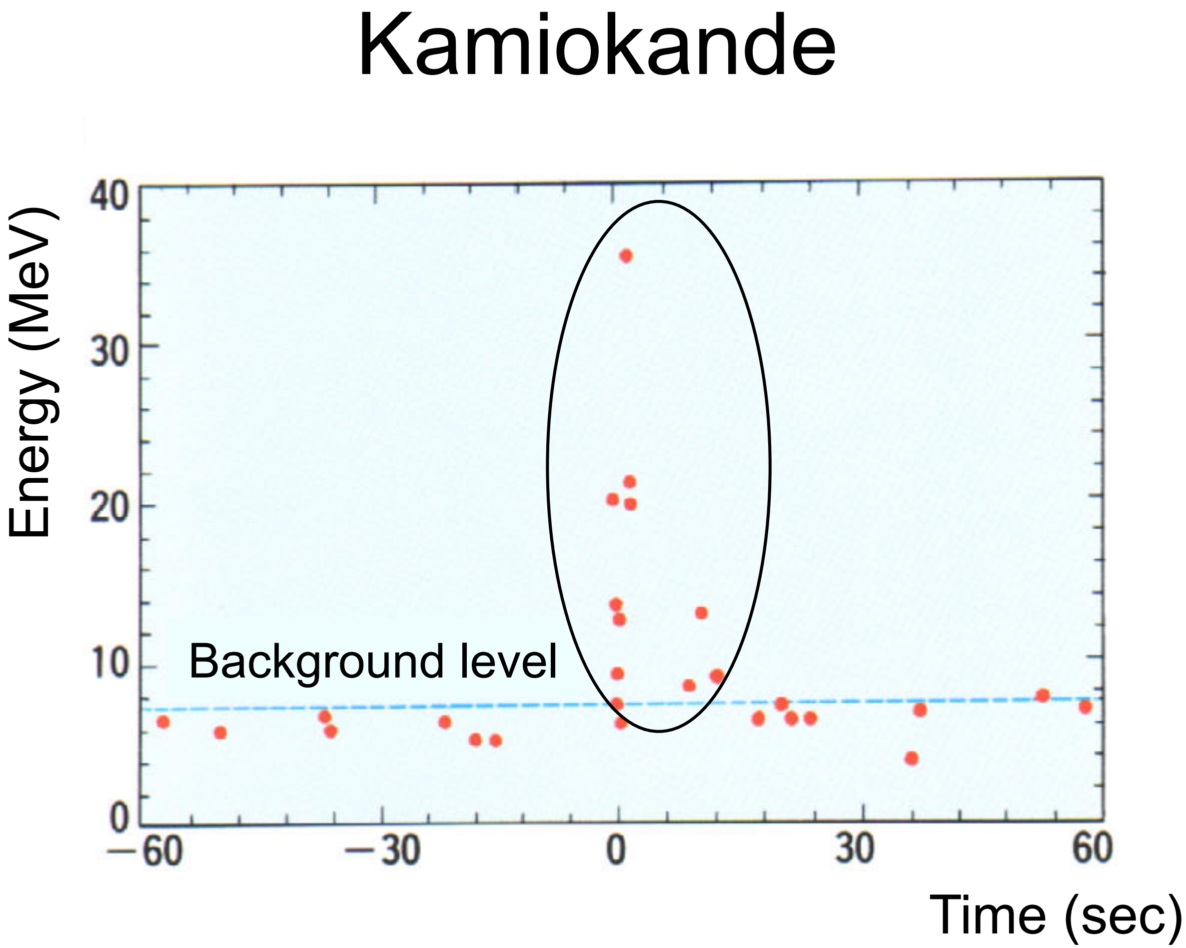


Figure 13.3 Three generations of Kamiokande neutrino experimentalists

3000トン水タンク、約1000本の光電子増倍管

Review of the SN1987A in LMC



Realtime detector

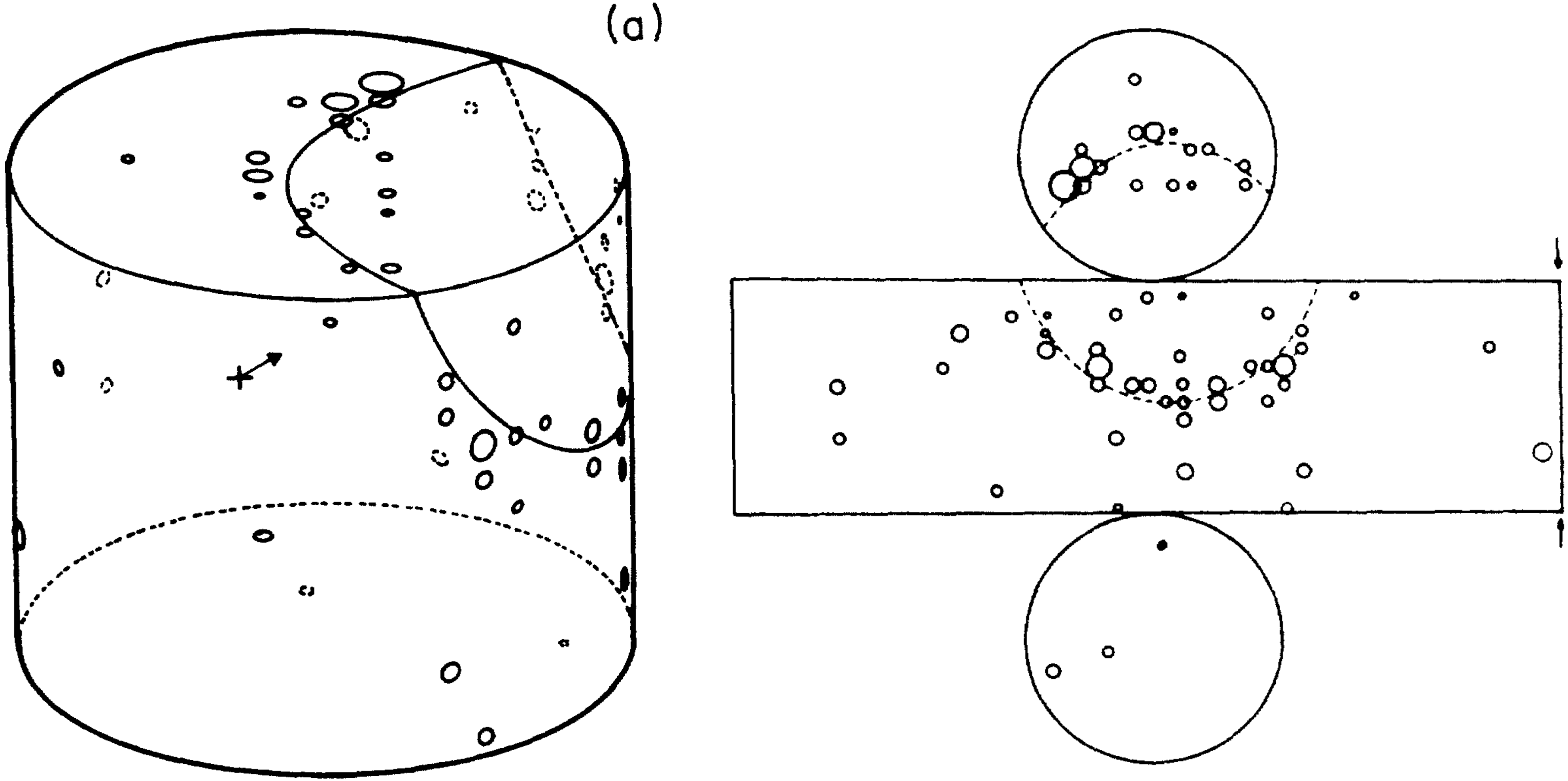
- Date : 23 Feb. 1987
- Time : 07:35:35 (UT)
- 11 events in 13 sec.

Energy is determined by the number of hit PMTs for which the residual time (T-Tof) is ± 15nsec

Trigger if 20 hits within 100 nsec ~ 7.5 MeV (@50% eff.)

Review of the SN1987A in LMC

Kamiokande



Review of the SN1987A in LMC

IMB (Irvine-Michigan-Brookhaven)

Einstein LoSecco

Smith Wuest Sinclair Learned Cortez

Bratton Sobel Vander Velde Goldhaber Reines Sulak

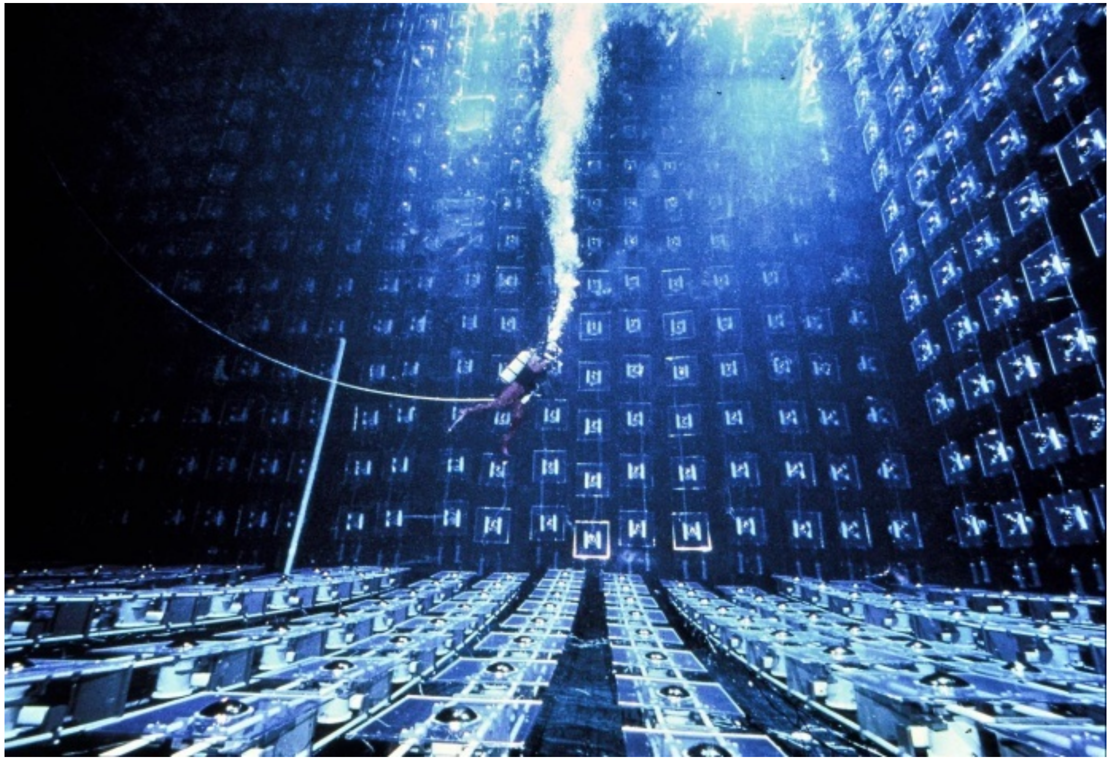
Review of the SN1987A in LMC

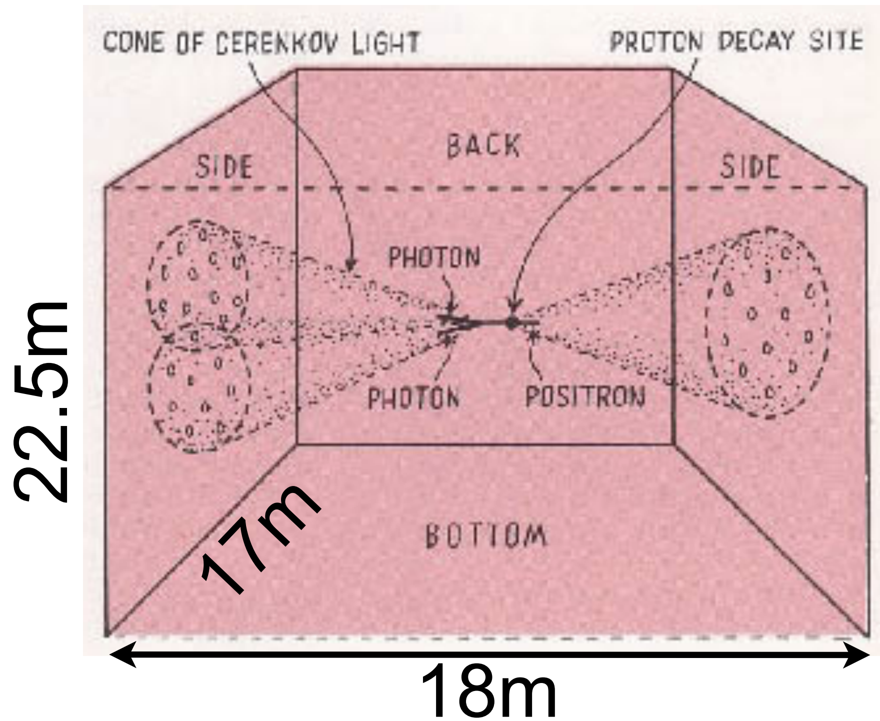
IMB (1979-1989)

Morton salt mine in Mentor, Ohio, USA (1570mwe)

(close to the Lake Erie)

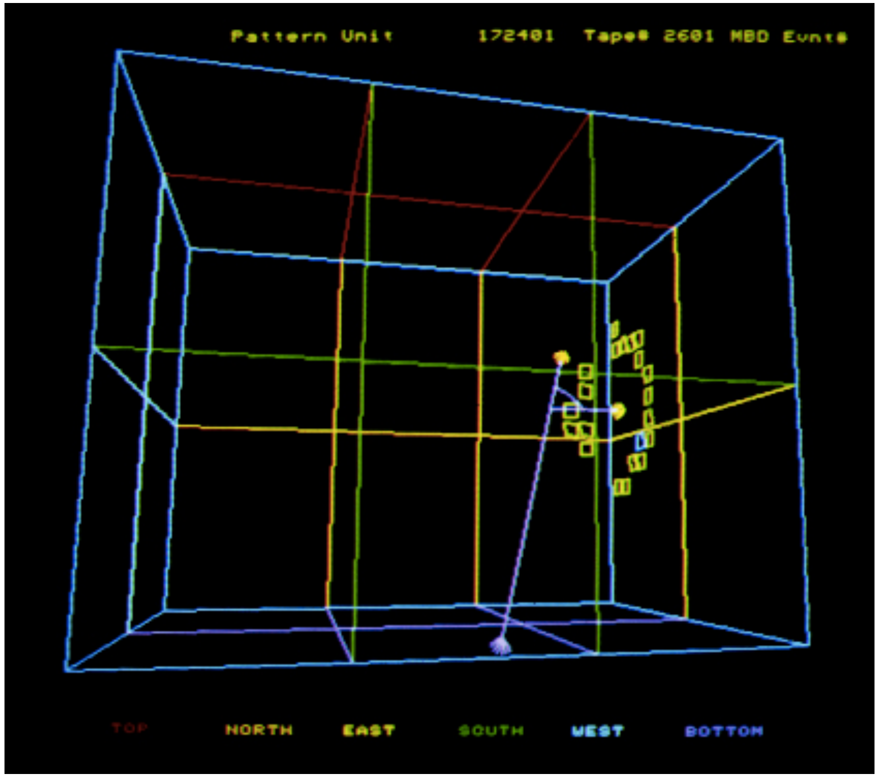
8 kton water (3.3kton F.V.) with 2048 8' PMTs





Review of the SN1987A in LMC

SN1987A in IMB



Realtime detector

- Date : 23 Feb. 1987
- Time : 07:35:41 (UT)
- 8 events in 6 sec.

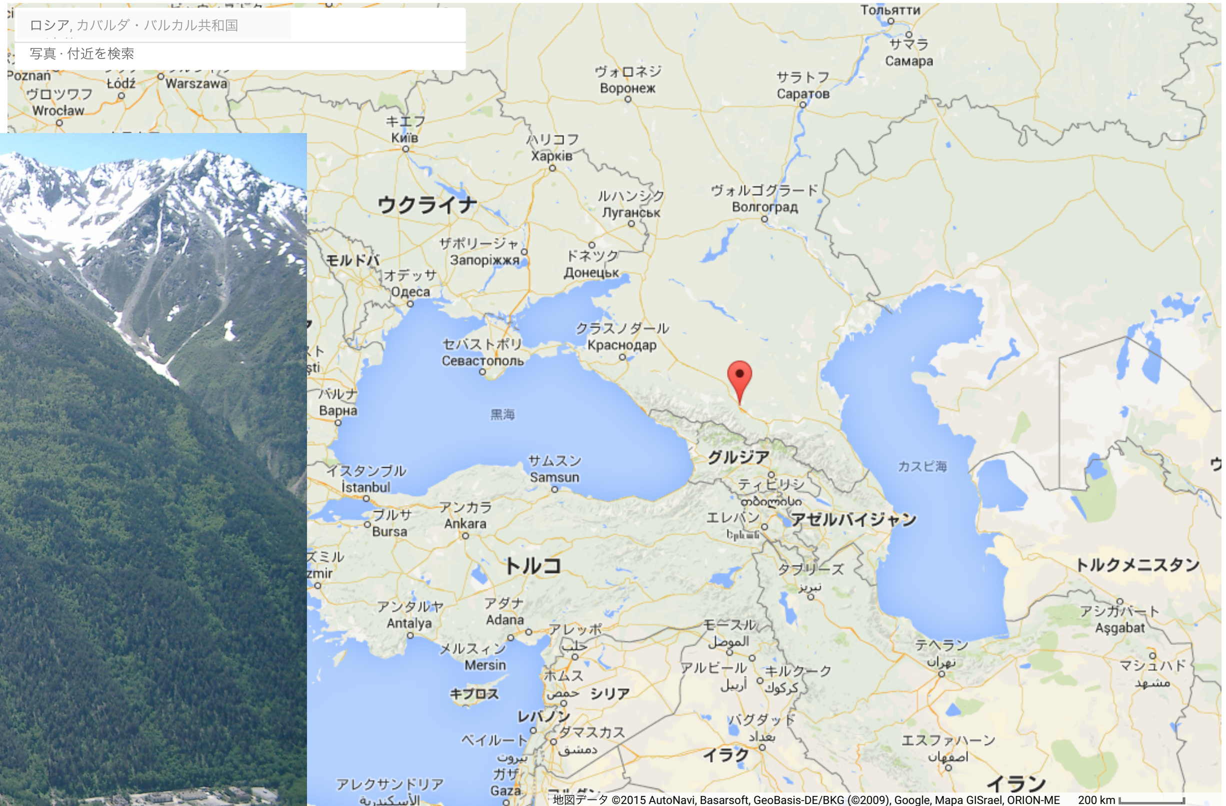
Energy is determined by the number of hit PMTs for which the residual time is within 50nsec

Trigger if 25 hits within 50 nsec ~ 35 MeV (@50% eff.)

Review of the SN1987A in LMC

Baksan underground scintillator telescope

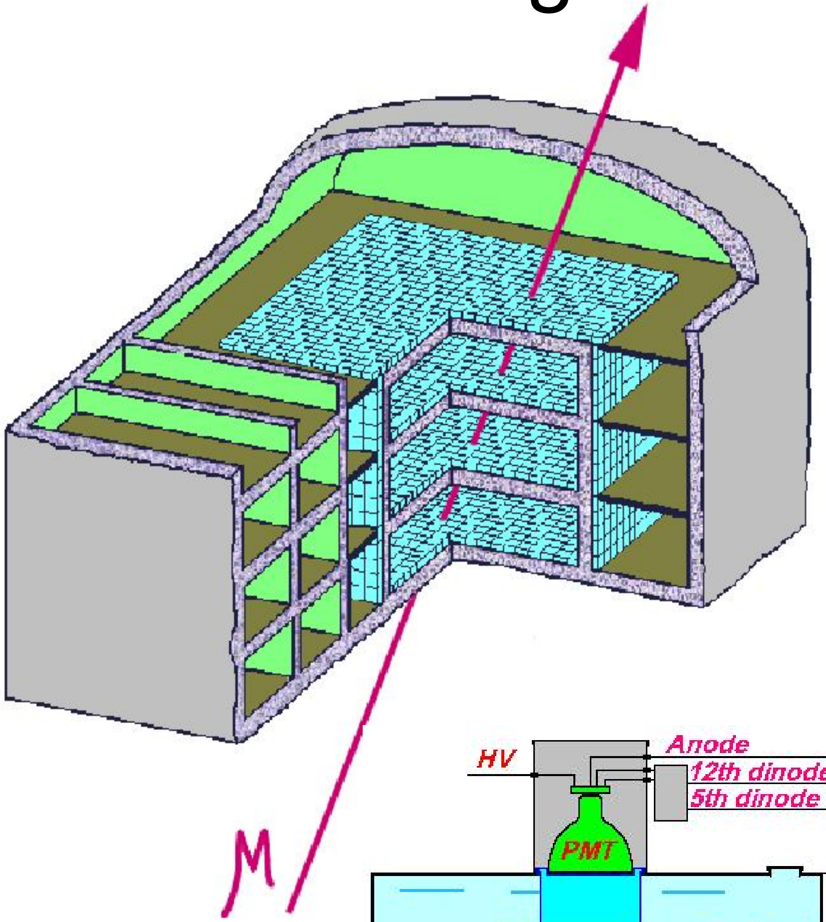
(2700mwe)

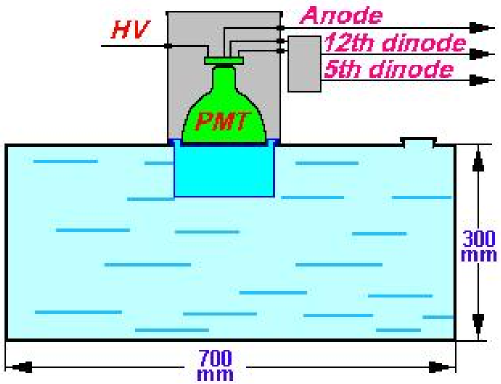


ロシア／コーカサス

Review of the SN1987A in LMC

Baksan underground scintillator telescope (1978~)





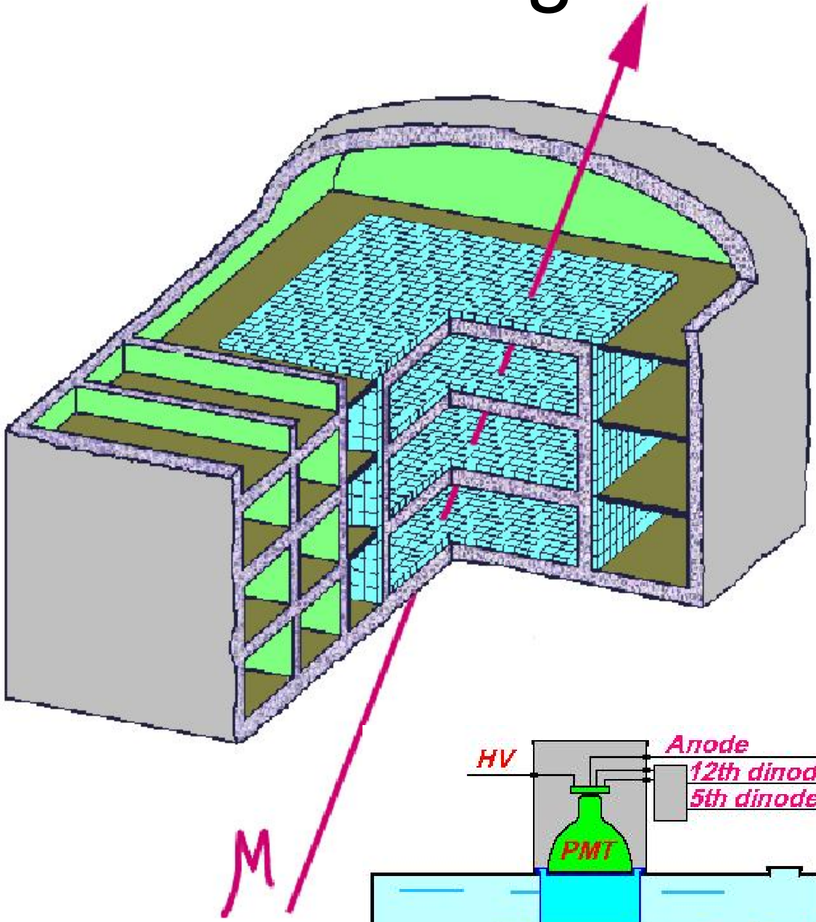
3156 tanks filled with liquid scintillator and one 15cm PMT

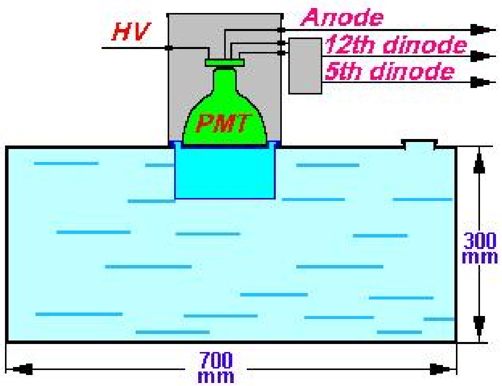
Total target mass : 330 ton

Detection eff. 10MeV @ 50%

Review of the SN1987A in LMC

Baksan underground scintillator telescope (1978~)





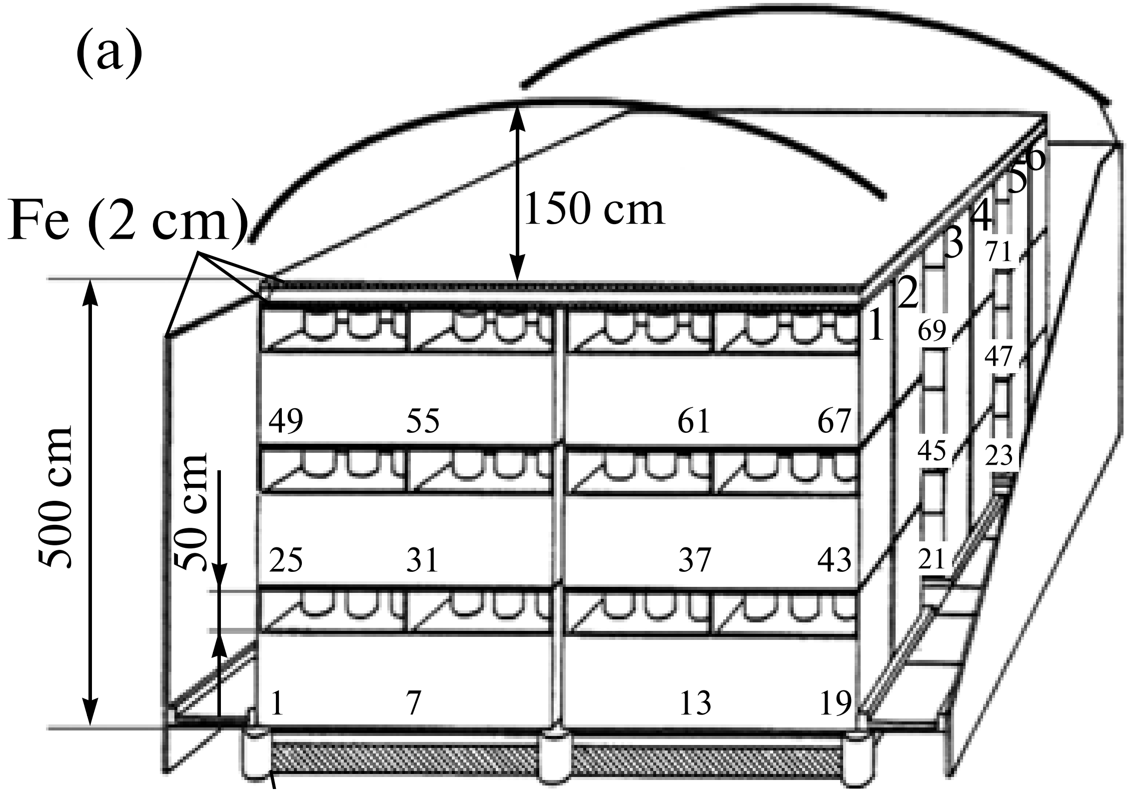
Realtime detector

- Date : 23 Feb. 1987
- Time : 07:36:11 (UT)
- 5 events in 9 sec.

Review of the SN1987A in LMC

Soviet-Italian LSD (Liquid Scintillation Detector)
under Mont Blanc (5200mwq, 1985~1999)

72 scintillation counters (1.5m^3, 1.2ton) with three PMTs



Total target mass : 90 tons

Energy threshold > 5MeV

Realtime detector

- Date : 23 Feb. 1987
- Time : 02:52:32 (UT)
- 5 events in 7 sec.

(7~11MeV,
one has delayed coincidence)

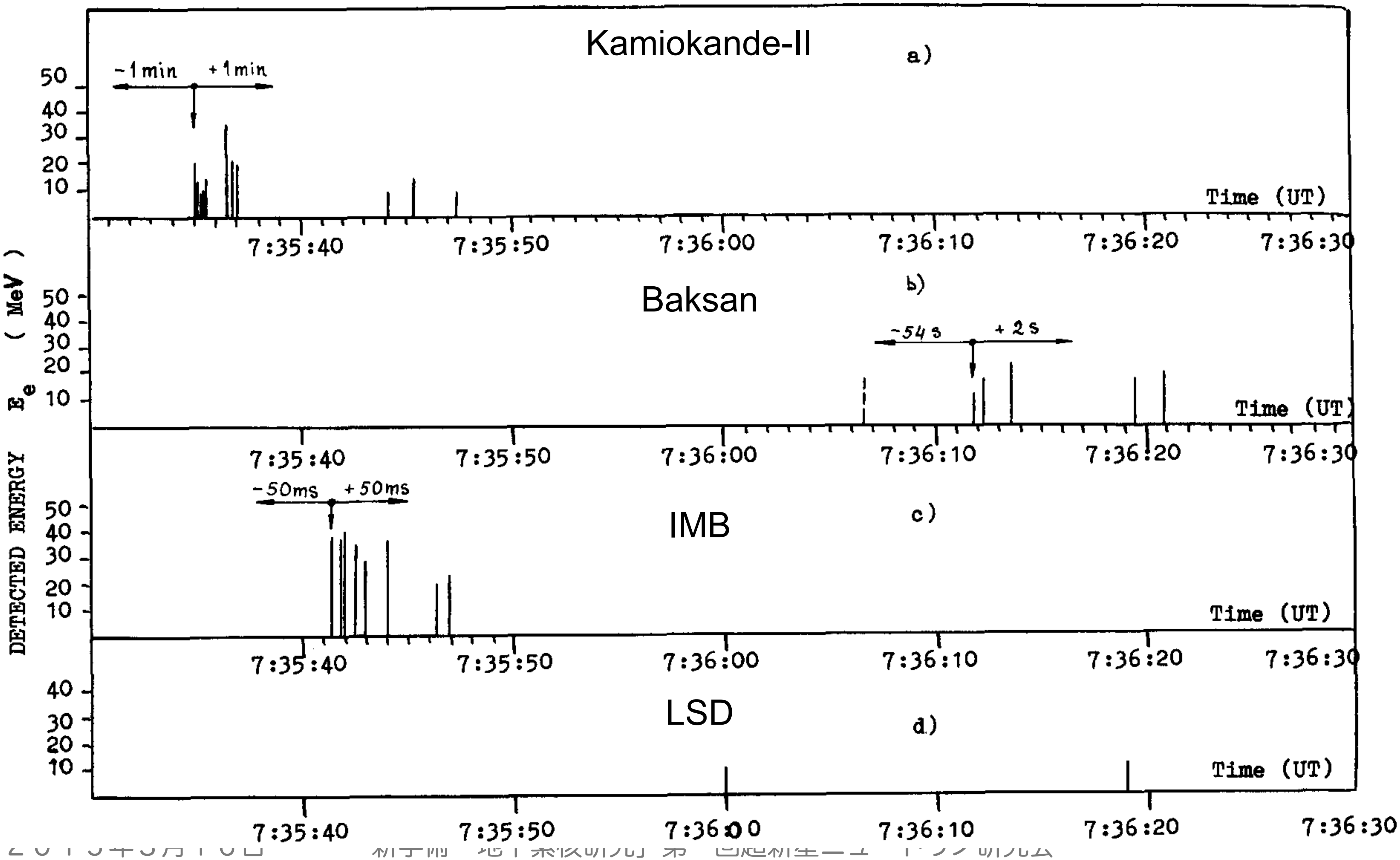
Review of the SN1987A in LMC

LSD vs Others ?

Annu. Rev. Astron. Astrophys. 1989, 27 : 629-700

Our reasons for this belief are as follows: (*a*) No neutrino events (which were clearly different from background) were observed in the much larger Kamiokande II and IMB detectors at the earlier time reported by the scintillator detectors [(55, 179) and especially (180)]. The number of free protons in the Mont Blanc telescope (0.08×10^{32}) is more than an order of magnitude less than in the Kamiokande II detector (1.4×10^{32} protons) and the IMB detector (4.5×10^{32} protons). (*b*) The expected number of events in the Mont Blanc detector for a standard stellar collapse (see Table 3) is only ~ 1 event, assuming a 100% detection efficiency (40). The satisfactory agreement between the a priori model predictions and the observations made with the Kamiokande II and IMB detectors strengthens this argument. (*c*) The reported events have energies that are close to the threshold energy for the detection, which is between 5 and 7 MeV [depending upon which counters were excited; see (2)]. The measured energies are (in MeV) 7, 8, 11, 7, and 9. Theoretically, one expects a greater spread in energy, since the absorption cross section increases with the square of the neutrino energy for charged-current absorption, and the numerical models predict an average antineutrino energy of more than 10 MeV. (*d*) No plausible astrophysical scenario has been suggested for two distinct neutrino bursts [cf. (126)]. (*e*) It is difficult to obtain a satisfactory light curve for the visual supernova if the earlier time indicated by the scintillation experiments is adopted as the time at which the star collapsed [cf. (22–25, 353) and Figure 1].

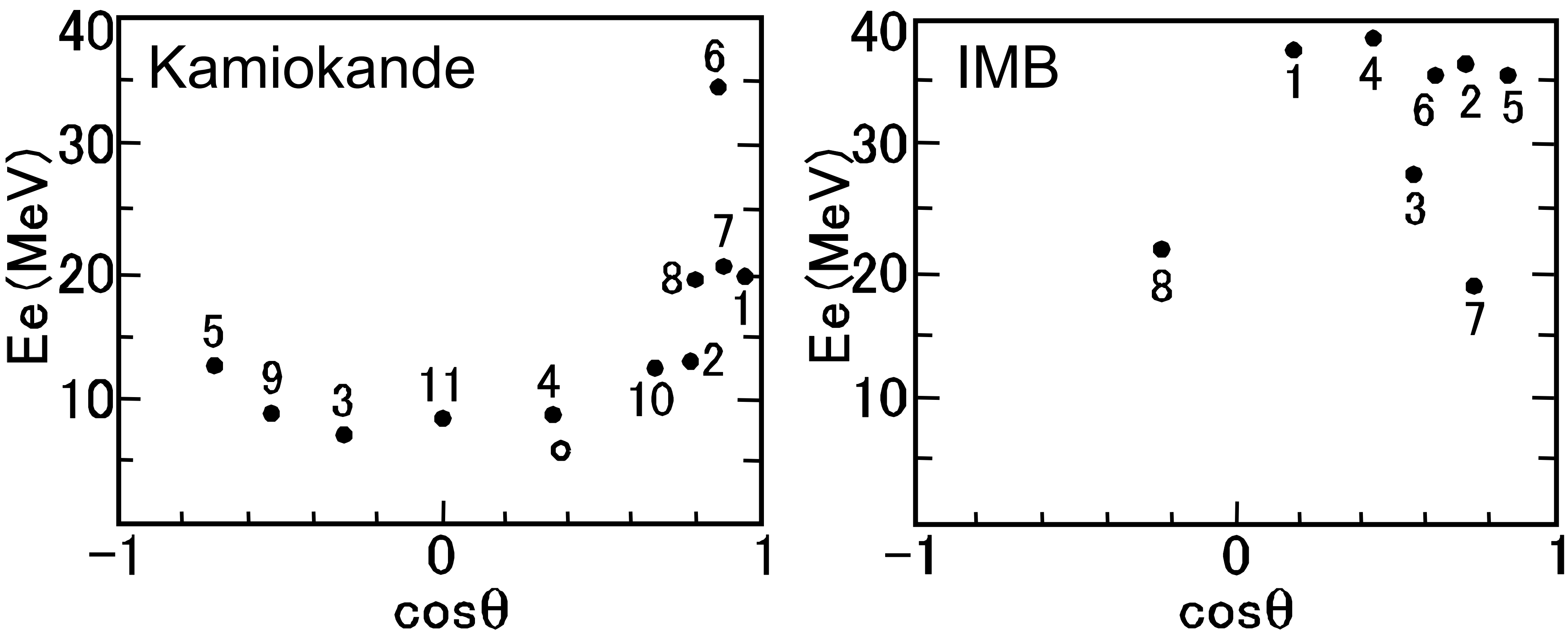
Review of the SN1987A in LMC



Review of the SN1987A in LMC

Angular distribution

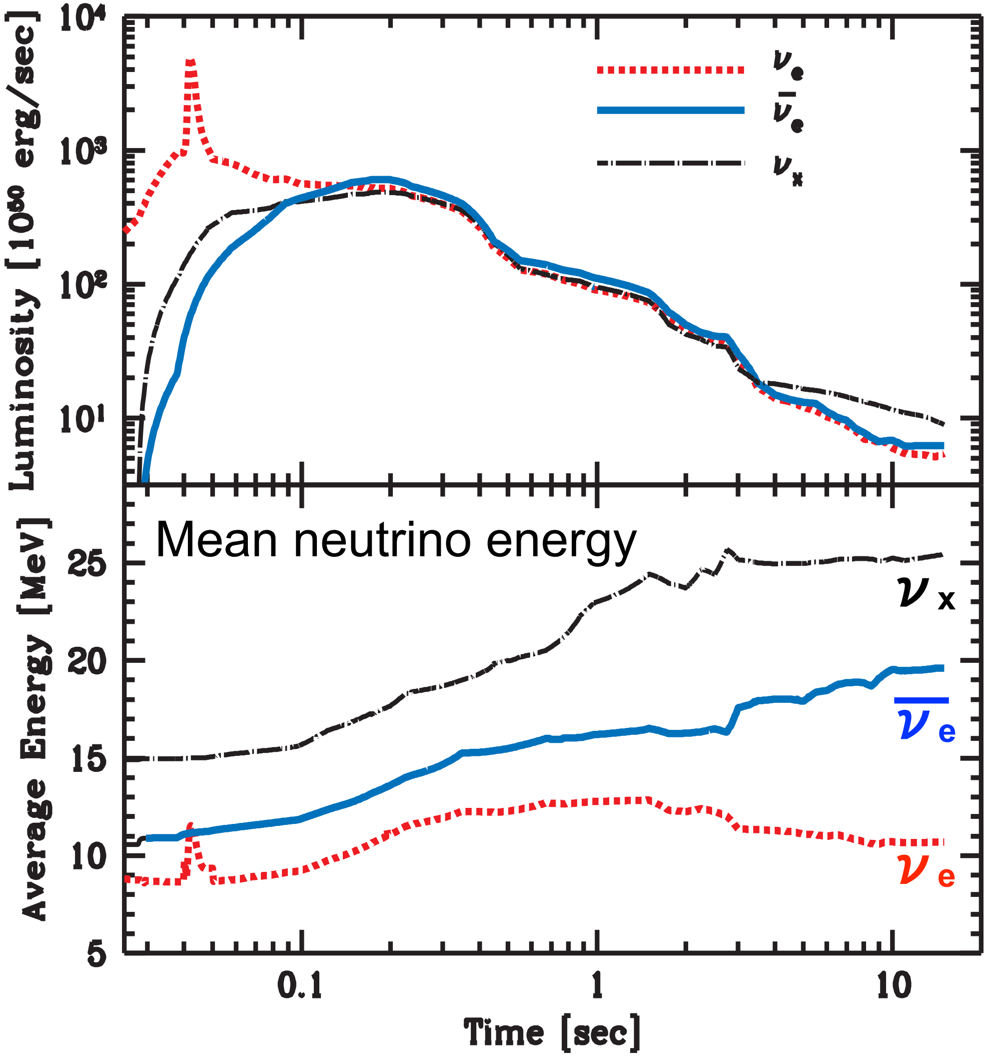
ν_e event ?



Hard to say anything...

Neutrinos from supernova burst

Expected time profile
(Livermore simulation)



What we can learn

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

✓Neutrino physics
- neutrino oscillation
- etc..

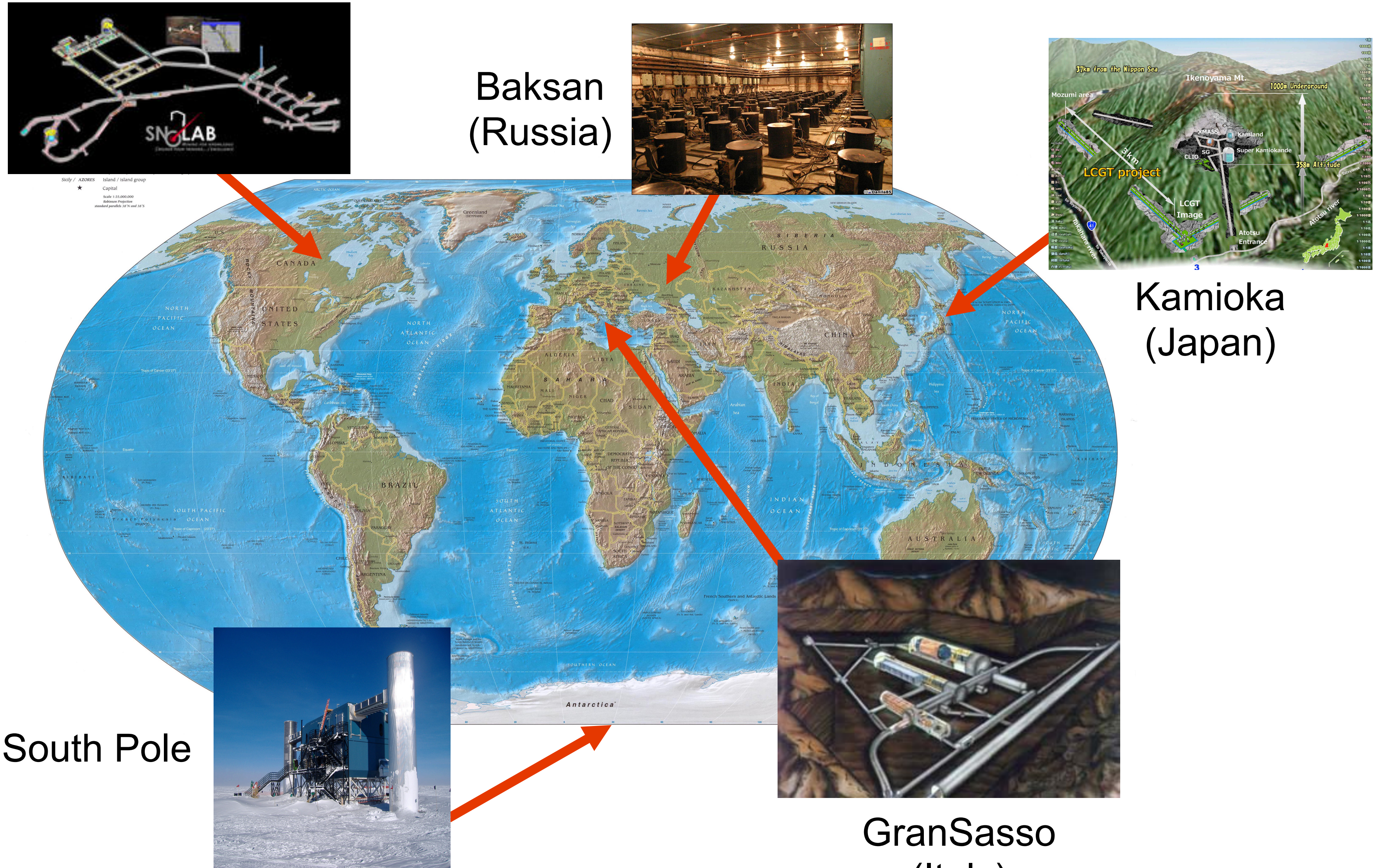
Measurements of neutrino
flavor, energy, time profile
are the key points

Neutrinos from supernova burst

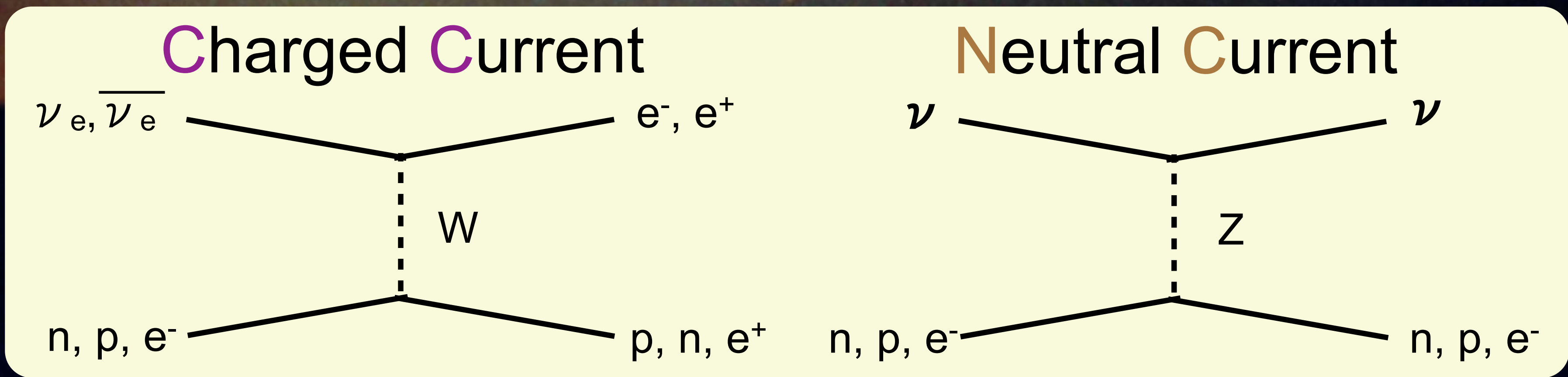
What we want for a detector

- ✓ Massive target
  - Now : O(kton), sensitive for galactic center
  - Future : O(Mton), sensitive for ~Mpc(?)
- ✓ Low background rate ~MeV energy region
  - Easy for underground detector
- ✓ Precise timing measurement
- ✓ Good energy resolution
  - Energy spectrum measurement is crucial for all the physics
- ✓ Measurable for direction, if possible
- ✓ Neutrino flavor sensitivity
  - Use specific neutrino interactions

Underground facilities for SN ν



Neutrino interaction for supernova neutrino detection



Neutrino interaction for SN ν

Inverse beta decay

$\bar{\nu}_e + p \rightarrow e^+ + n$ (Charged Current interaction)

- ✓ Dominates for detectors with lots of free proton
  - Detect positron signal in water, scintillator, etc.
- ✓ $\bar{\nu}_e$ sensitive
- ✓ Obtain the neutrino energy from the positron energy
  - $E_e \sim E_\nu - (m_n - m_p)$, $E_\nu > 1.86$MeV
- ✓ Well known cross section
- ✓ Poor directionality
- ✓ Neutron tagging using delayed coincidence
  - $n + p \rightarrow d + \gamma$

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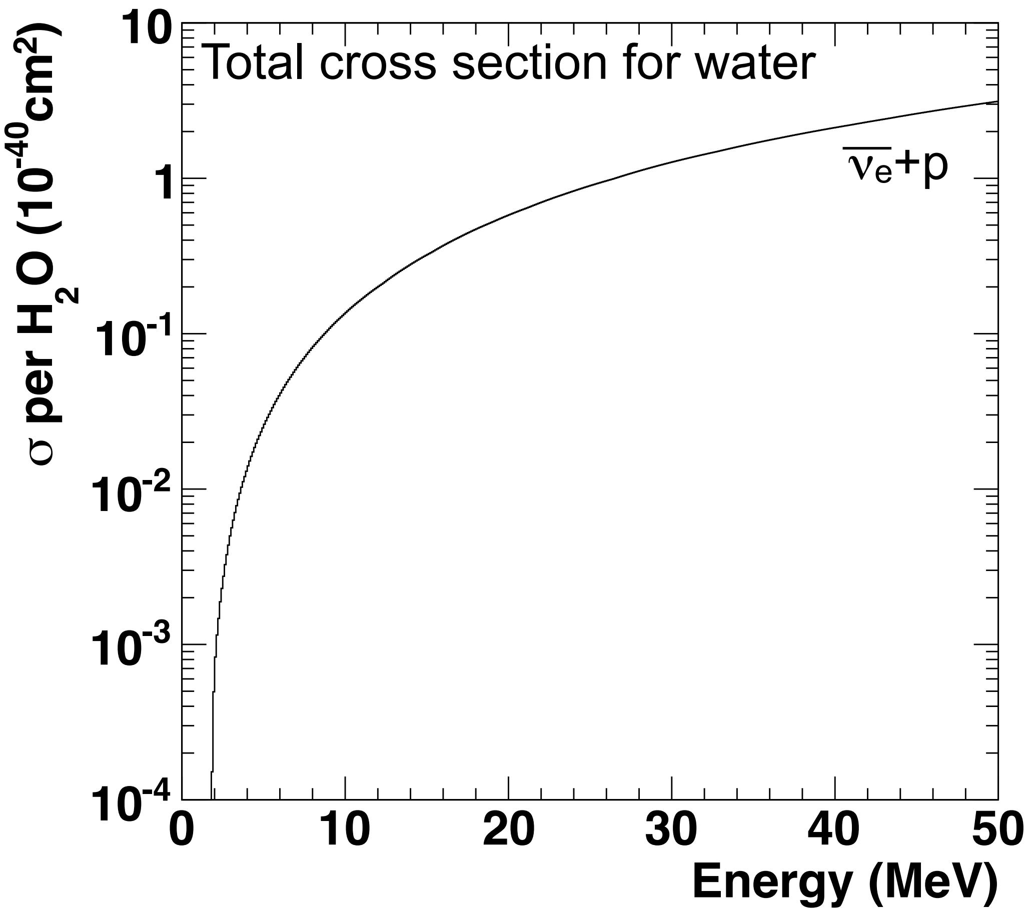
Strumia, Vissani
Phys. Lett. B564 (2003) 42



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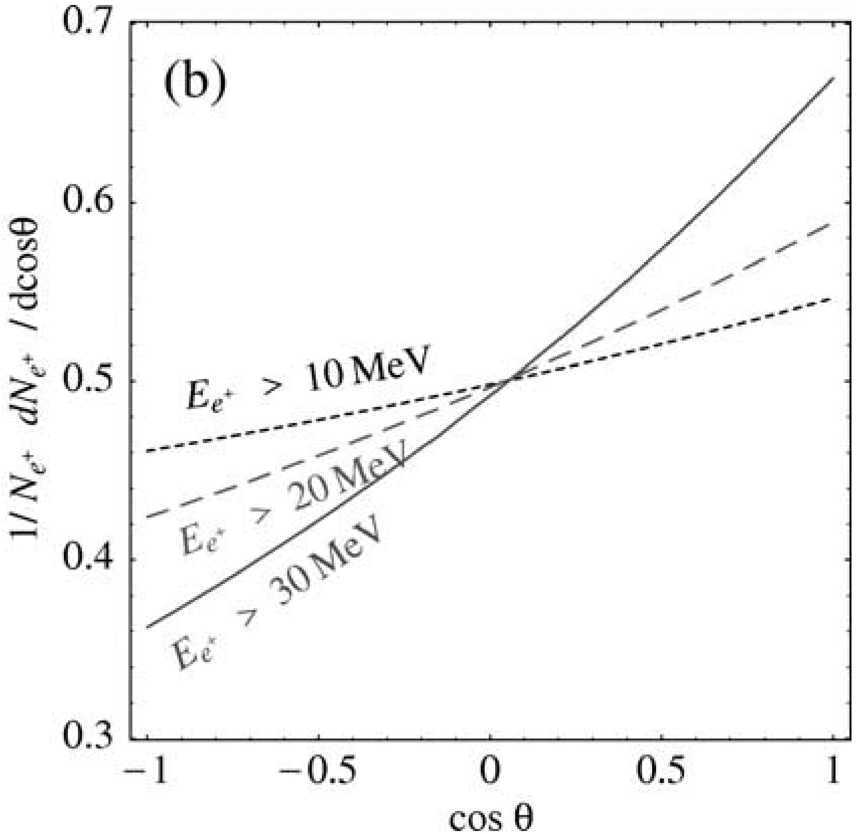

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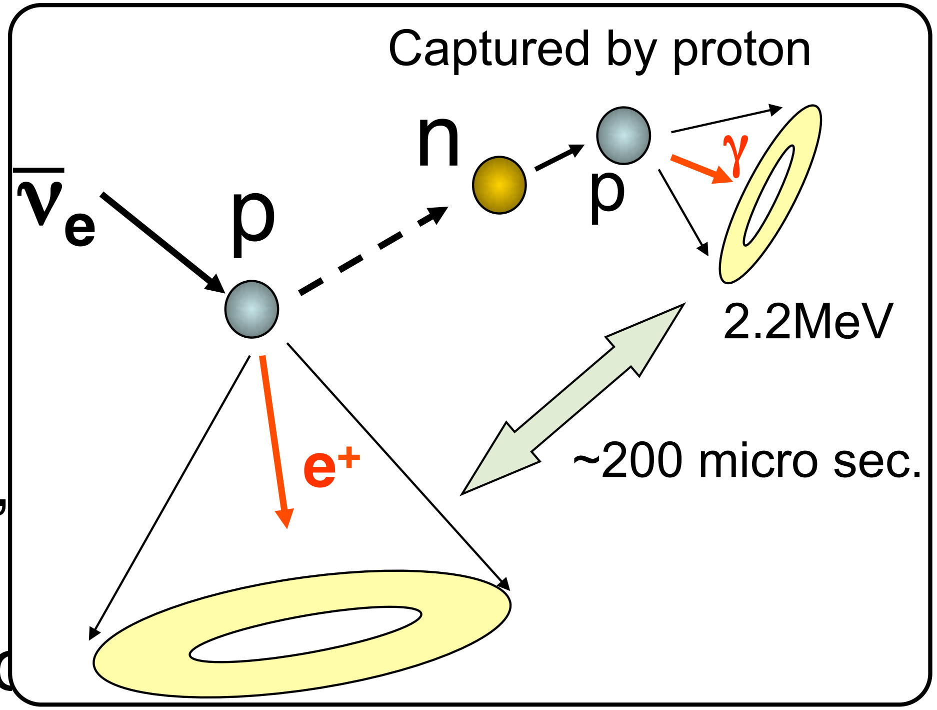

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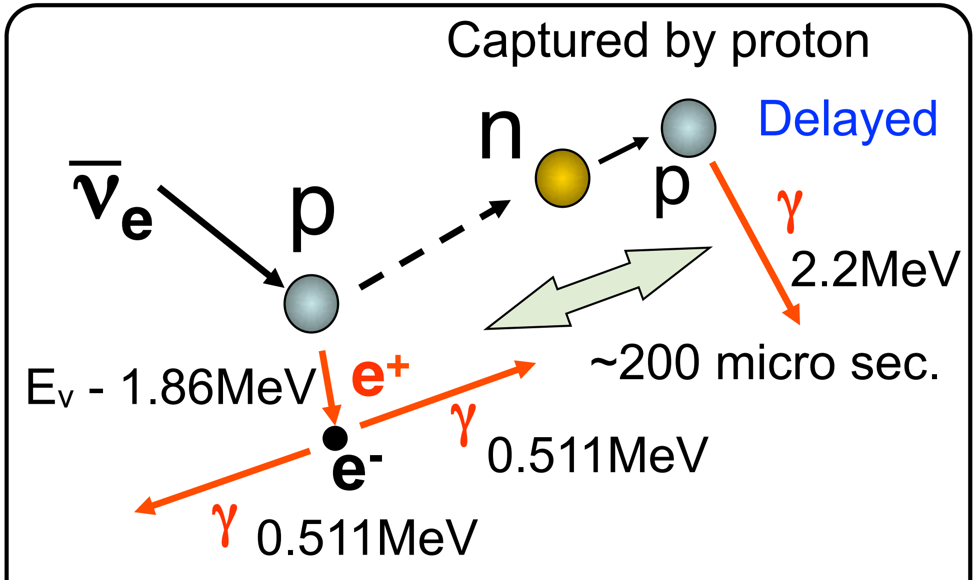
Possible to enhance this signal if Gd loaded
(→ M.Ikeda's presentation)

Neutrino interaction for SN ν

Inverse beta decay

$\bar{\nu}_e + p \rightarrow e^+ + n$

Liquid Scintillator
(→ K.Ishidoshiro's presentation)



Prompt signal :

$E_{vis} = E_\nu - 1.86 + 2 \times 0.511$
$= E_\nu - 0.84$ (MeV)
> 1.022 MeV

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  - Detect positron signal in wat
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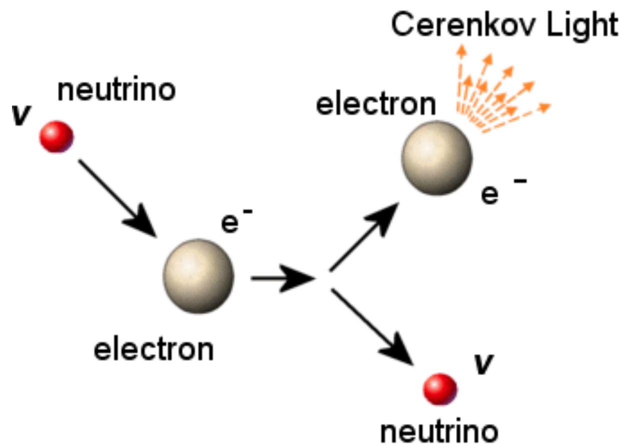
Neutrino interaction for SN ν

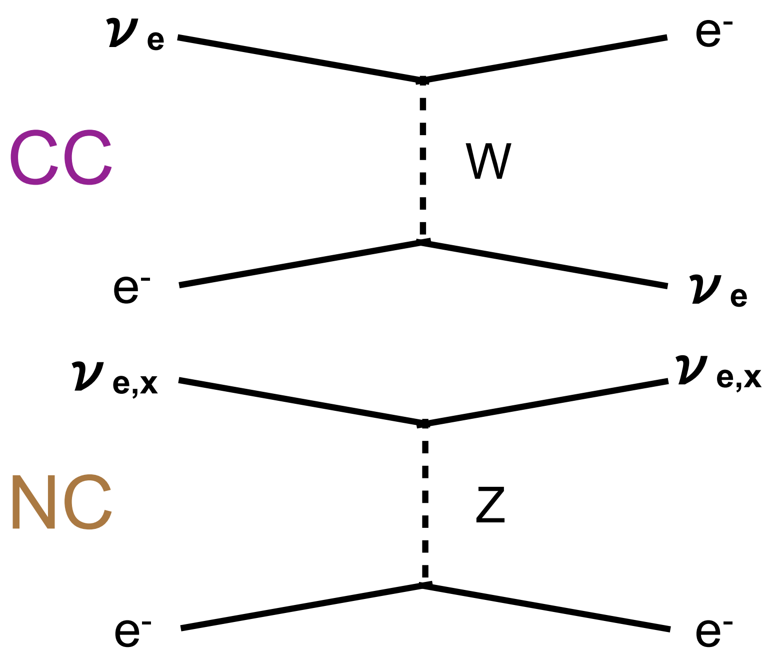
Elastic scattering

$$\nu_{e,x} + e^- \rightarrow \nu_{e,x} + e^-$$

(Both Charged Current and Neutral Current interaction)



- ✓ All neutrinos are sensitive
- ✓ The cross section for ν_e is larger than others because of CC effect.
- ✓ Well known cross section.
  - few % of inverse beta decay
- ✓ Good directionality
- ✓ Measurable for only recoil electron energy, not neutrino energy



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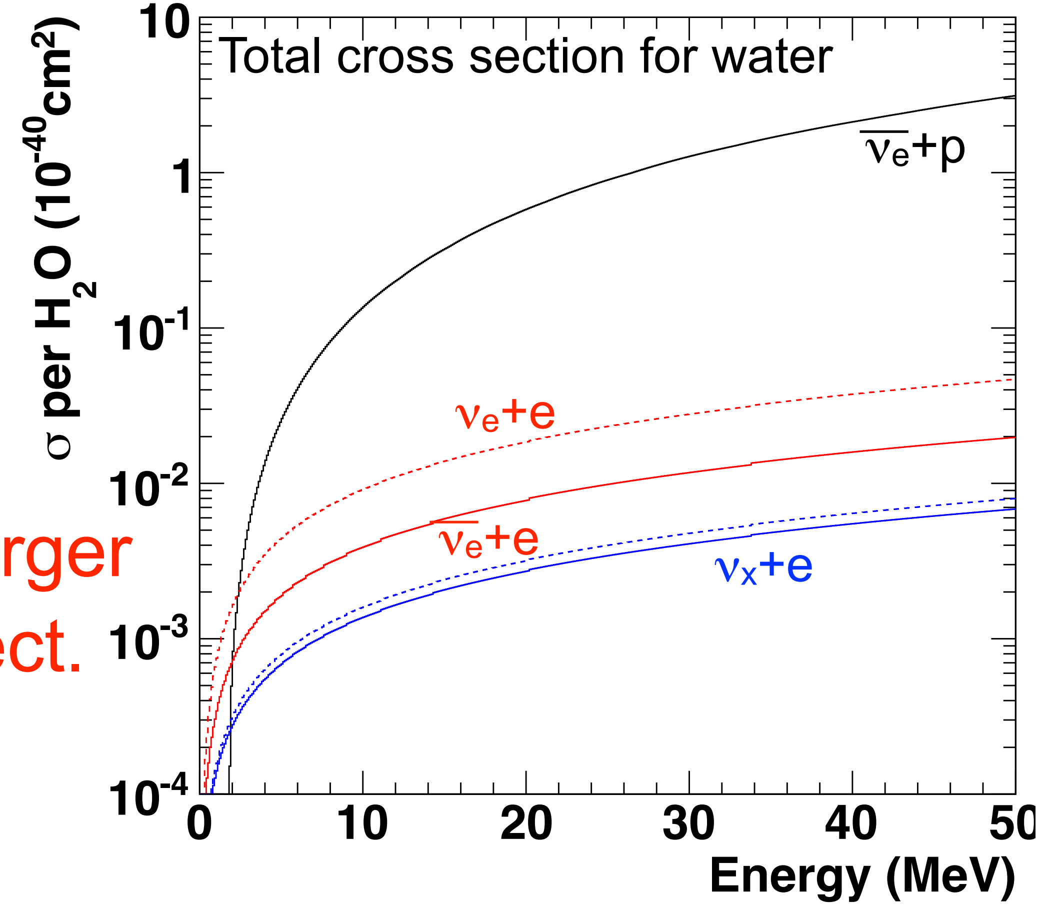

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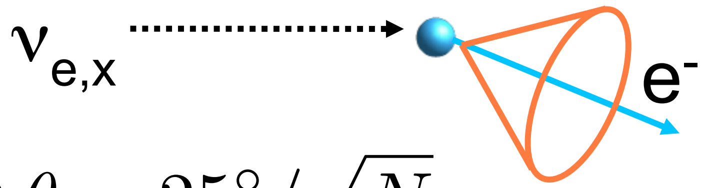
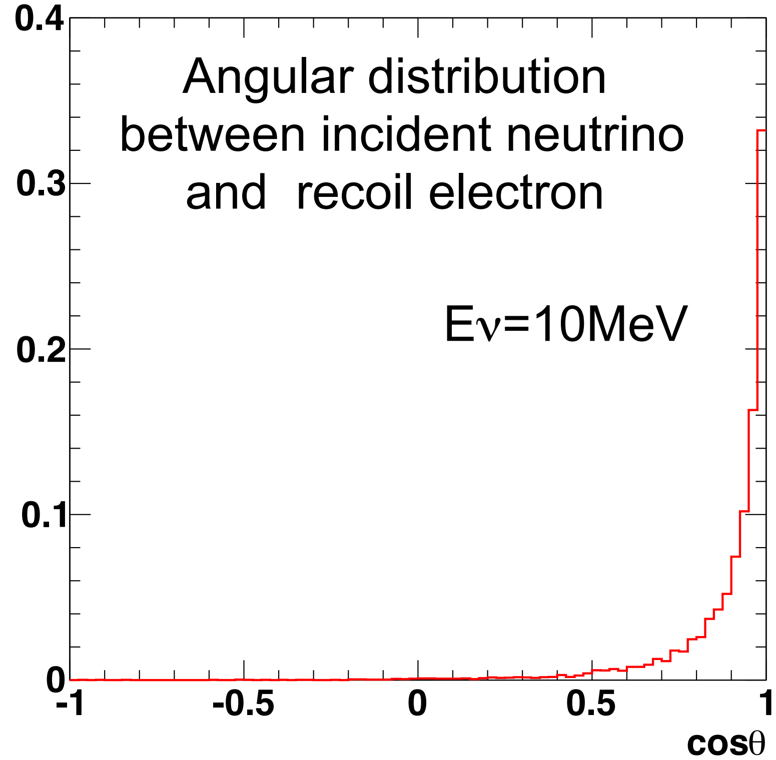
Water Cherenkov



$$\Delta\theta \sim 25^\circ/\sqrt{N}$$



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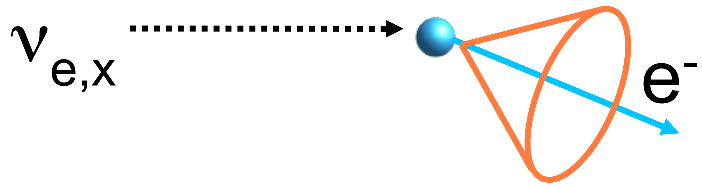
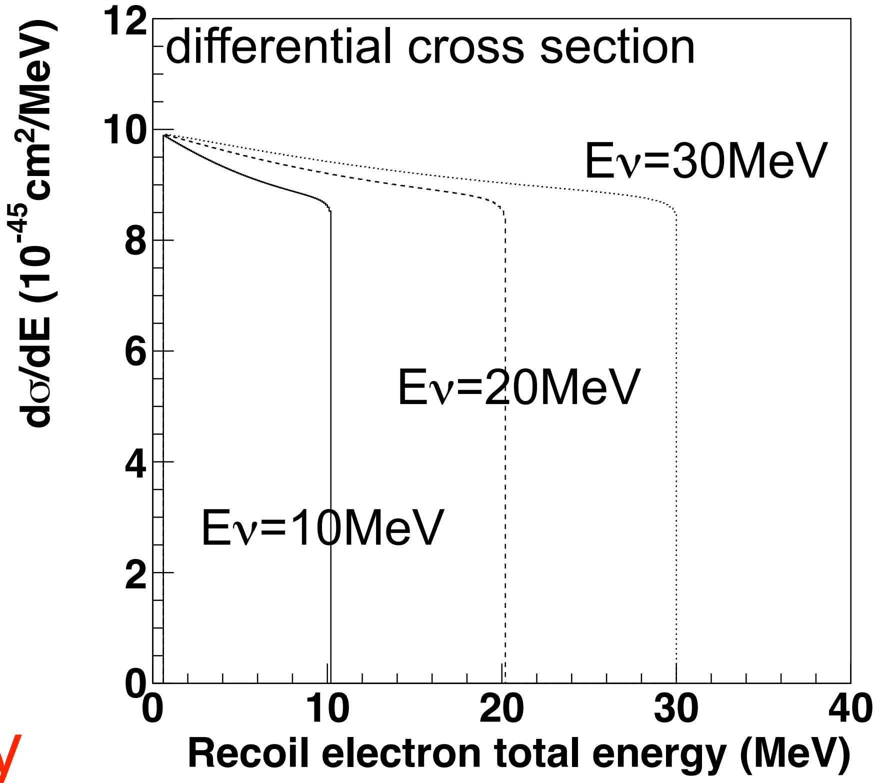


$$\Delta E \sim 15\%/\sqrt{E/10MeV}$$



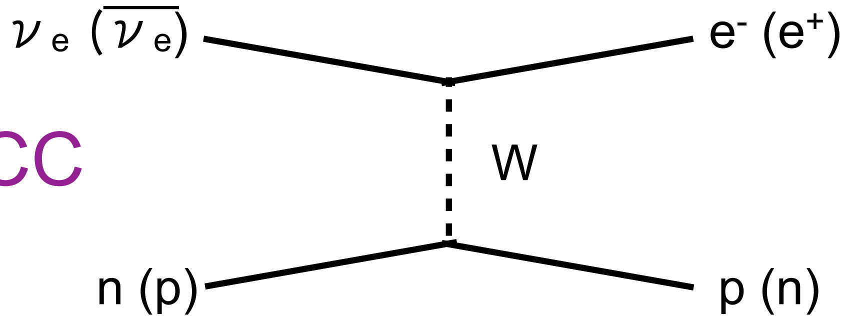
Neutrino interaction for SN ν

CC interactions on nuclei

$\nu_e + n \rightarrow p + e^-$: $\nu_e + (N,Z) \rightarrow (N-1, Z+1) + e^-$

$\overline{\nu}_e + p \rightarrow n + e^+$: $\overline{\nu}_e + (N,Z) \rightarrow (N+1, Z-1) + e^+$

CC



✓Observables:

- charged lepton $e^{+/-}$
- possibly ejected nucleons
- possibly nuclear γ's

(for example)

oxygen in water

$\nu_e + {}^{16,18}O \rightarrow {}^{16,18}F + e^-$

$\overline{\nu}_e + {}^{16}O \rightarrow {}^{16}N + e^+$

carbon in scintillator

$\nu_e + {}^{12}C \rightarrow {}^{12}N + e^-$

$\overline{\nu}_e + {}^{12}C \rightarrow {}^{12}B + e^+$

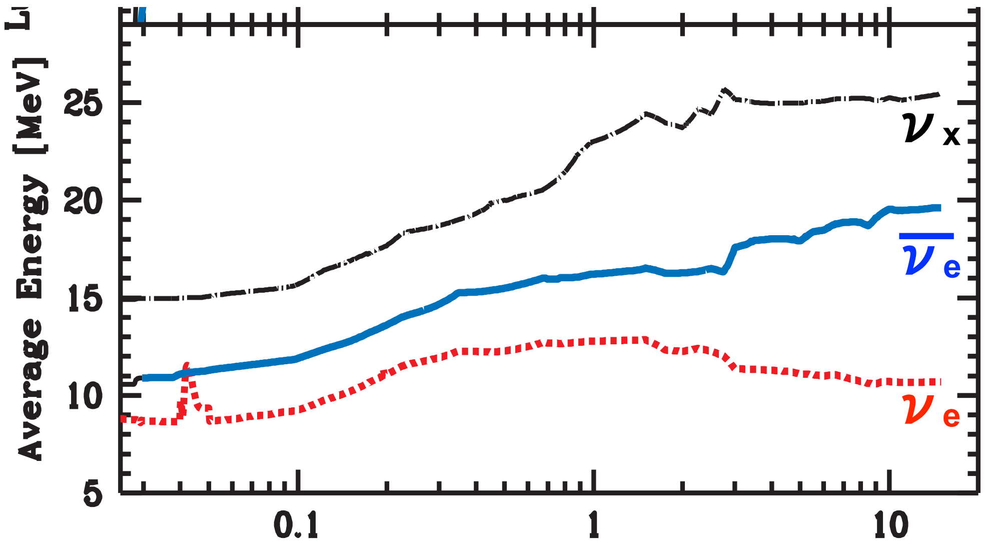
Neutrino interaction for SN ν

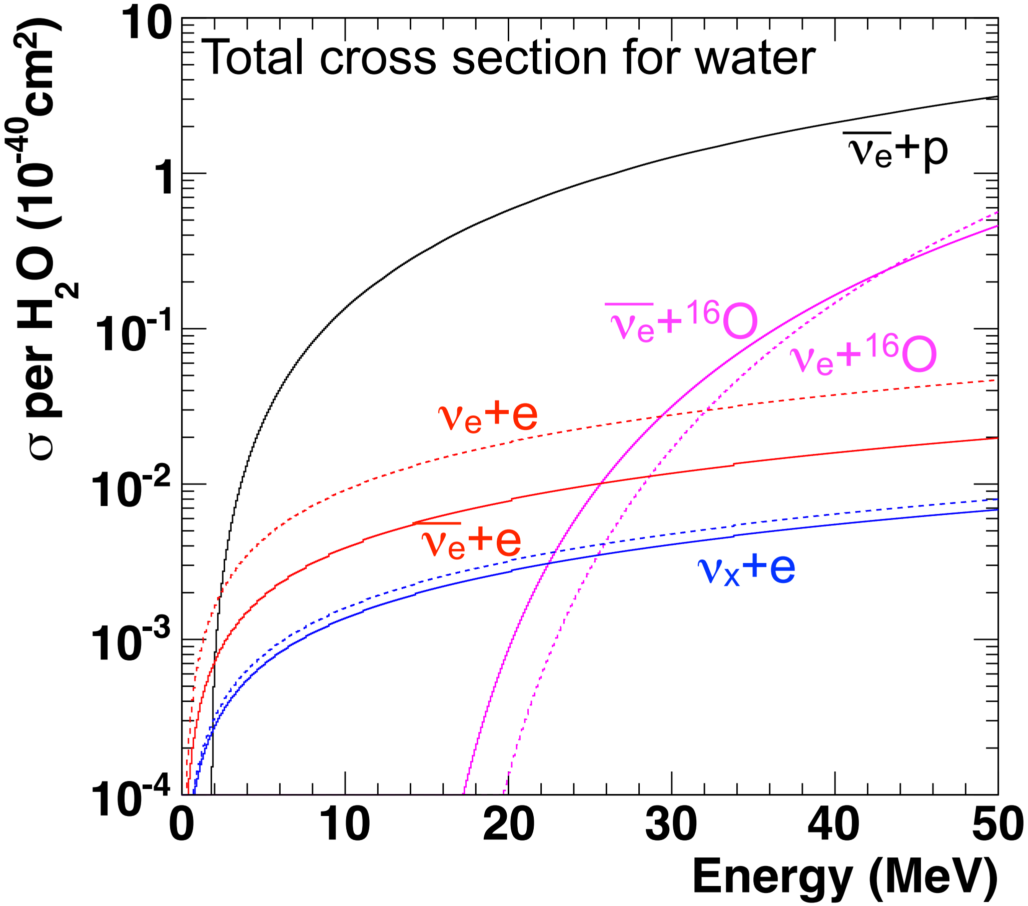
CC interactions on nuclei

✓ Small cross section by bound nucleons

✓ Also has large uncertainties

- Nuclear physics is important

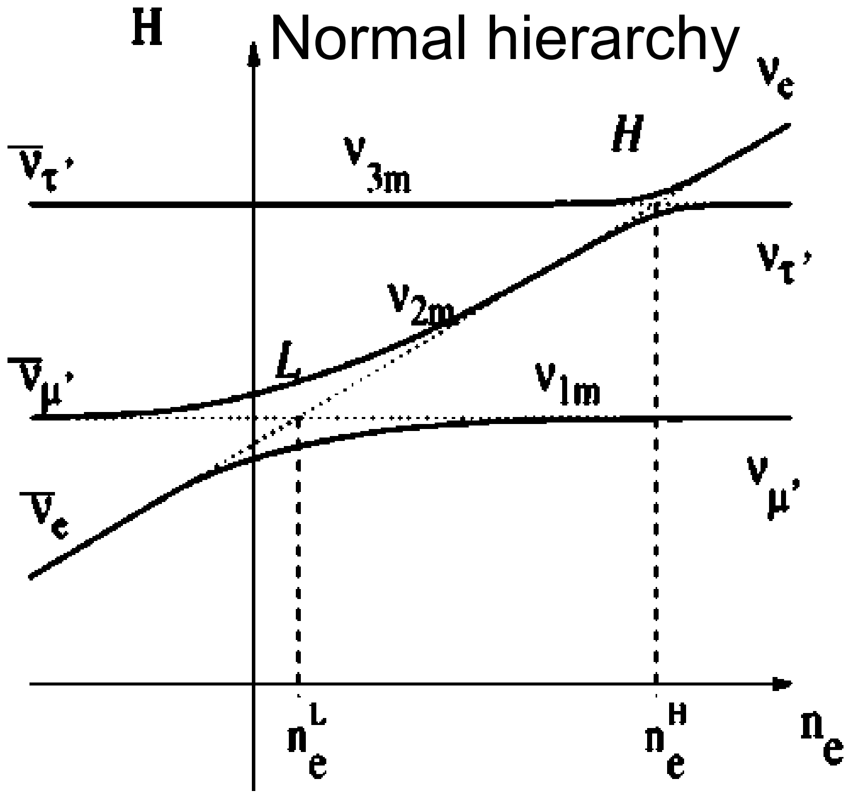


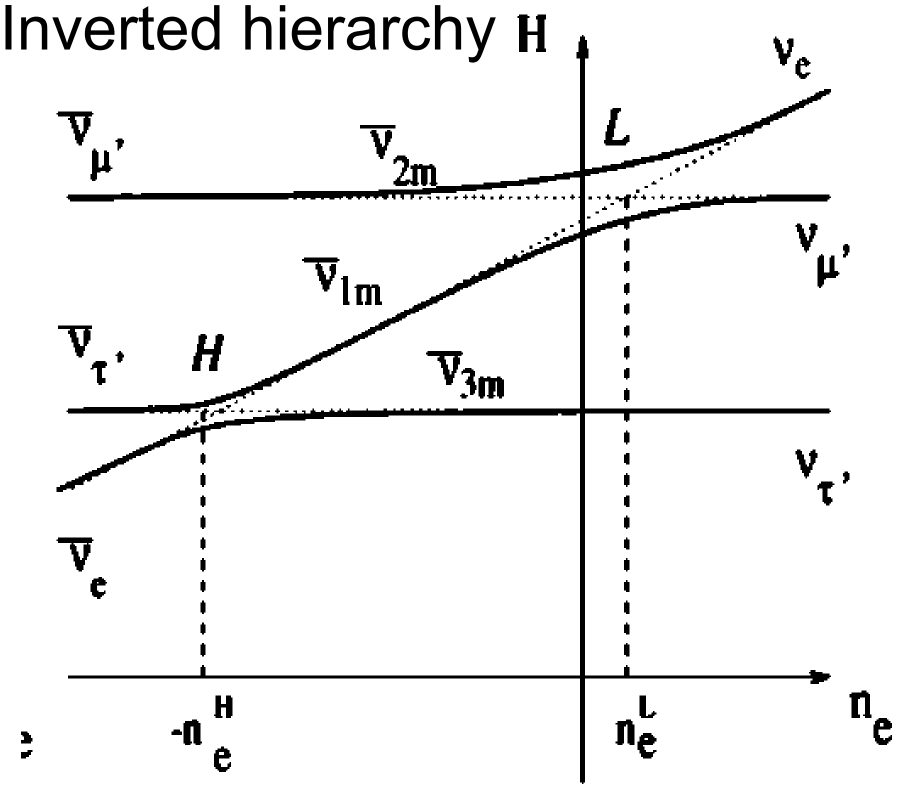


This signal is small portion, but may access neutrino oscillation effect

Dighe and Smirnov, PRD 62 (2000) 033007

Neutrino oscillation in SN





$$N_{\nu_e}^{sur} = N_{\nu_e}^{gen} \times \sin^2\theta_{12} \times P_H + N_{\nu_x}^{gen} \times (1 - \sin^2\theta_{12} \times P_H)$$

$$N_{\nu_e}^{sur} = N_{\nu_e}^{gen} \times \sin^2\theta_{12} + N_{\nu_x}^{gen} \times \cos^2\theta_{12}$$

$$N_{\nu_x}^{sur} = N_{\nu_e}^{gen} \times (1 - \sin^2\theta_{12} \times P_H) + N_{\nu_x}^{gen} \times (1 + \sin^2\theta_{12} \times P_H)$$

$$N_{\nu_x}^{sur} = N_{\nu_e}^{gen} \times \cos^2\theta_{12} + N_{\nu_x}^{gen} \times (1 + \sin^2\theta_{12})$$

$$N_{\bar{\nu}_e}^{sur} = N_{\bar{\nu}_e}^{gen} \times \cos^2\theta_{12} + N_{\bar{\nu}_x}^{gen} \times \sin^2\theta_{12}$$

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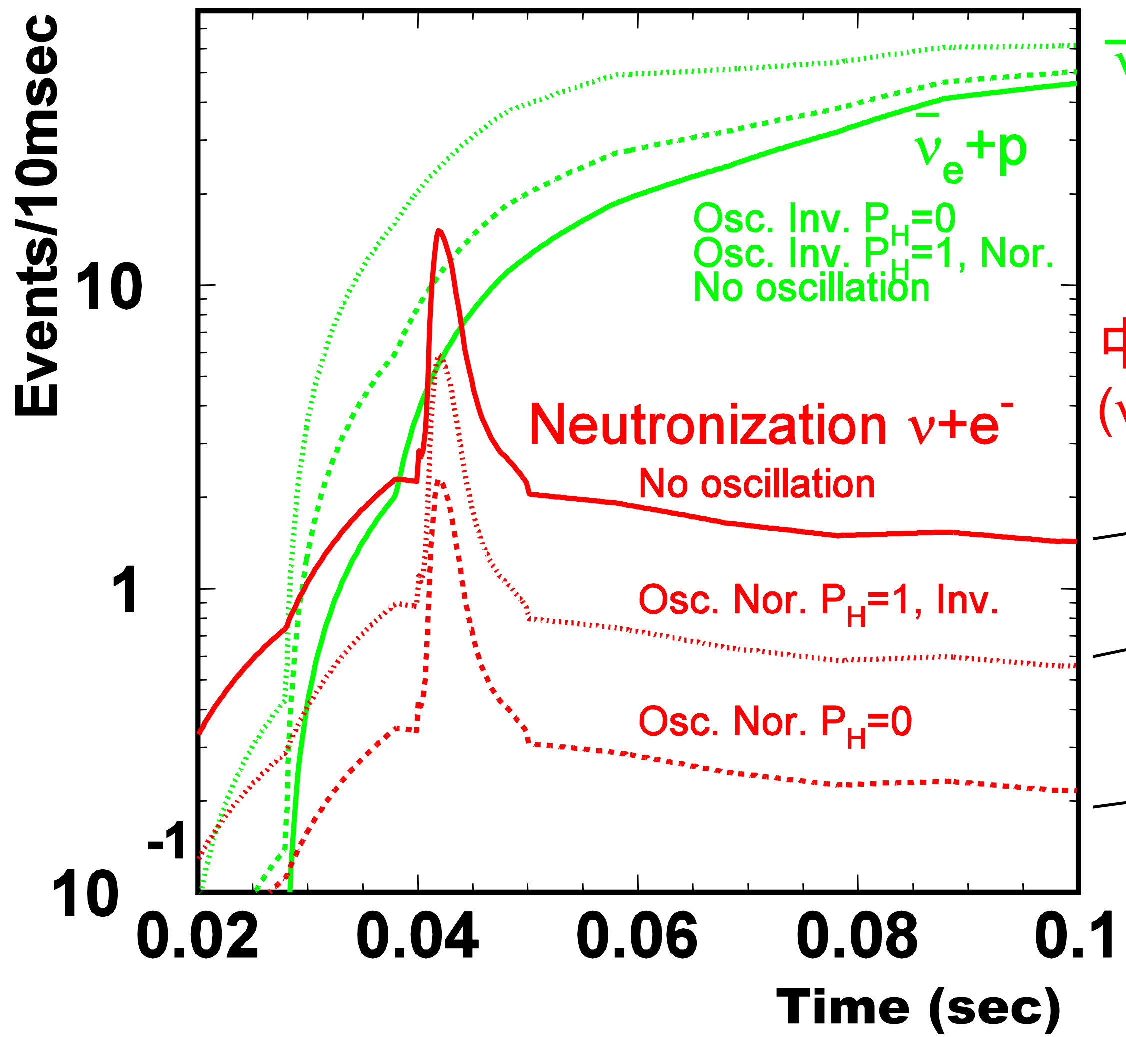
Neutrino oscillation in SK

SN at 10kpc

ニュートリノフラックスはLivermoreシミュレーションより



$\bar{\nu}_e$+p 事象の数

中性子化バーストの信号
(ν+e 散乱の前方散乱事象としてみえる

振動なし

正階層性 P_H=1、あるいは
逆階層性

正階層性でP_H=0の場合

P_H: crossing probability at H resonance
(P_H=0: 断熱的な場合に相当)

Neutrino interaction for SN ν

NC interactions on nuclei

Langanke, Vogel, Kolbe
Phys. Rev. Lett. 76 (1996) 2629

$\nu + (N,Z) \rightarrow (N,Z) + \nu$
$\nu + (N,Z) \rightarrow (N-1,Z) + n + \nu$
$\nu + (N,Z) \rightarrow (N,Z-1) + p + \nu$

✓ Important to probe ν_μ, ν_τ flux

✓ Observables:

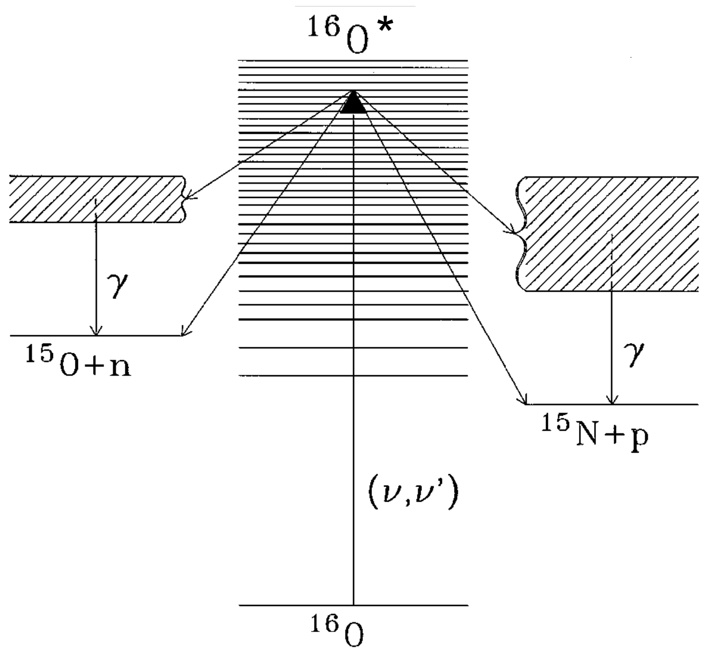
- nuclear emission (p,n)
- γ's by giant resonance

✓ Need nuclear physics info.

carbon in scintillator

$\nu + {}^{12}C \rightarrow \nu + {}^{12}C^*$
$\hookrightarrow {}^{12}C + \gamma$ (15.11MeV)

giant resonance



oxygen in water

$\nu + {}^{16}O \rightarrow \nu + {}^{16}O^*$
$\hookrightarrow {}^{16}O + \gamma$
($E\nu$ < ~150MeV)

Neutrino interaction for SN ν

NC interactions on nuclei

Langanke, Vogel, Kolbe
Phys. Rev. Lett. 76 (1996) 2629

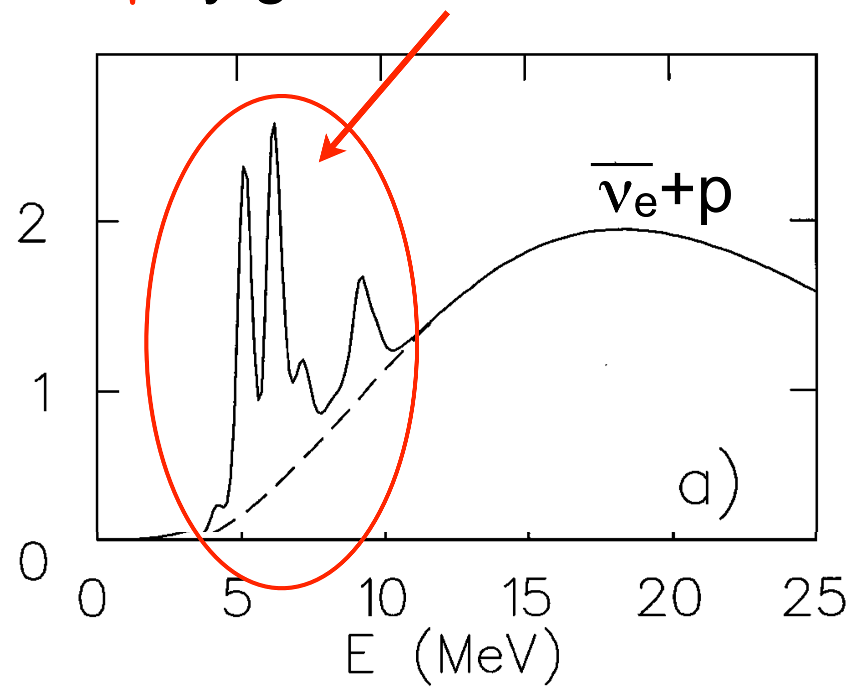
$\nu + (N,Z) \rightarrow (N,Z) + \nu$
$\nu + (N,Z) \rightarrow (N-1,Z) + n + \nu$
$\nu + (N,Z) \rightarrow (N,Z-1) + p + \nu$

✓ Important to probe ν_μ, ν_τ flux

✓ Observables:
- nuclear emission (p,n)
- γ's by giant resonance

✓ Need nuclear physics info.

γ by giant resonance



carbon in scintillator

$\nu + {}^{12}C \rightarrow \nu + {}^{12}C^*$
$\quad \hookrightarrow {}^{12}C + \gamma$ (15.11MeV)

oxygen in water

$\nu + {}^{16}O \rightarrow \nu + {}^{16}O^*$
$\quad \hookrightarrow {}^{16}O + \gamma$
($E\nu$ < ~150MeV)

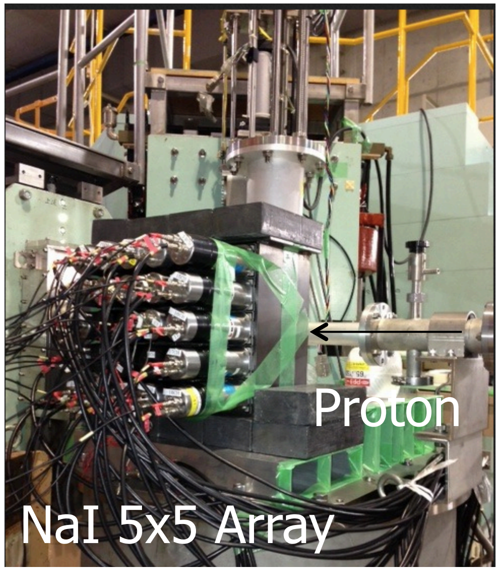
Neutrino interaction for SN ν

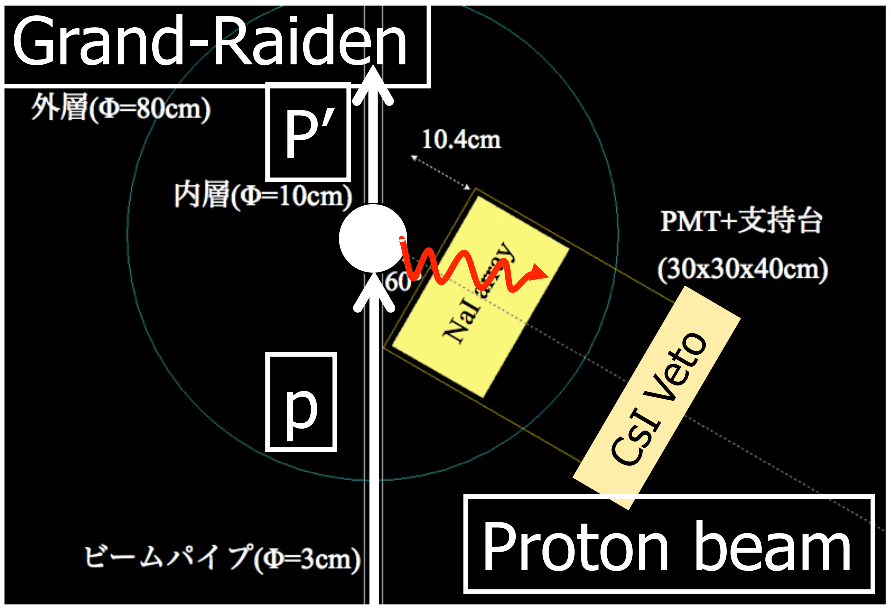
NC interactions on nuclei

Measurement of γ's from giant resonance in oxygen and carbon

→ precise cross section measurement

I.Ou's presentation





Neutrino interaction for SN ν

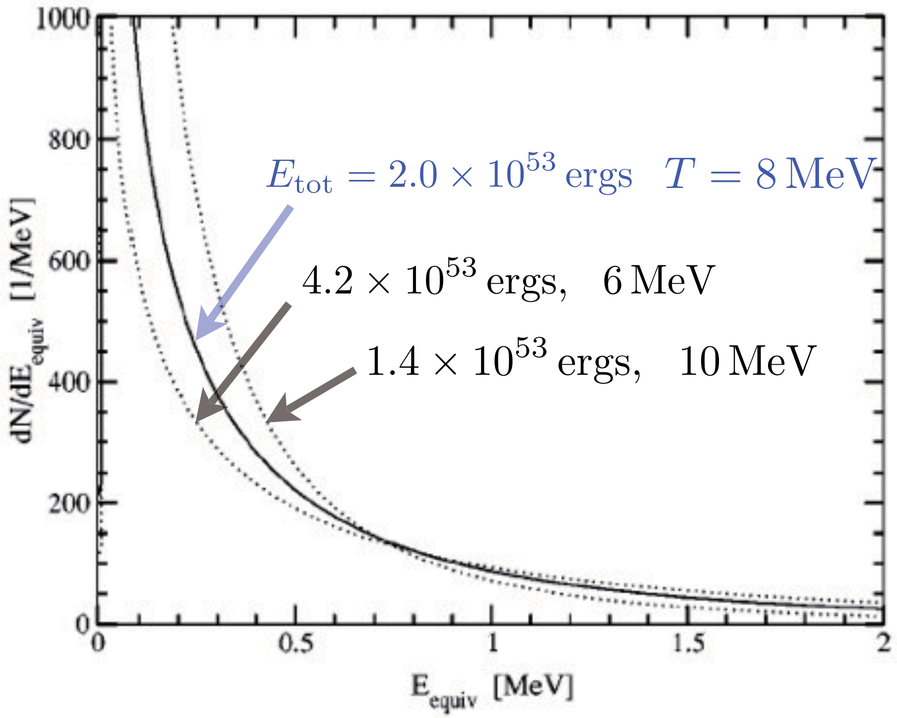
NC neutrino-proton elastic scattering

$\nu + p \rightarrow \nu + p$

Beacom, Farr, Vogel
PRD 66 (2002) 033001

✓ Observables:

- recoil proton by liquid scintillator detector
- free from neutrino oscillation



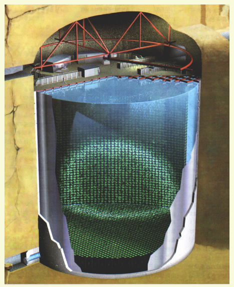
Original neutrino energy and temperature can be determined by recoil proton spectrum

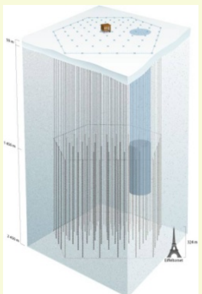
~300 events/1000ton above 200 keV
~150 events/1000ton above 350 keV

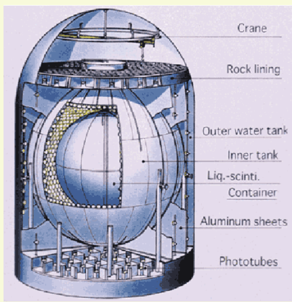
c.f.
KamLAND : 1000 ton with 350 keV threshold
Borexino : 300 ton with 200 keV therehold

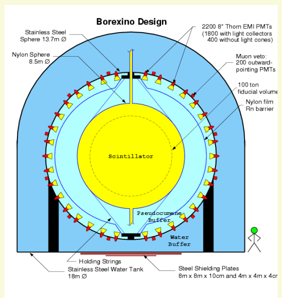
Supernova neutrino detectors

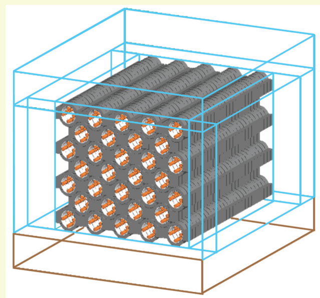
Water Cherenkov / Liquid scintillator / Others



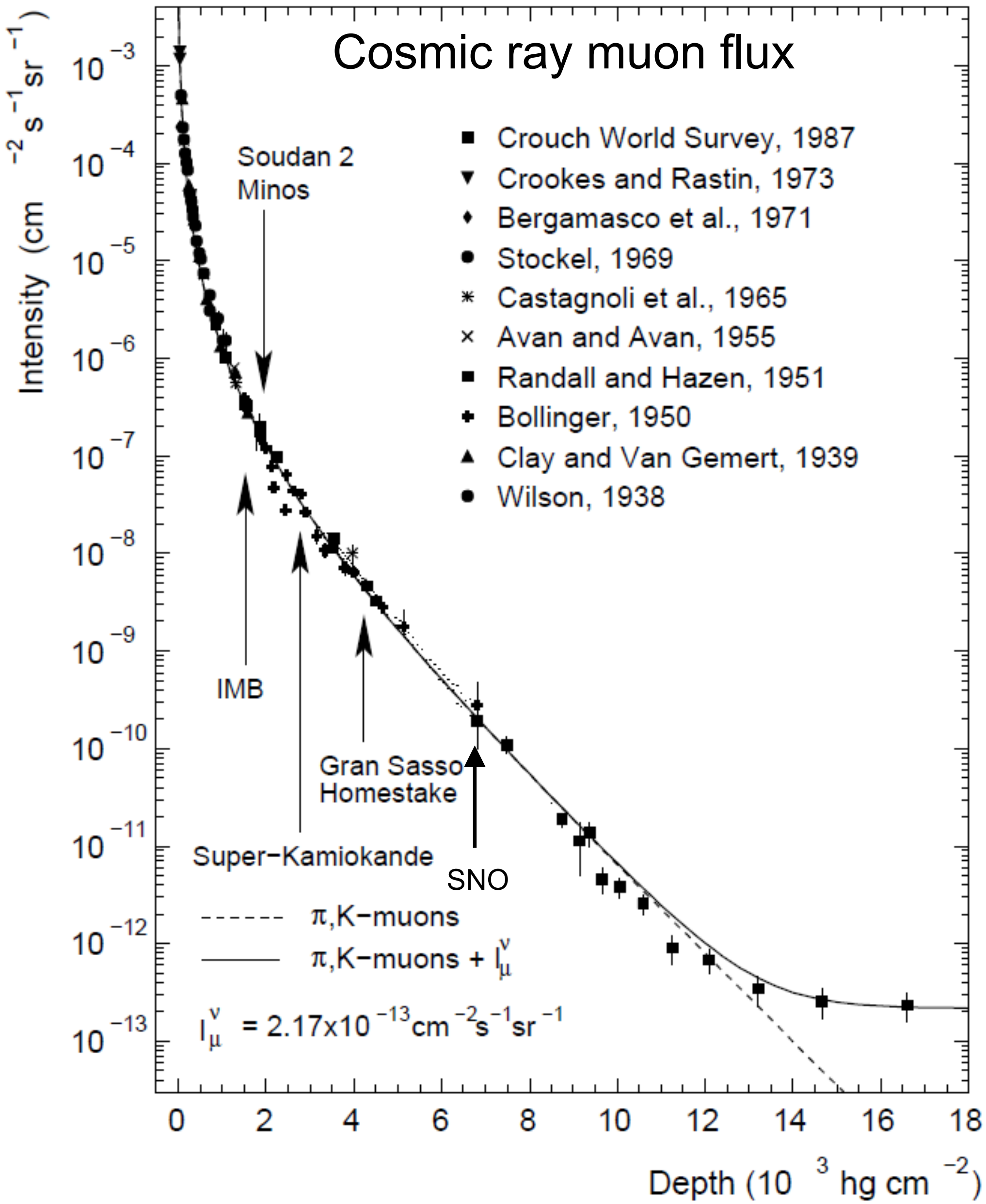








Neutrino experiment

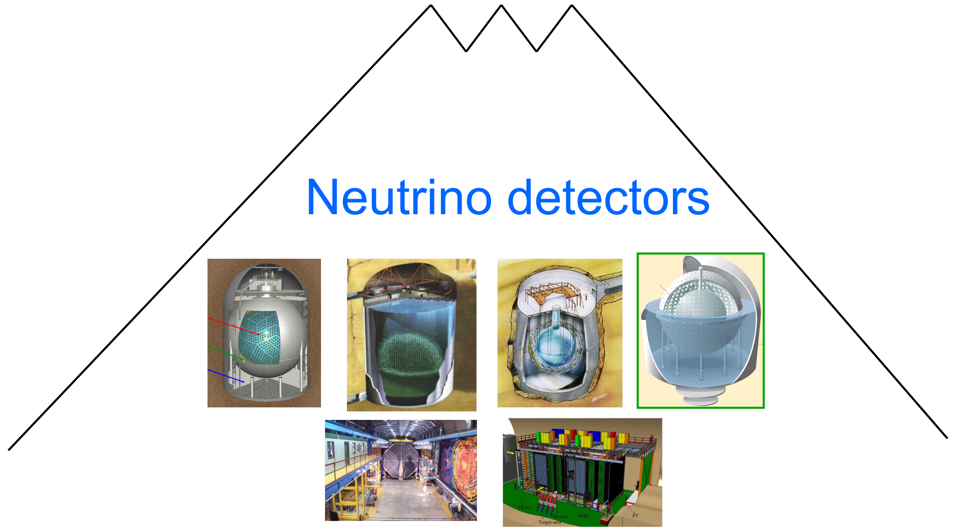


Large size of detector is required, because of very small cross section

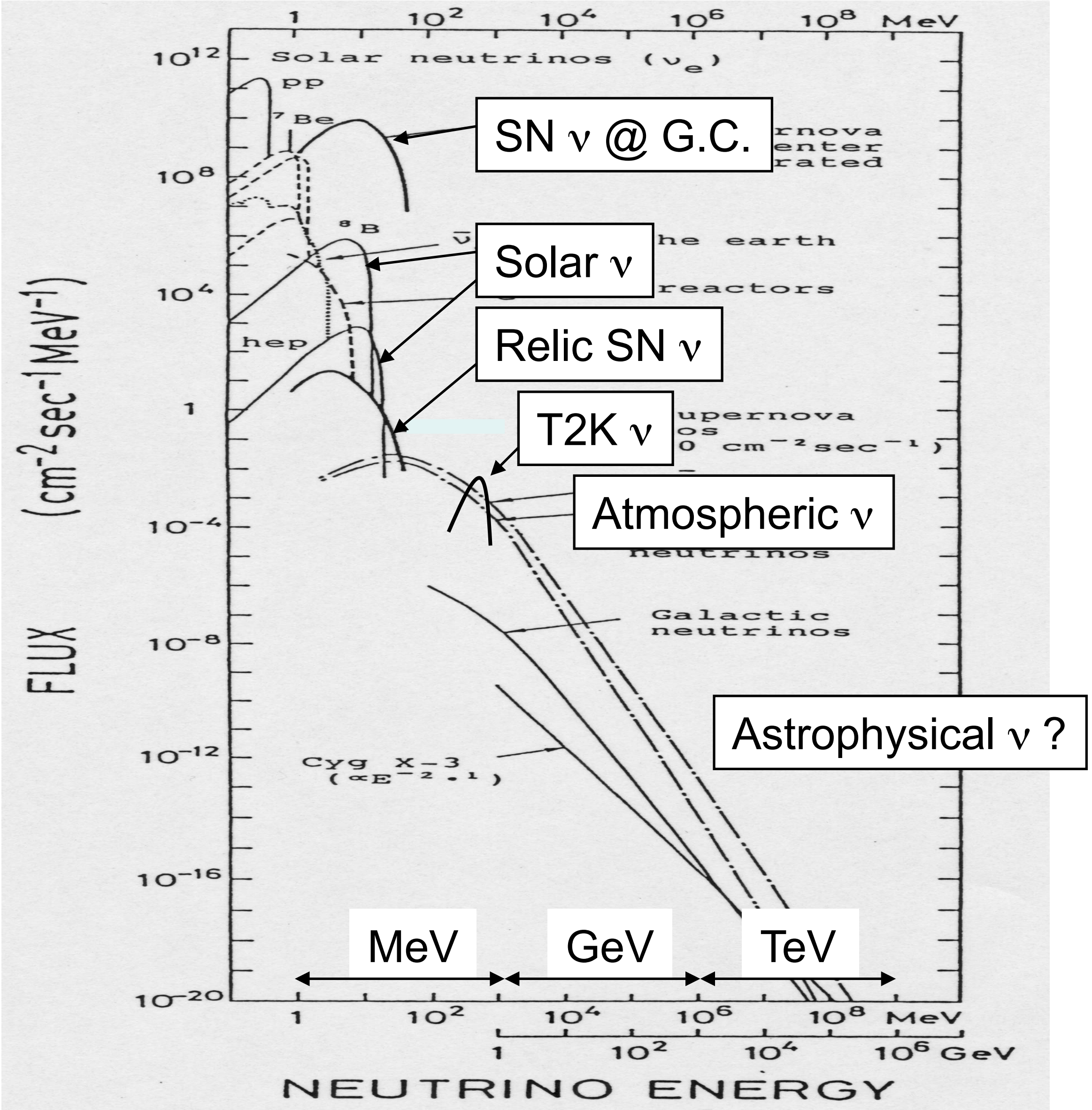
$$\sigma = \frac{G_F^2 s}{\pi}$$

~(E_ν[GeV])x10^{-41}cm^2

quite small cross section,
e.g. a neutrino with 10MeV interacts after transverse 3x10^{21} cm in the water.
(ref. 1 light year ~ 9.5x10^{17} cm)

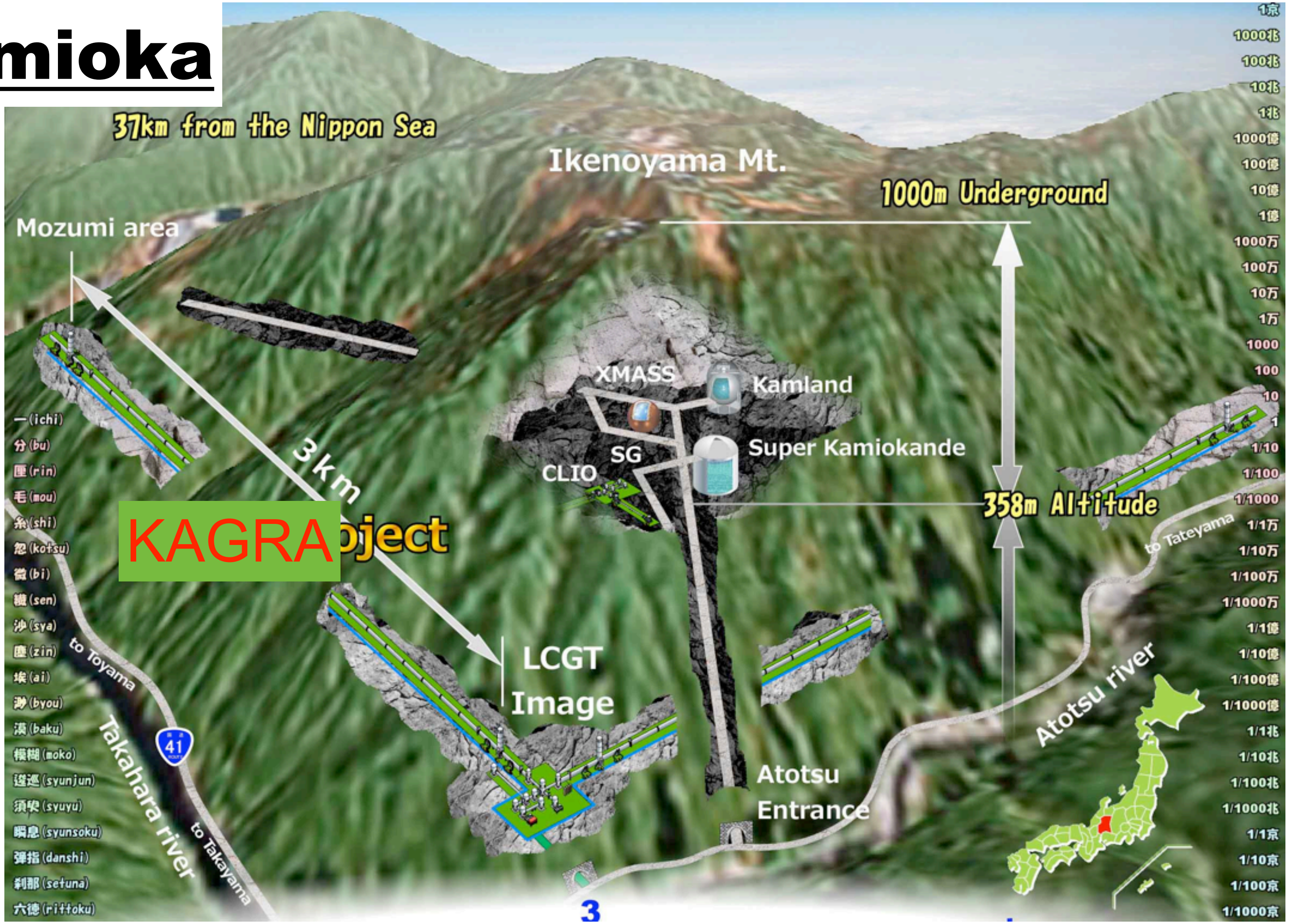


Low background



Current SN ν detectors

Kamioka



Current SN ν detectors

Kamioka

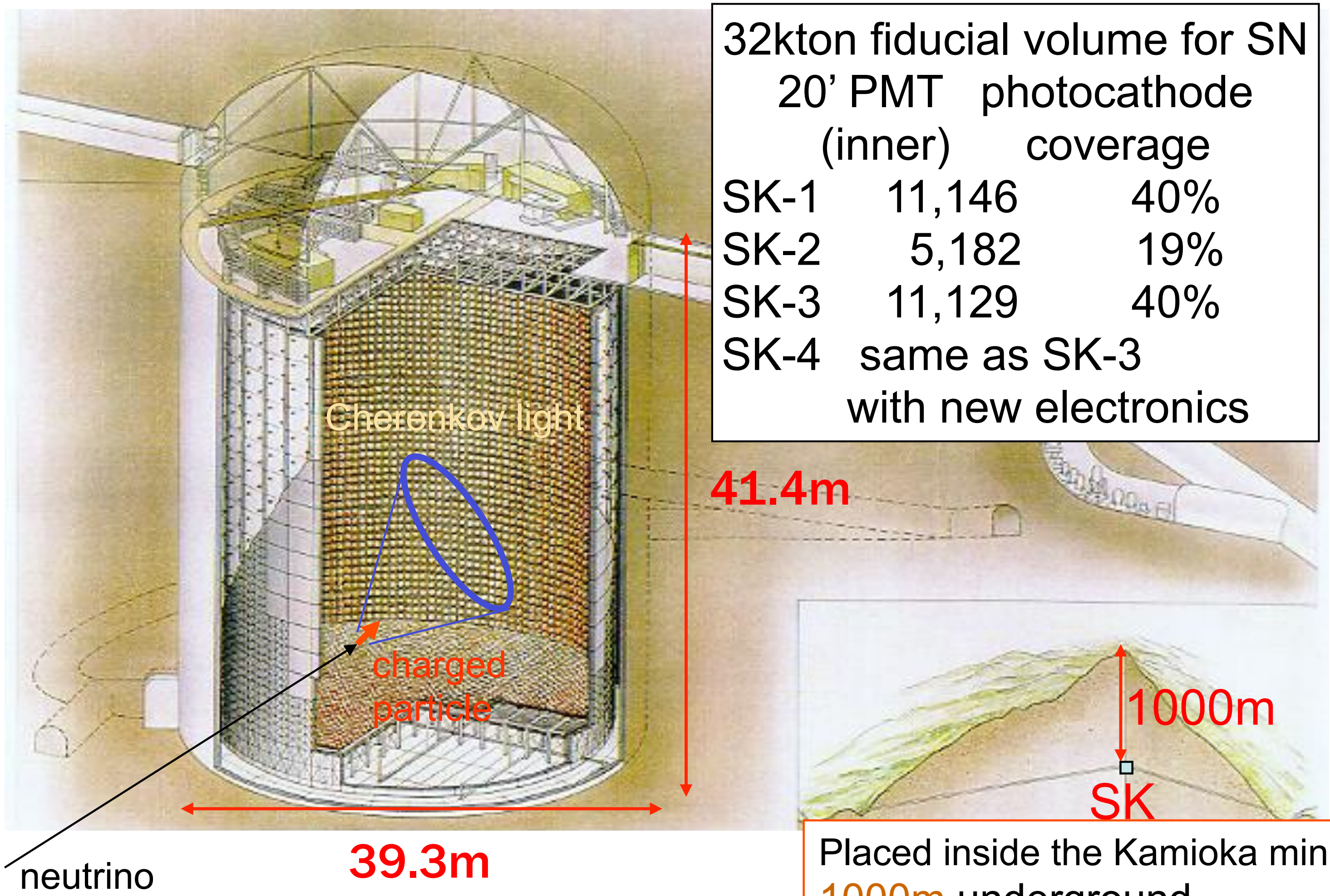
Current SN ν detectors

Kamioka

Current SN ν detectors

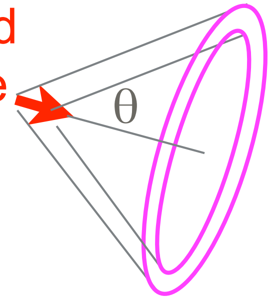
Super-Kamiokande

50kton Water Cherenkov detector

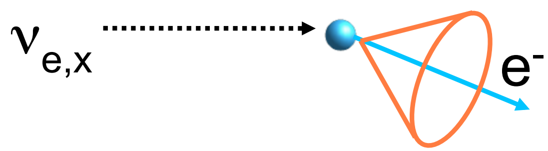


	20' PMT (inner)	photocathode coverage
32kton fiducial volume for SN		
SK-1	11,146	40%
SK-2	5,182	19%
SK-3	11,129	40%
SK-4	same as SK-3 with new electronics	

Placed inside the Kamioka mine
1000m underground



- ✓ Underground in Kamioka mine, (almost BG free)
- ✓ 3.5MeV energy threshold for recoil electron
- ✓ Dominant process is inverse beta decay
- ✓ Good directionality for νe elastic scattering



Current SN ν detectors

Super-Kamiokande

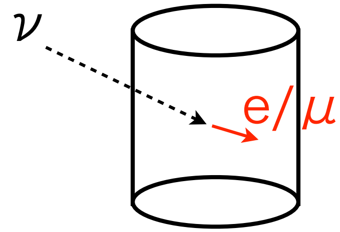
For atm./acc. neutrinos (~GeV)

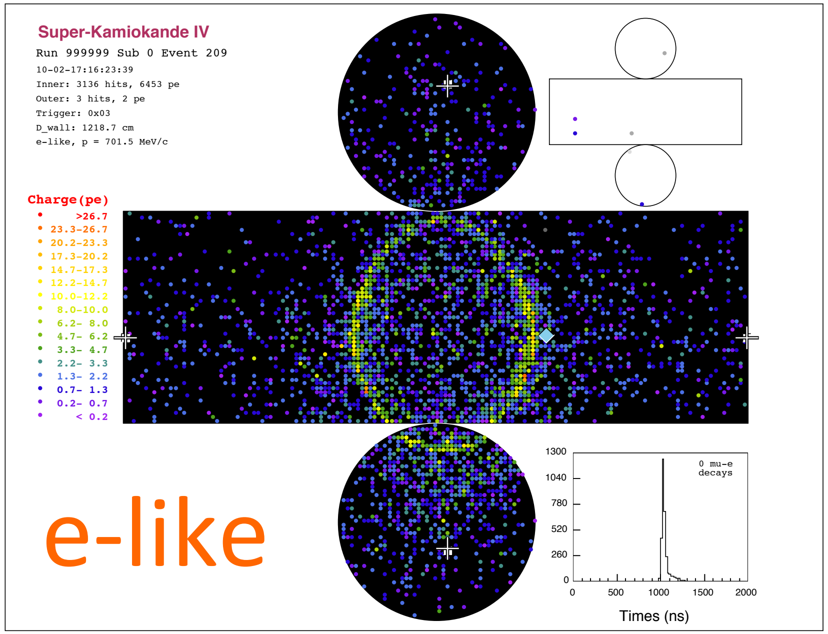
ν_e + n → e^- + p

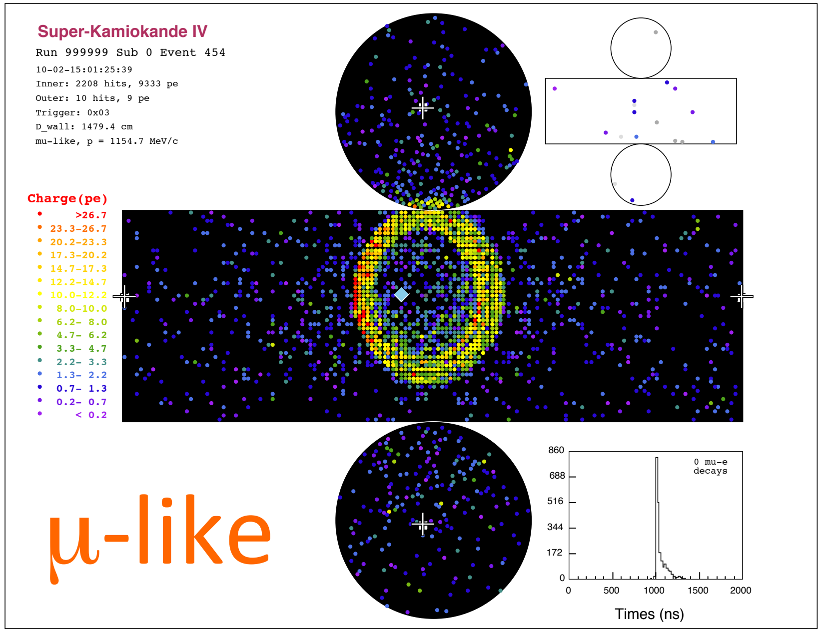
ν_μ + n → μ^- + p

発生する荷電レプトンは

- 元のニュートリノの種類を識別
- 元のニュートリノの方向を保存



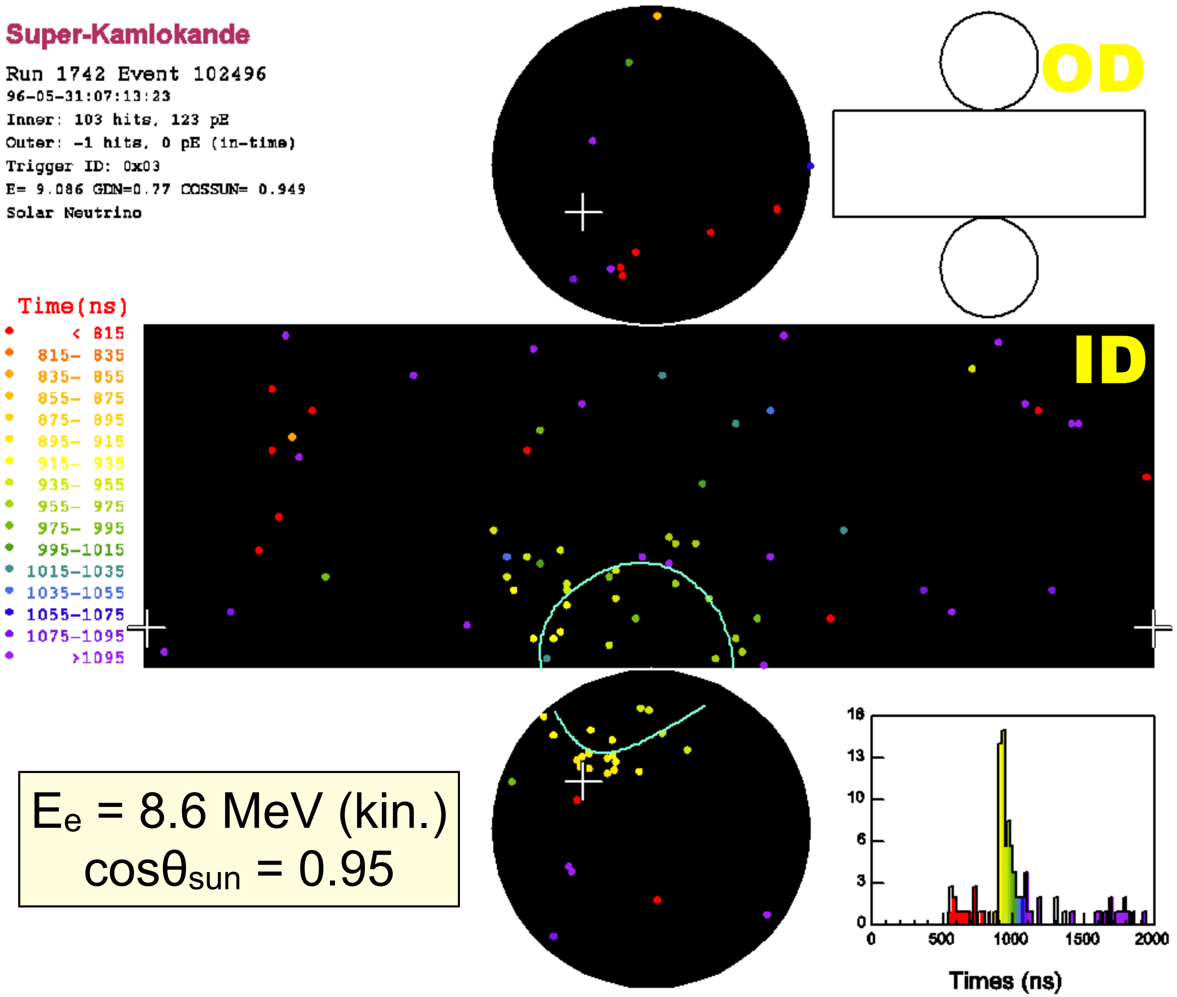




Current SN ν detectors

Super-Kamiokande

For solar / SN neutrinos (~MeV)



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

How to reconstruct?

Detector performance

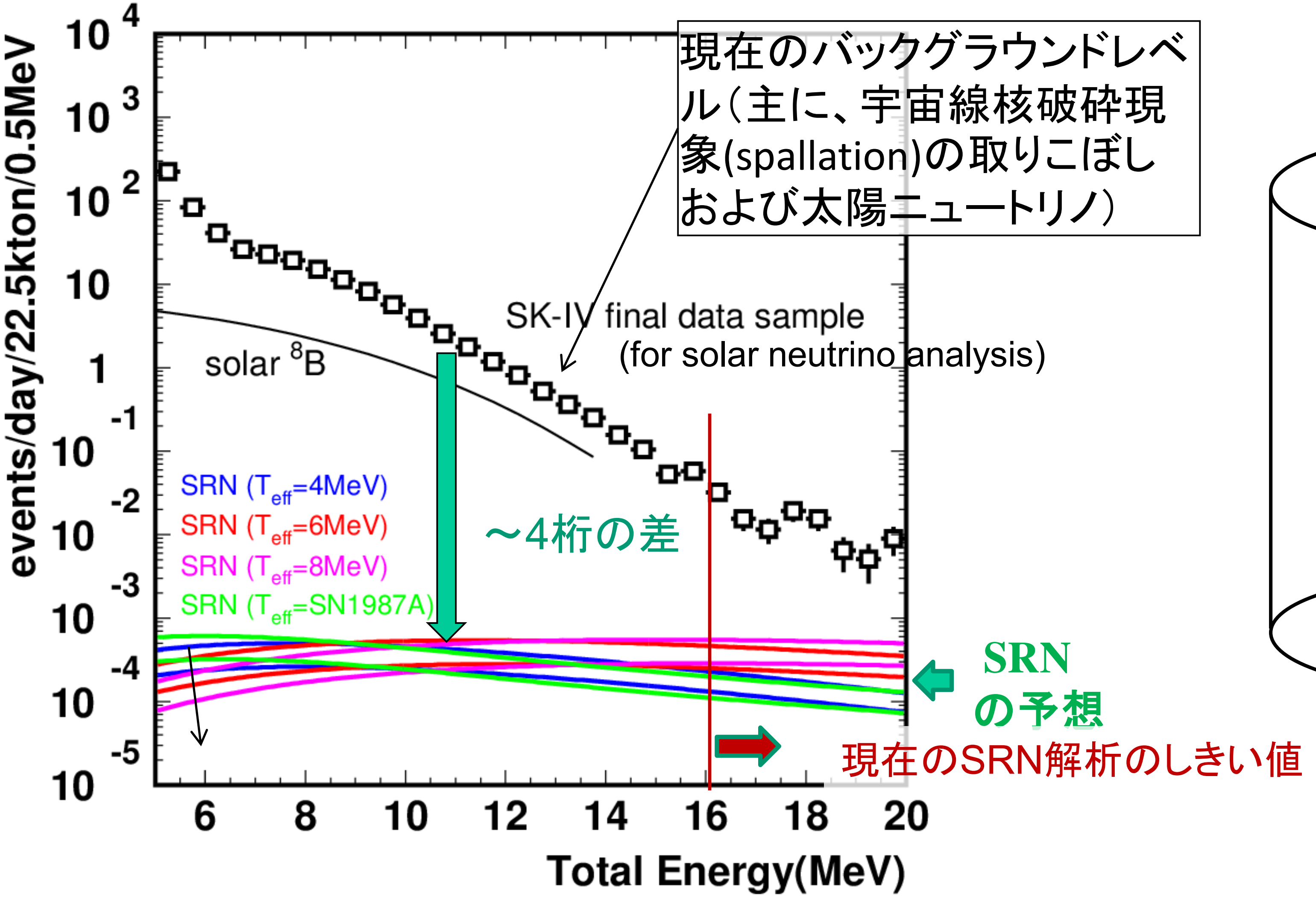
	Resolution@10MeV	Information
vertex	55cm	hit timing
direction	23deg.	hit pattern
energy	14%	# of hits.

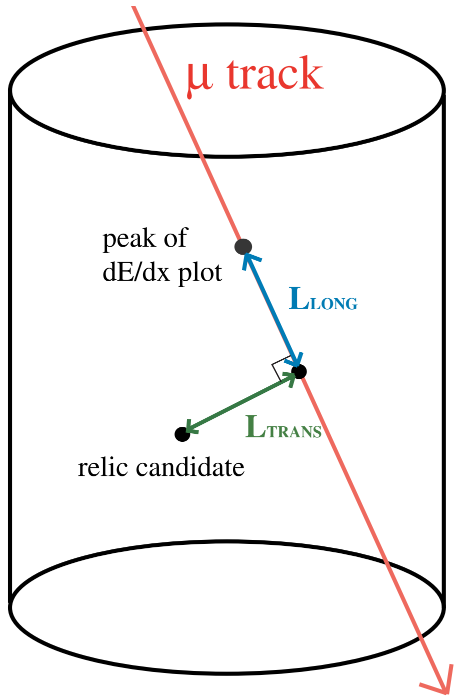
~ 6 hits/MeV
well calibrated by LINAC / DT within 0.5% precision

Current SN ν detectors

Super-Kamiokande

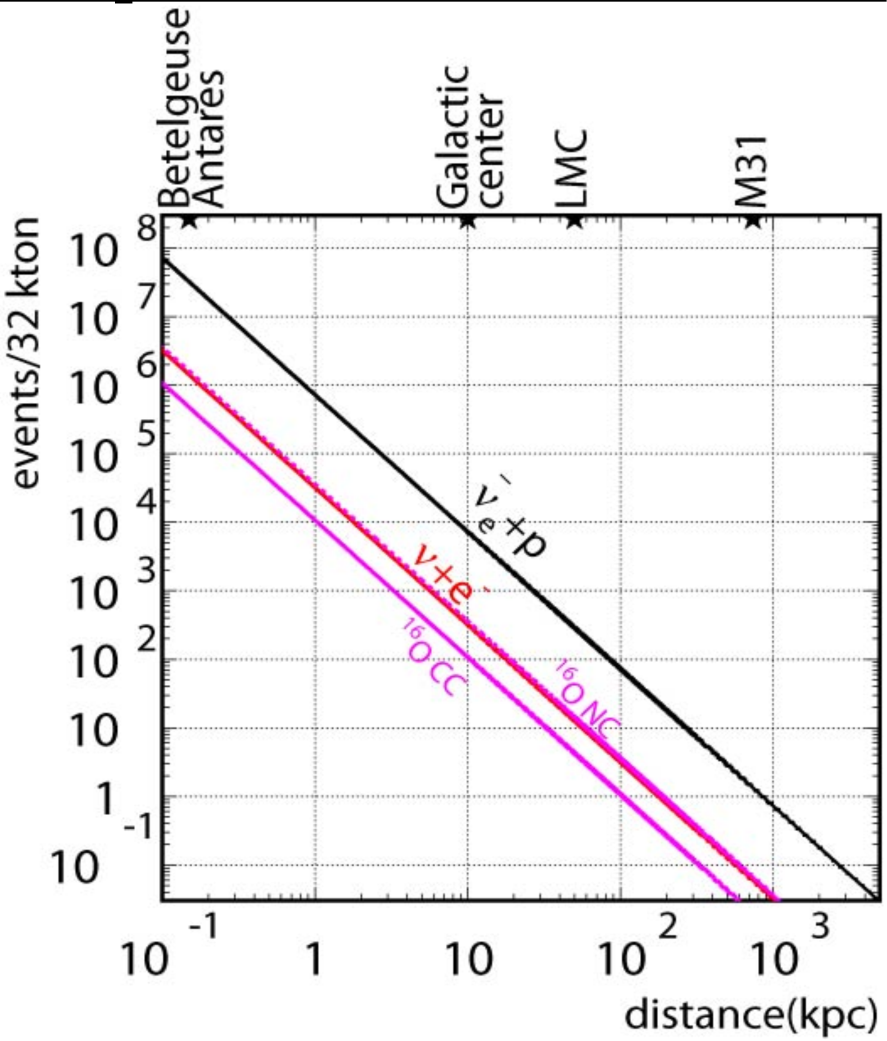
For solar / SN neutrinos (~MeV)



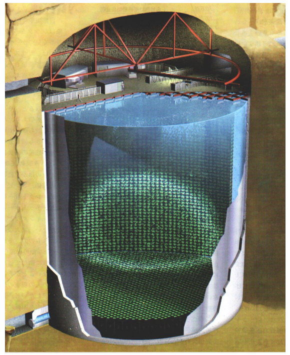


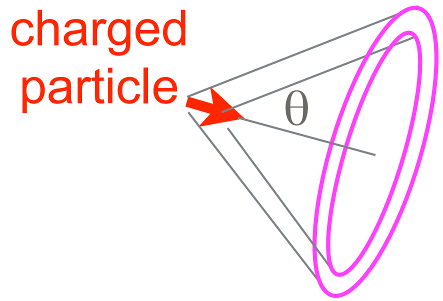
Current SN ν detectors

Super-Kamiokande



50kton Water Cherenkov detector





Expected number of event

~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

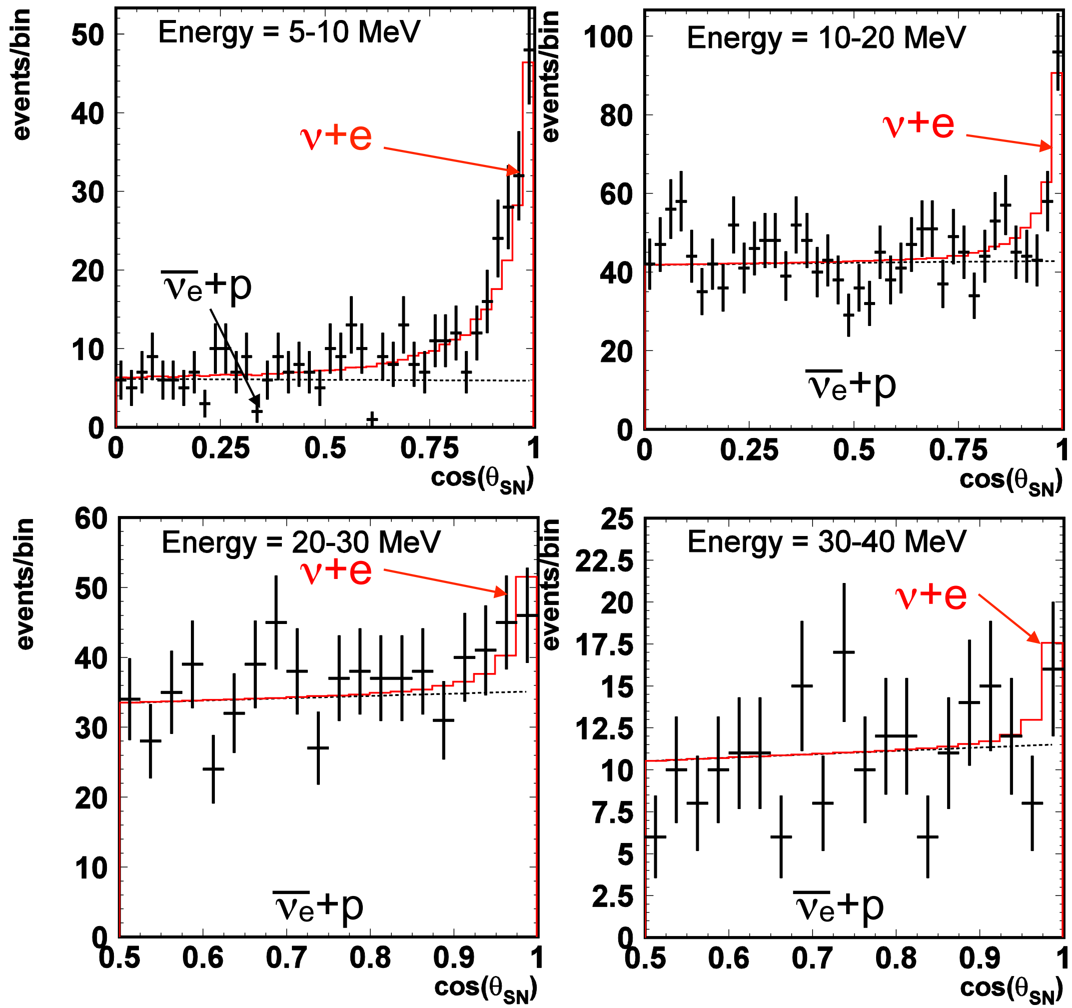
Livermore simulation
Totani, Sato, Dalhed, Wilson, ApJ. 496 (1998) 216

Current SN ν detectors

Super-Kamiokande

✓ ν-e elastic scattering has good directionality.
✓ Direction of supernova can be determined with an accuracy of 4~5 degree.
✓ Spectrum of νe events can be statistically extracted using the direction to supernova.
✓ If Gd loaded, it will be more accurate since ν_e signal can be separated. (later)

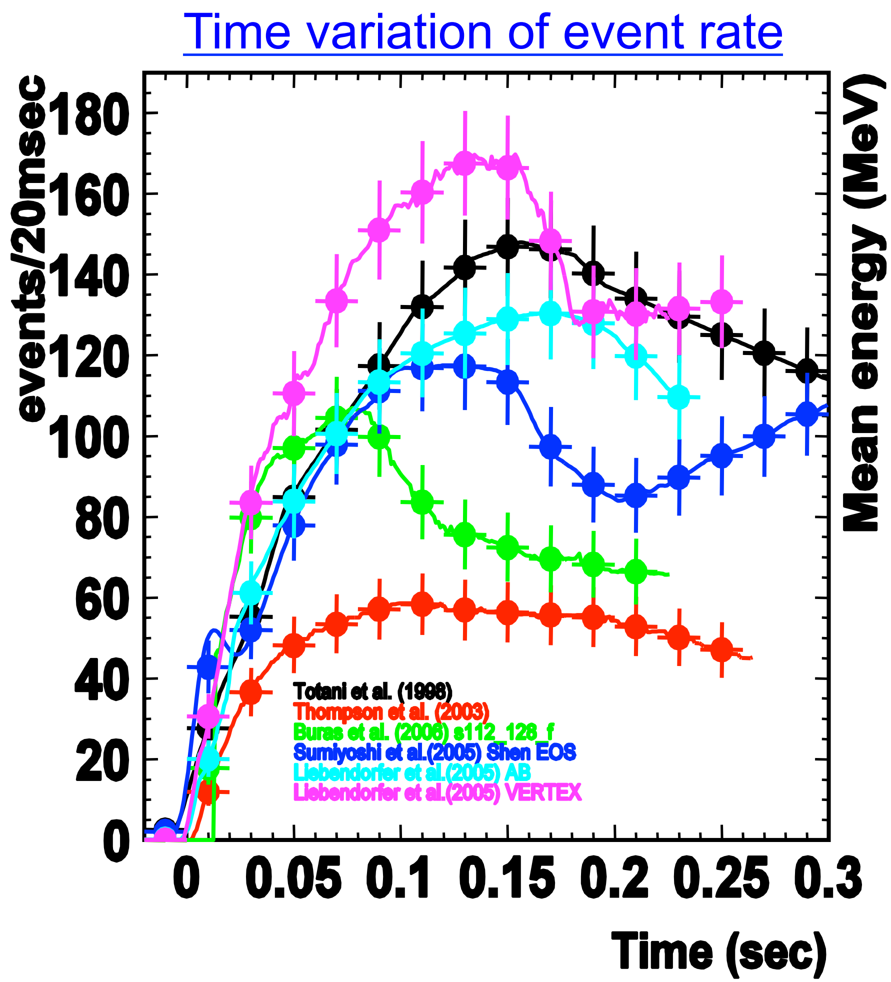
Simulation of angular distribution

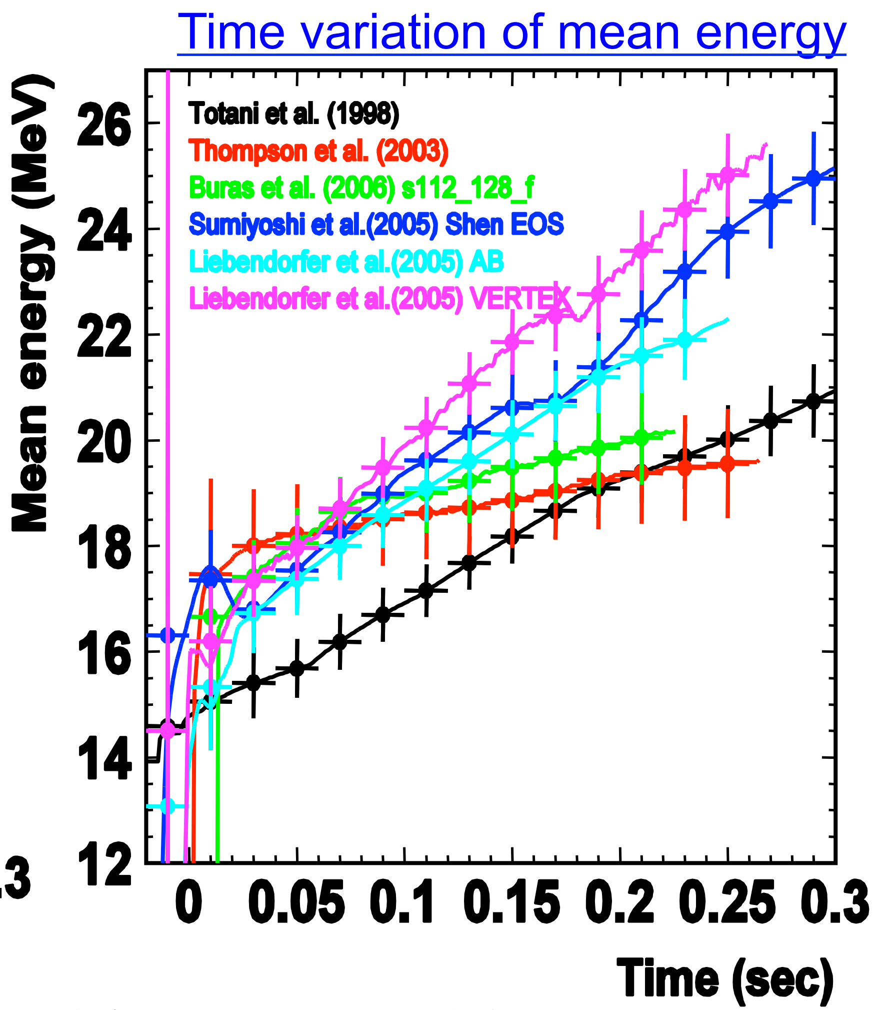


Current SN ν detectors

Super-Kamiokande

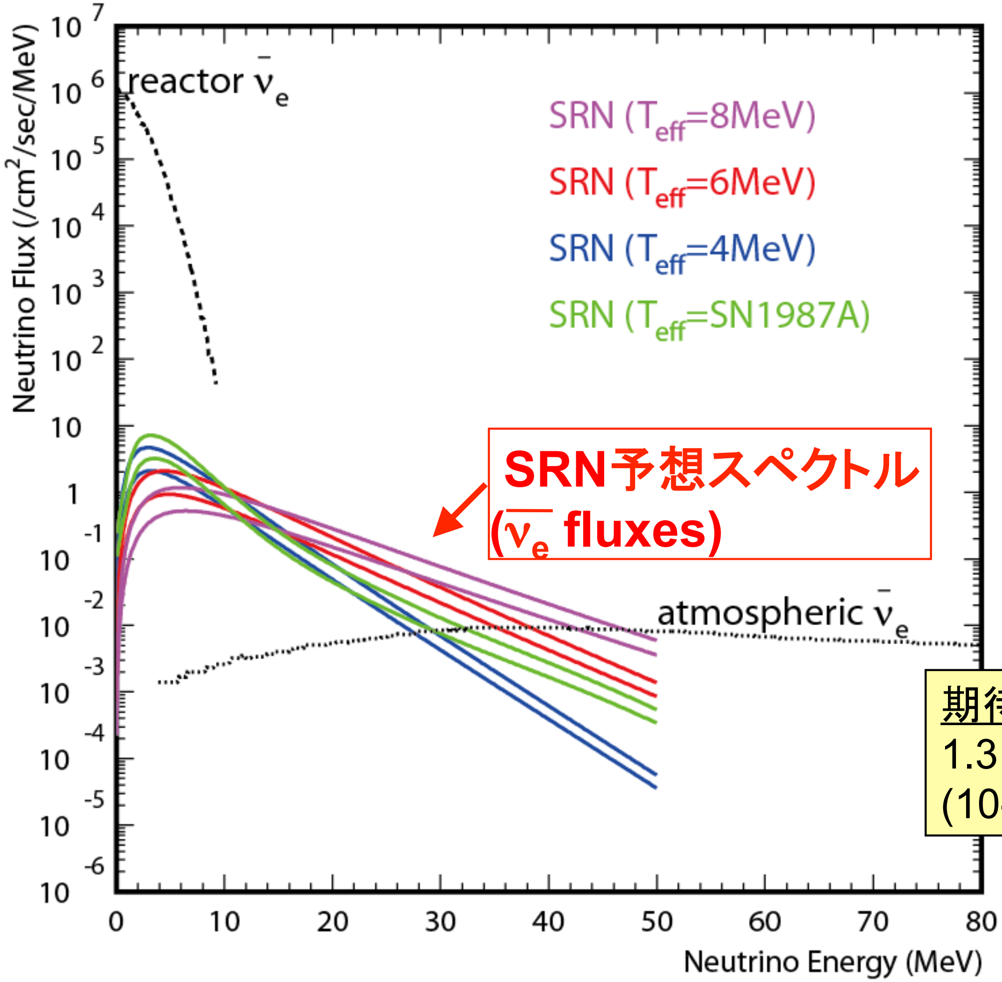
Time variation of $\overline{\nu_e}$+p at 10kpc





Current SN ν detectors

<u>Super-Kamiokande</u> For Supernova Relic Neutrinos



SRN flux の計算は、Horiuchi et al. PRD, 79, 083013 (2009)

<u>期待されるSRN信号の数</u>
1.3 -6.7 events/year/22.5kt
(10-30MeV)

SKの有効体積

Current SN ν detectors

<u>Super-Kamiokande</u> Backgrounds for SRN

NC Elastic

"reactor + solar"

Decay electron

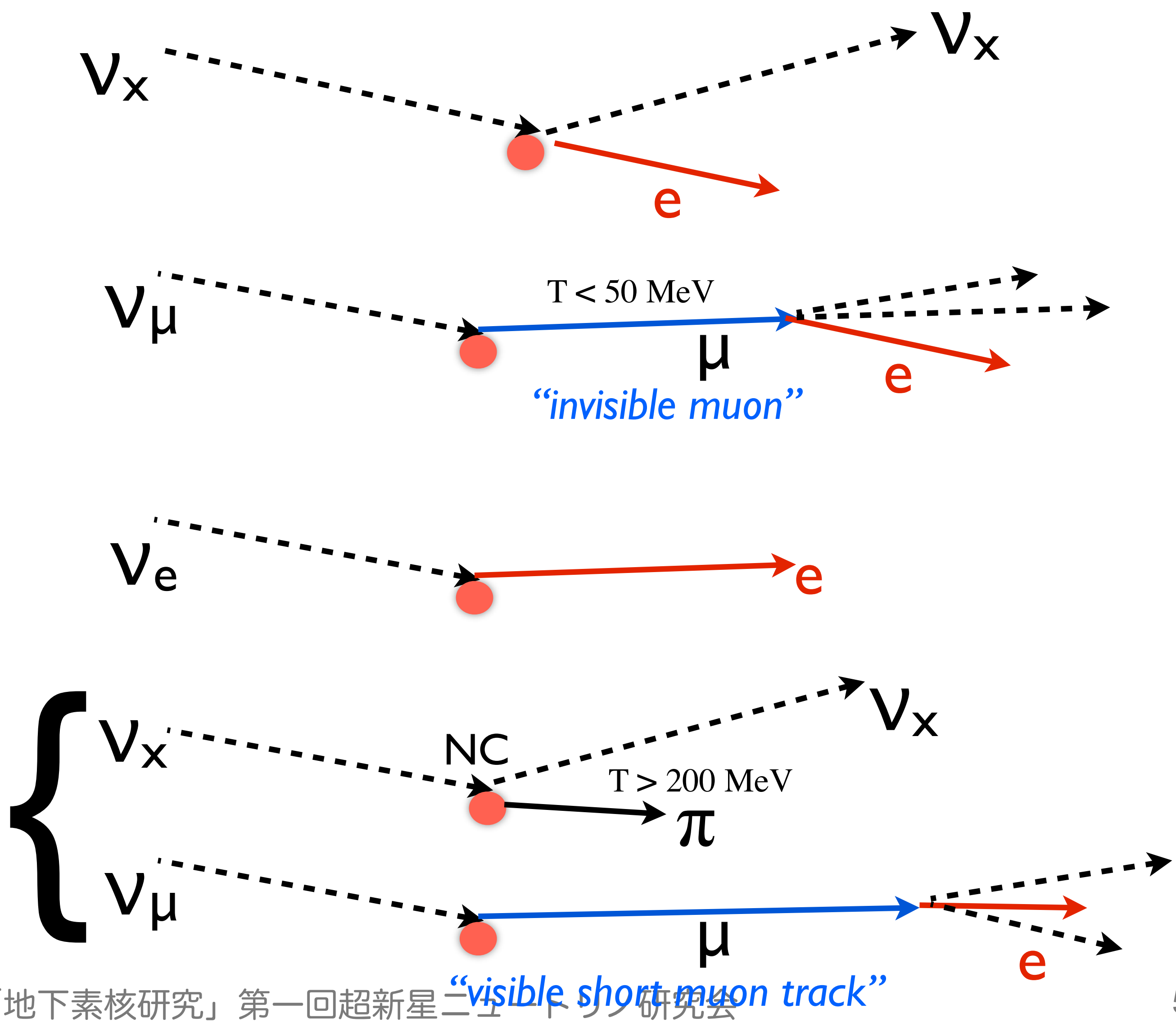
"atm. muon neutrinos"

ν_e CC

"atm. electron neutrinos"

μ/π

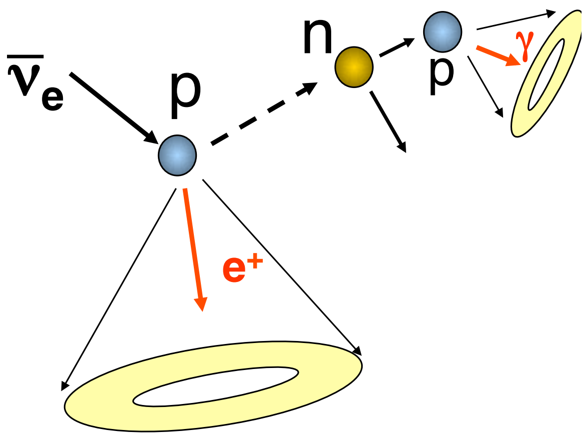
"μ/π production from atm. neutrinos"



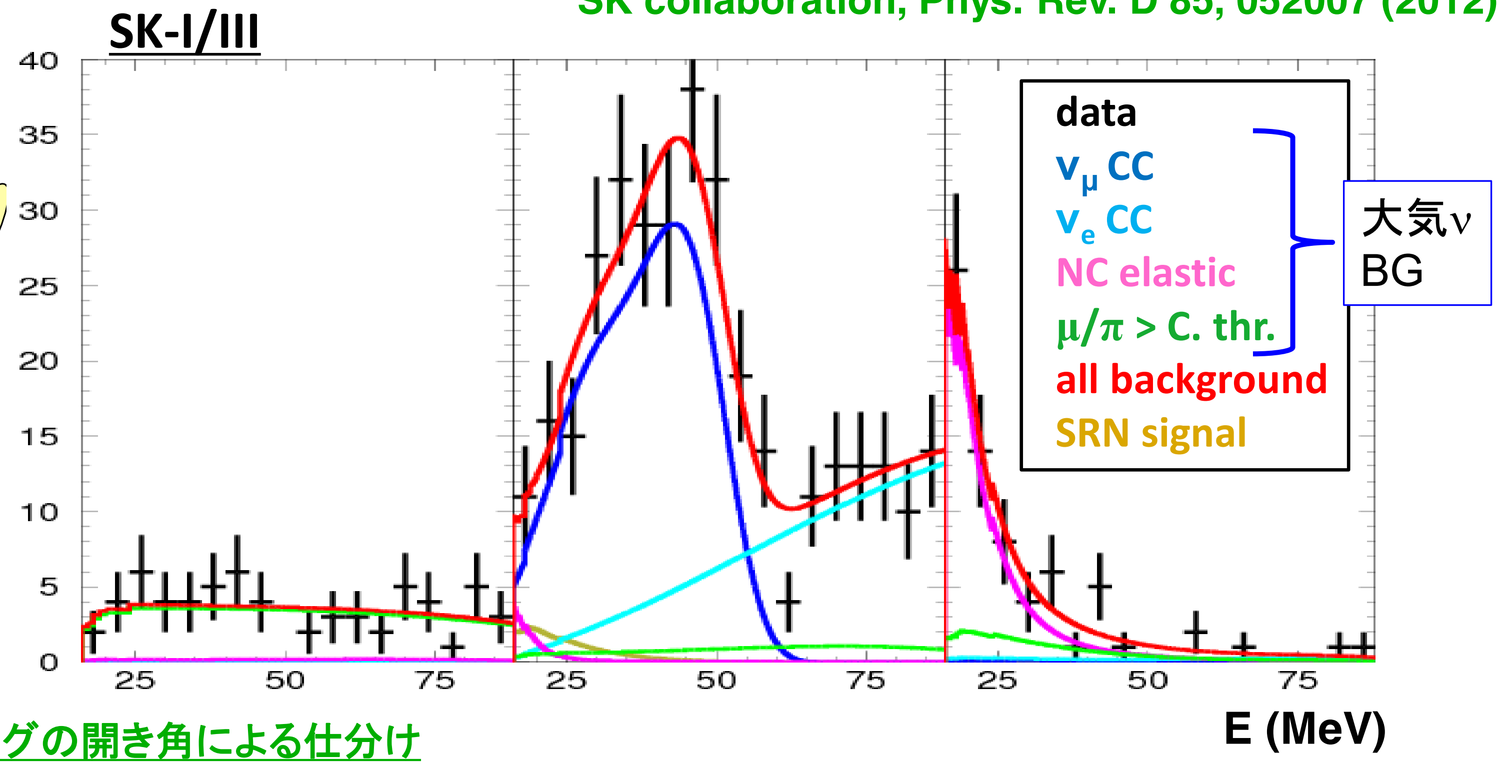
Supernova Relic Neutrinos

Current Super-K w/o neutron tagging

SK collaboration, Phys. Rev. D 85, 052007 (2012)

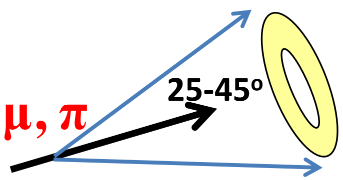


Only this signal

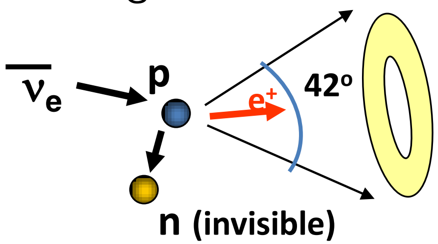


リングの開き角による仕分け

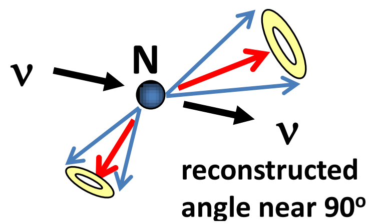
Low angle events



Signal Events



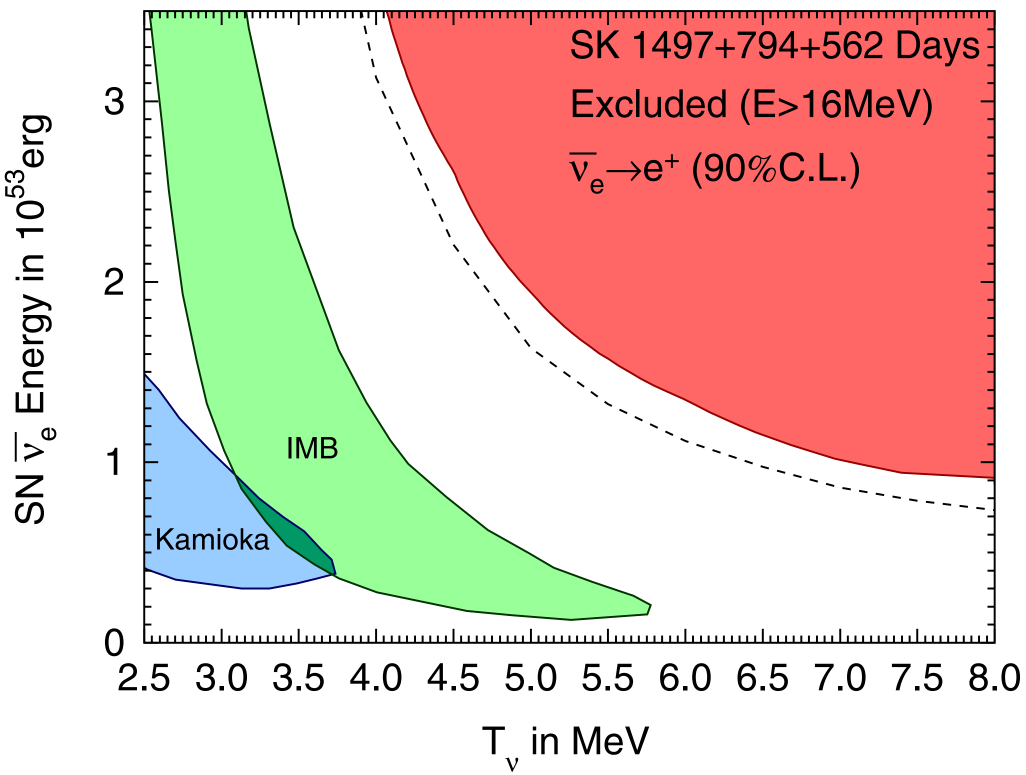
Isotropic Events

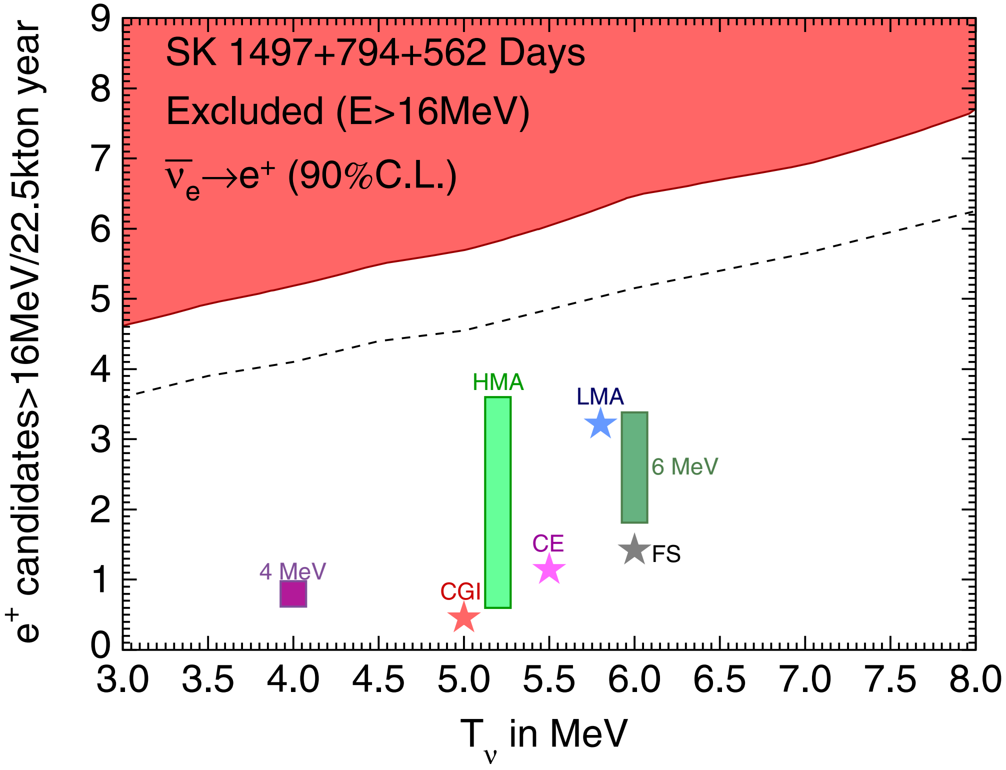


Supernova Relic Neutrinos

Current Super-K w/o neutron tagging

SK collaboration, Phys. Rev. D 85, 052007 (2012)

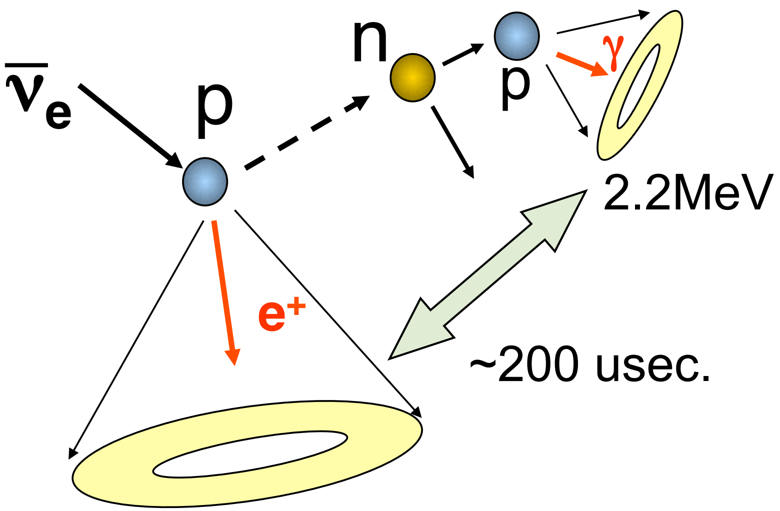




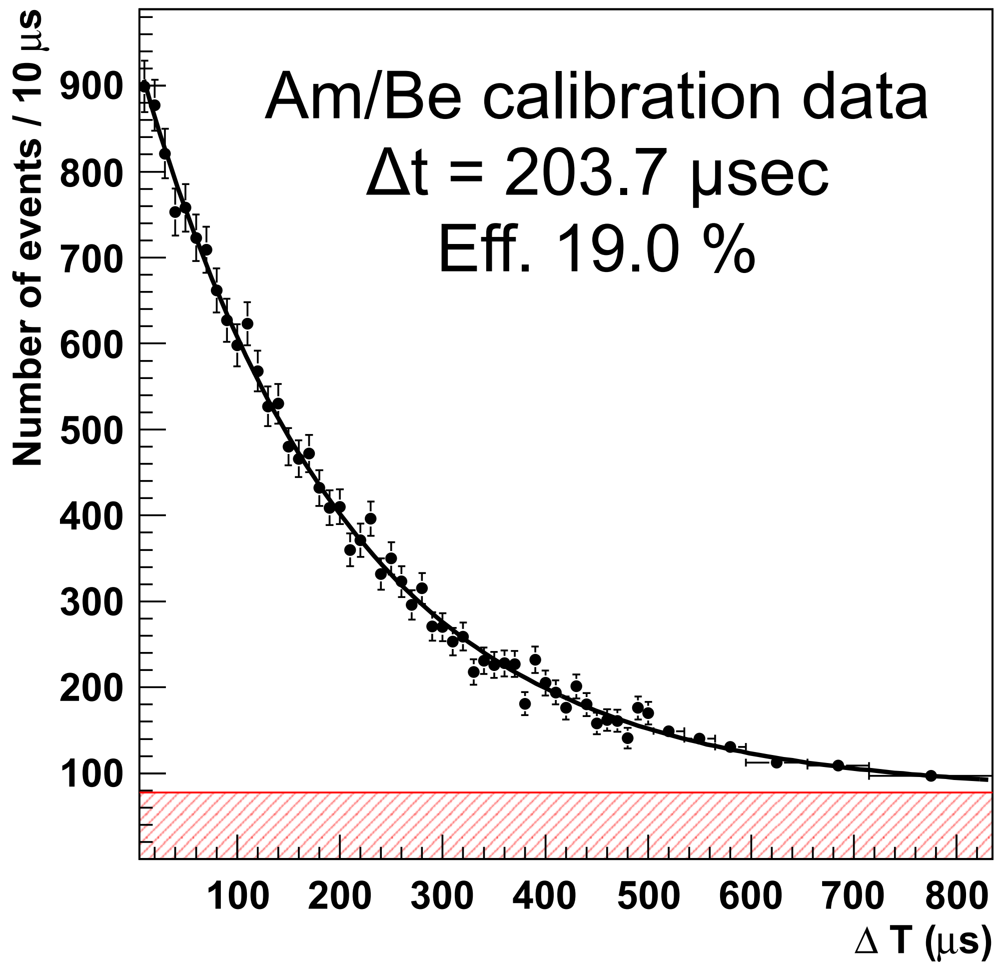
Supernova Relic Neutrinos

Current Super-K with neutron tagging (2.2MeV gamma)

✓ Good for $\overline{\nu}_e$+p signal
✓ 2.2MeV is below our energy threshold (~3.5MeV)
✓ It is possible to detect from SK-4 with new electronics.



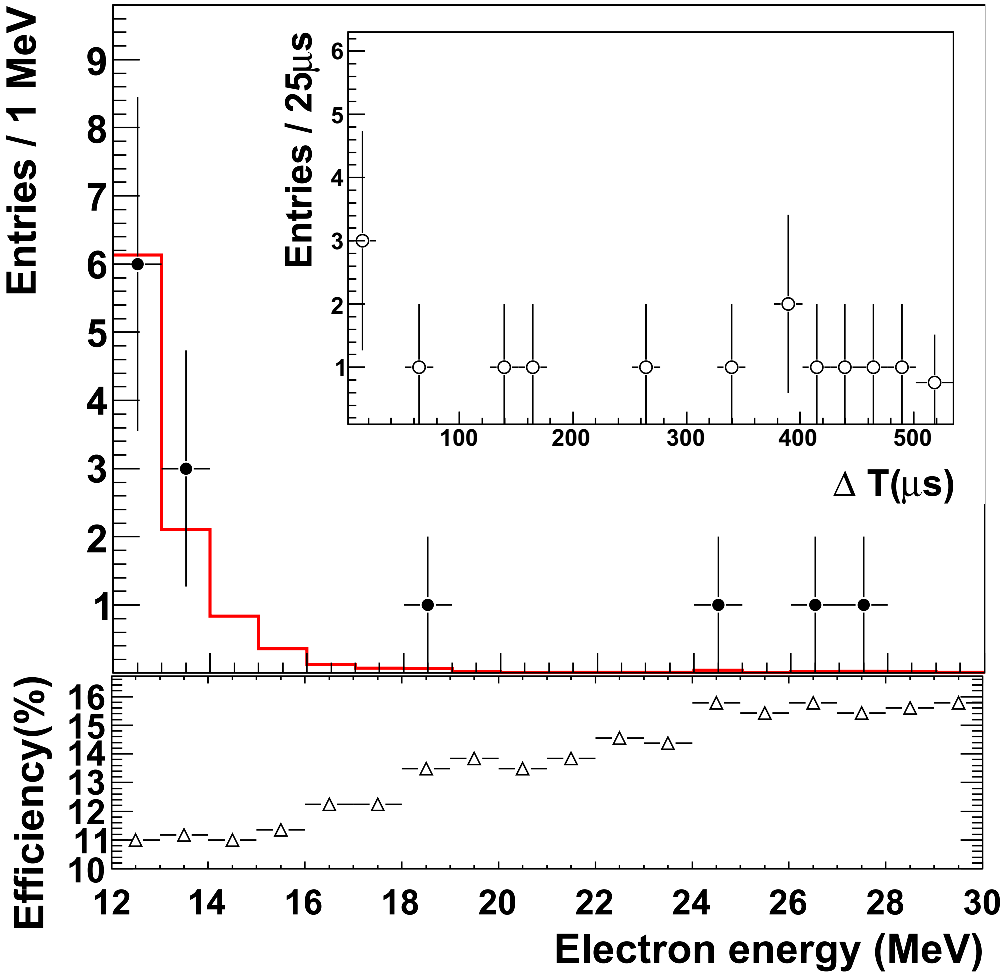
SK collaboration, Astropart. Phys. 60, 41-46 (2015)

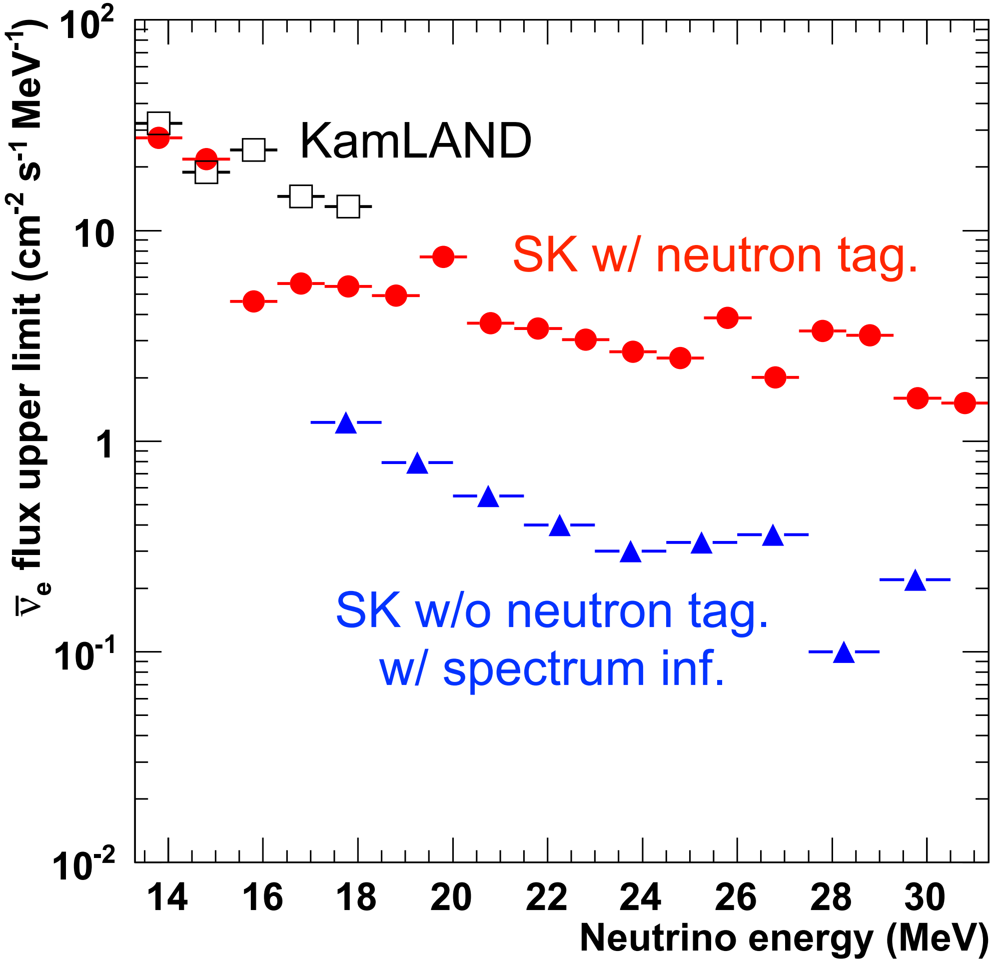


Supernova Relic Neutrinos

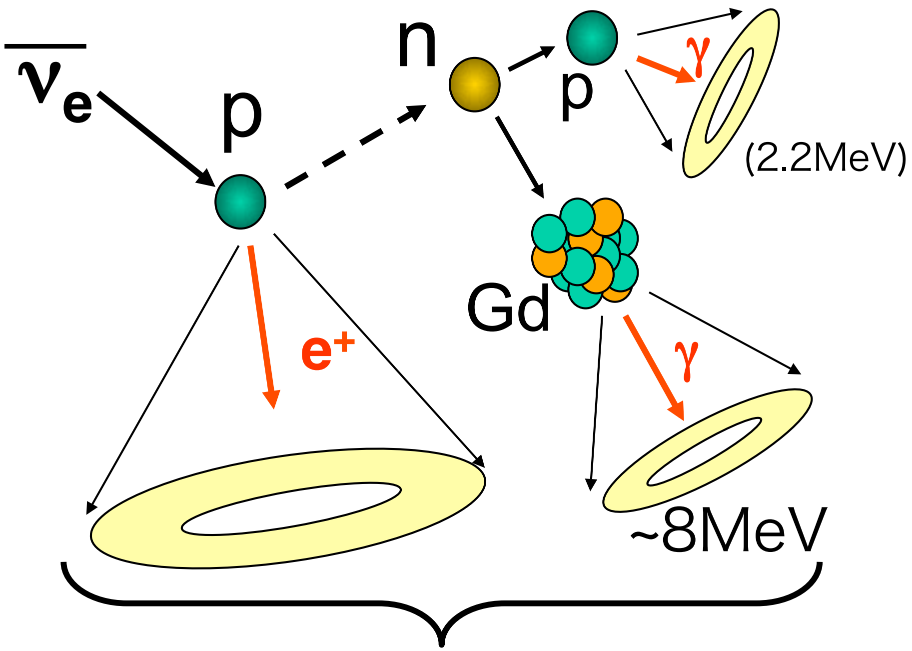
Current Super-K with neutron tagging (2.2MeV gamma)

SK collaboration, Astropart. Phys. 60, 41-46 (2015)





Supernova Relic Neutrinos

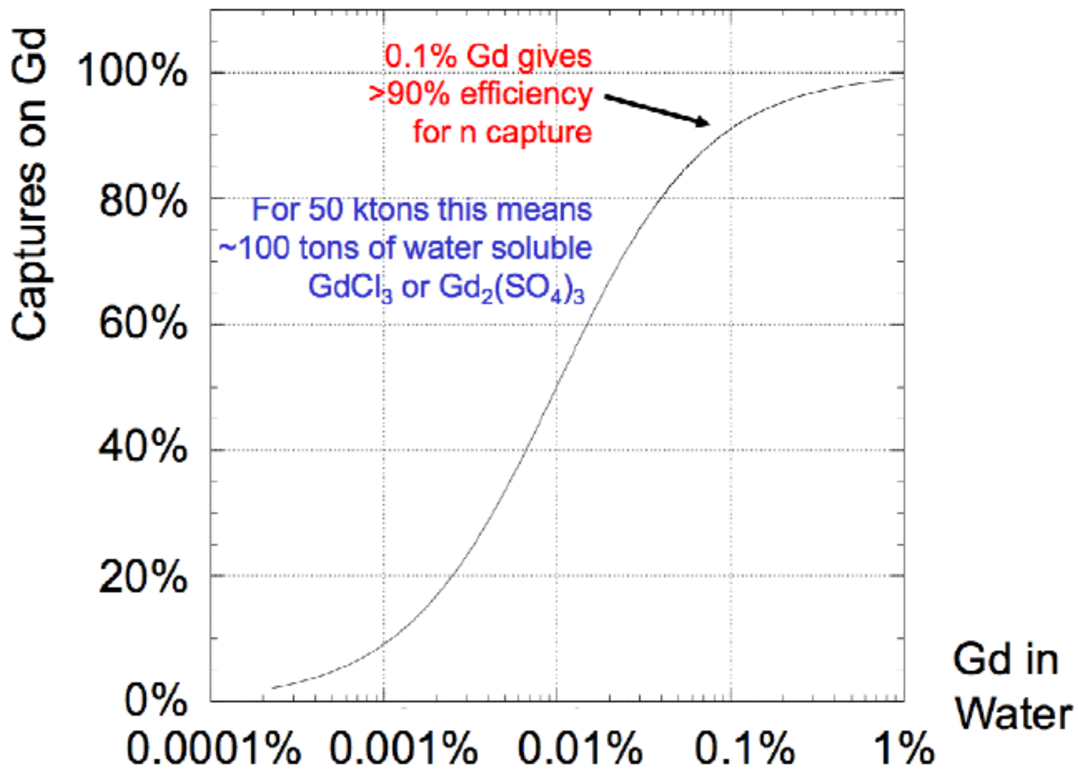


•Delayed coincidence

- Suppress B.G. drastically for $\overline{\nu}_e$ signal
- ΔT~20μsec
- Vertices within ~50cm

GADZOOKS!

Dissolve Gadolinium into Super-K
J.Beacom and M.Vagins, Phys.Rev.Lett.93(2004)171101



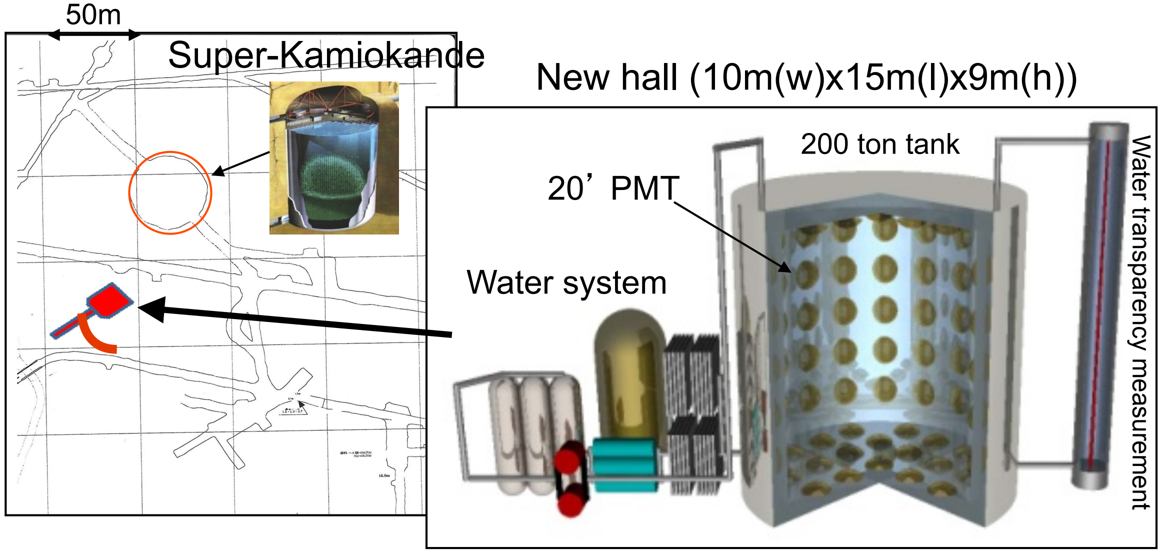
Supernova Relic Neutrinos

EGADS

(Evaluating Gadolinium's Action on Detector Systems)

Purpose
✓Water transparency
✓How to purify
✓How to introduce and remove
✓Effect on detector
✓Effect from environment neutrons
✓etc.

R&D for Gd test experiment



Now working well

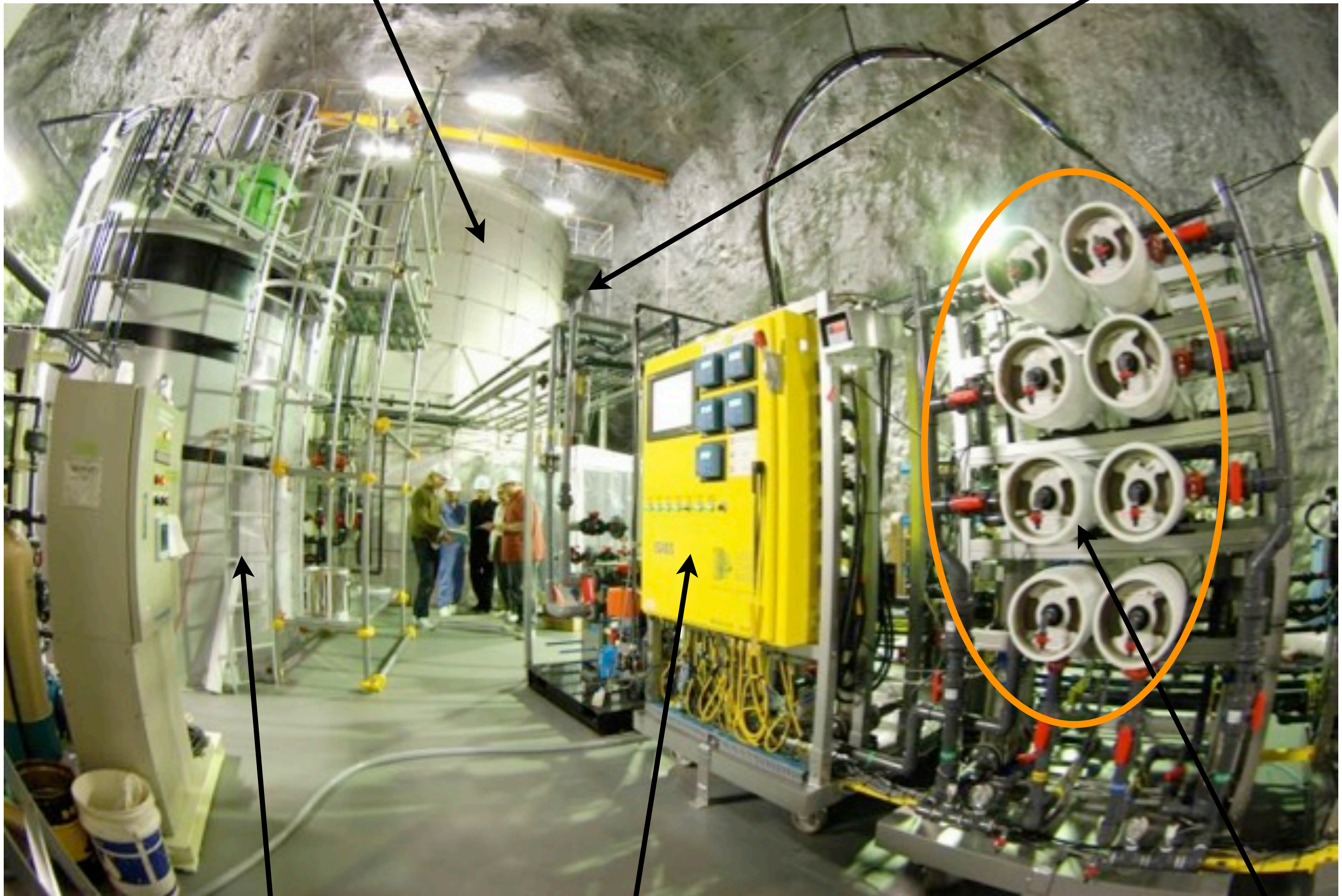
→ M.Ikeda's presentation

EGADS

UDEAL

water transparency measurement

200 ton tank

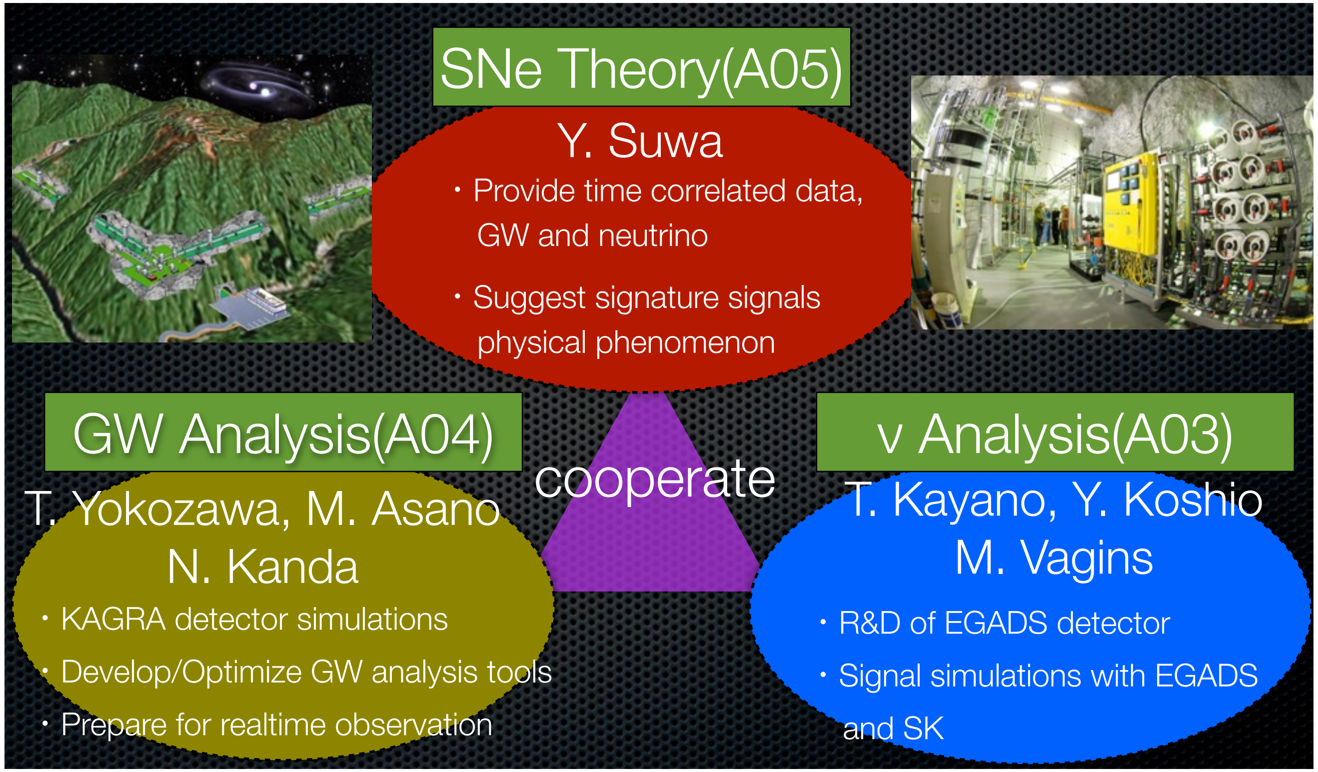


15 ton buffer tank

Control panel of circulation system

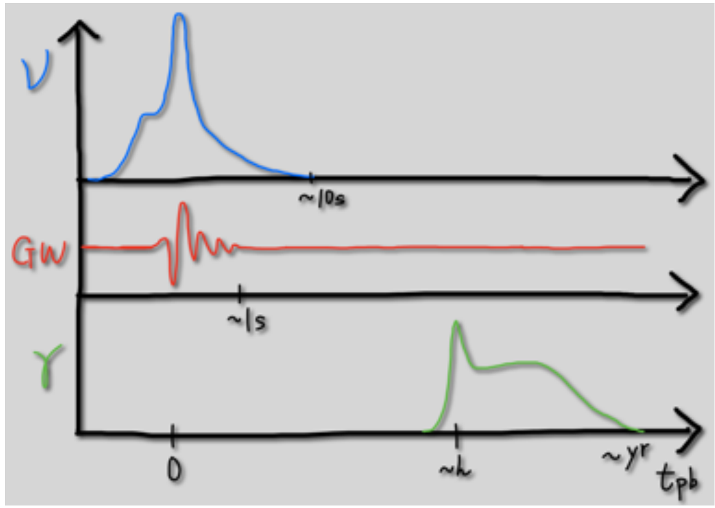
Filter

SKE (Supernova simulations with KAGRA and EGADS)



Betelgeuse SN burst
~80,000 events in EGADS

Y.Suwa's art



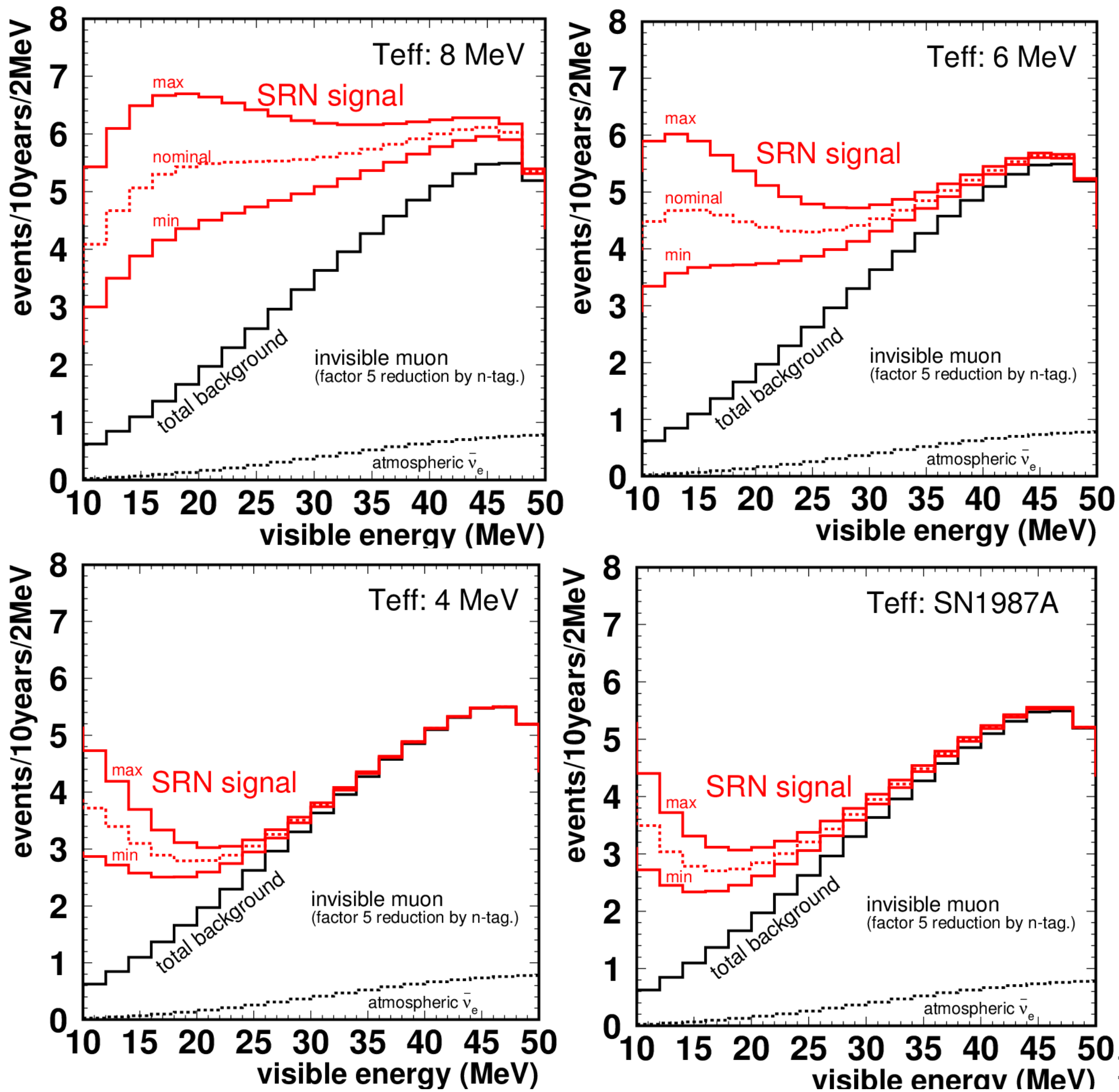
✓ Detectable or not
✓ Discussion about time variation
✓ GW search with neutrino trigger

→ T.Yokozawa's presentation

arXiv 1410:2050

GADZOOKS!

Expected signal of Supernova Relic Neutrinos



Assumption:
- 90% neutron capture efficiency
- 74% Gd γ detection efficiency
- Invisible muon B.G. is 35% of ones in the SK-IV

10~45 SRN events in 10 years data taking (E_{vis}=10-30MeV)

GADZOOKS!

Super-Kamiokande

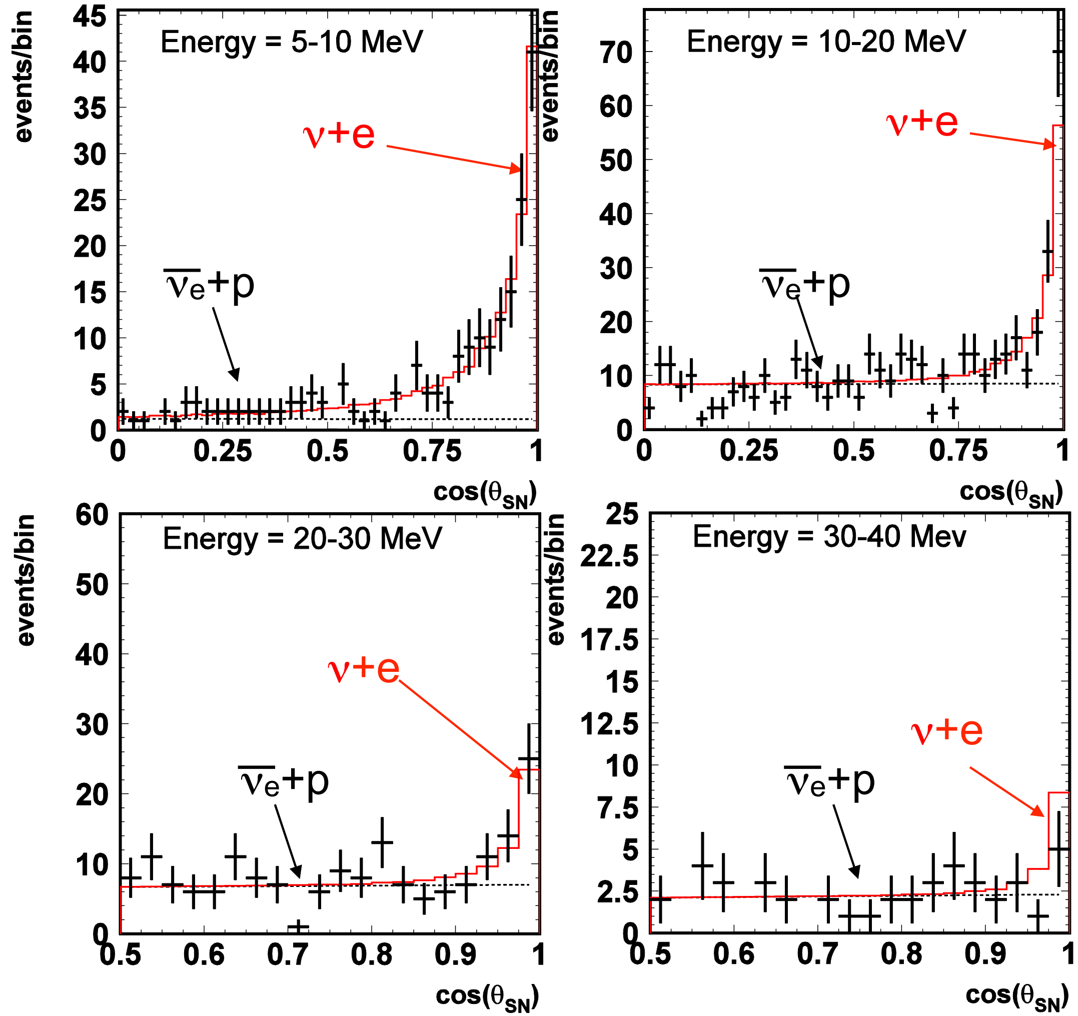
✓ ν-e elastic scattering has good directionality.

✓ Direction of supernova can be determined with an accuracy of 4~5 degree.

✓ Spectrum of νe events can be statistically extracted using the direction to supernova.

✓ If Gd loaded, it will be more accurate since ν_e signal can be separated.

Simulation of angular distribution



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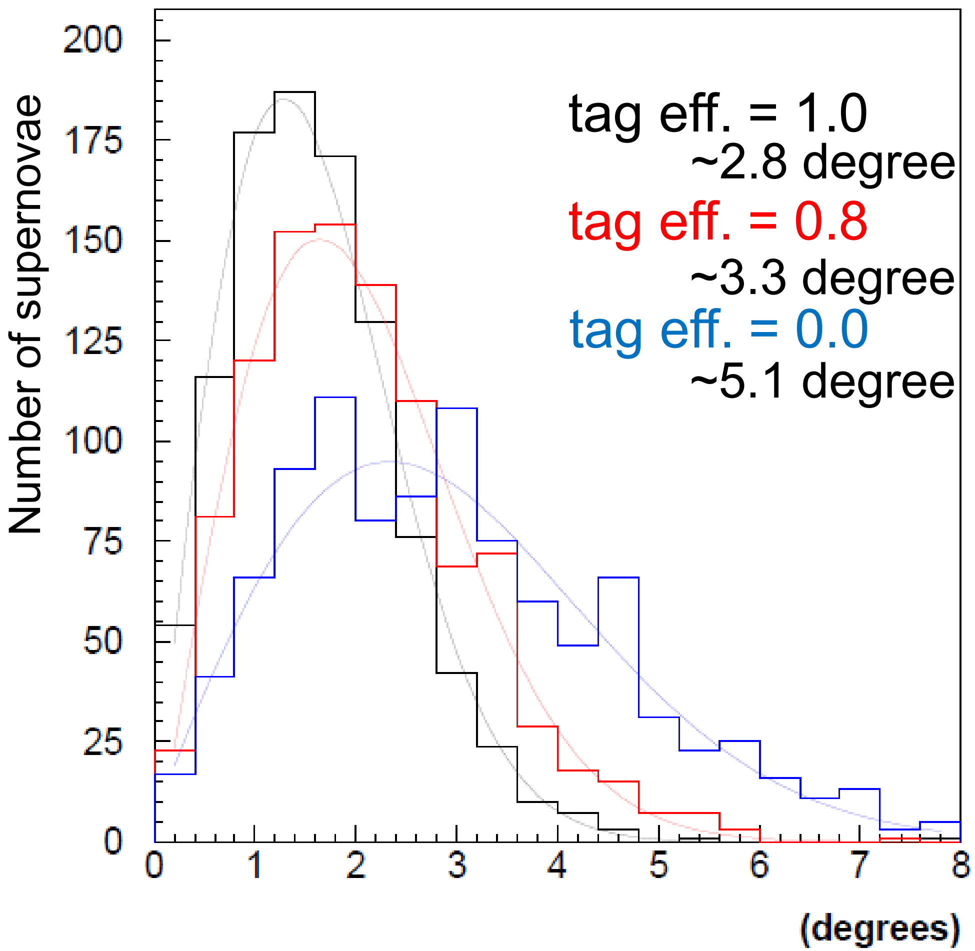
Determination of the SN direction

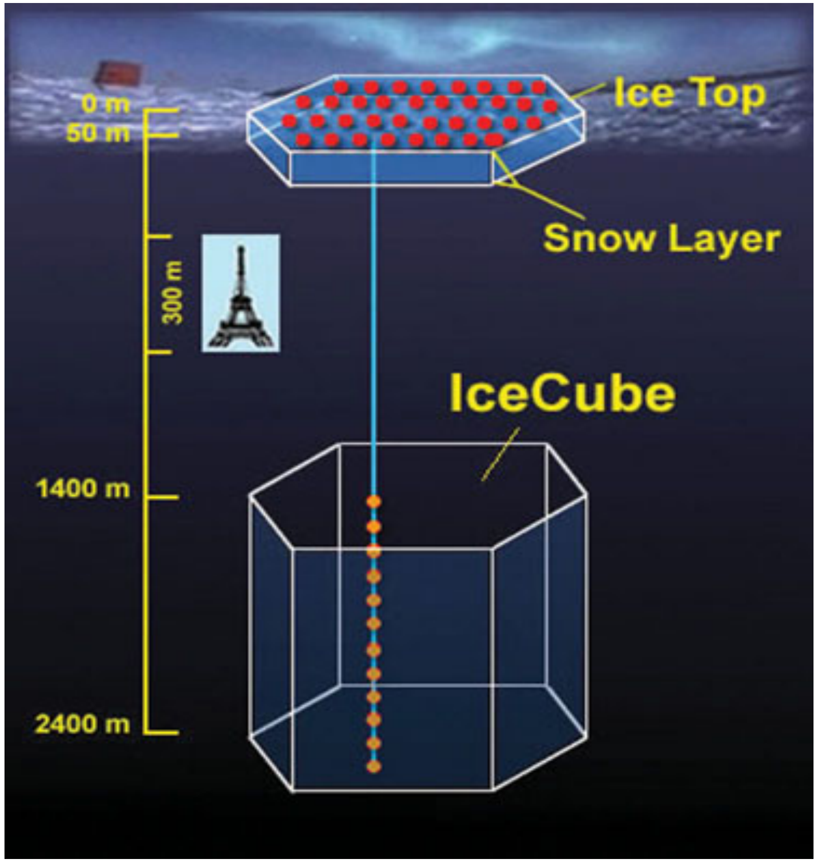


Current SN ν detectors

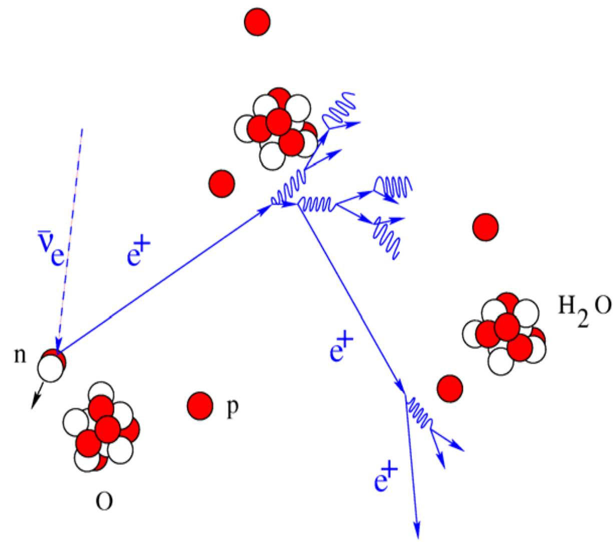
IceCUBE

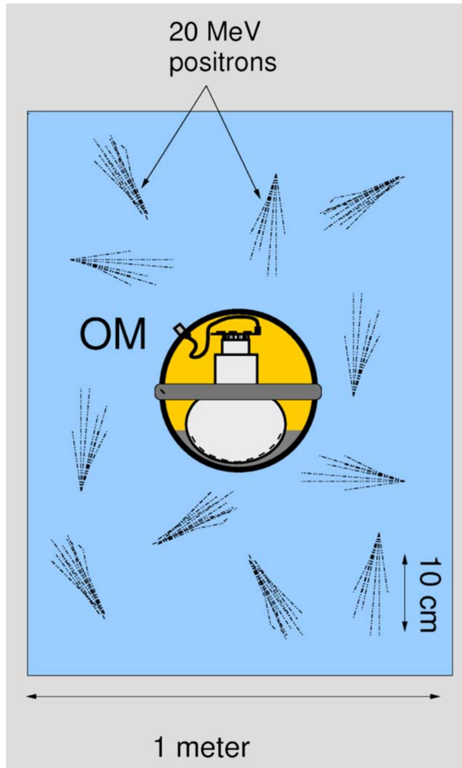
~km long string Water Cherenkov detector at the South Pole

Giga-ton detector



✓ Nominally multi-GeV energy threshold, but can see burst of low energy $\overline{\nu}_e$'s as increase in single PMT count rates.





☞ ice uniformly illuminated

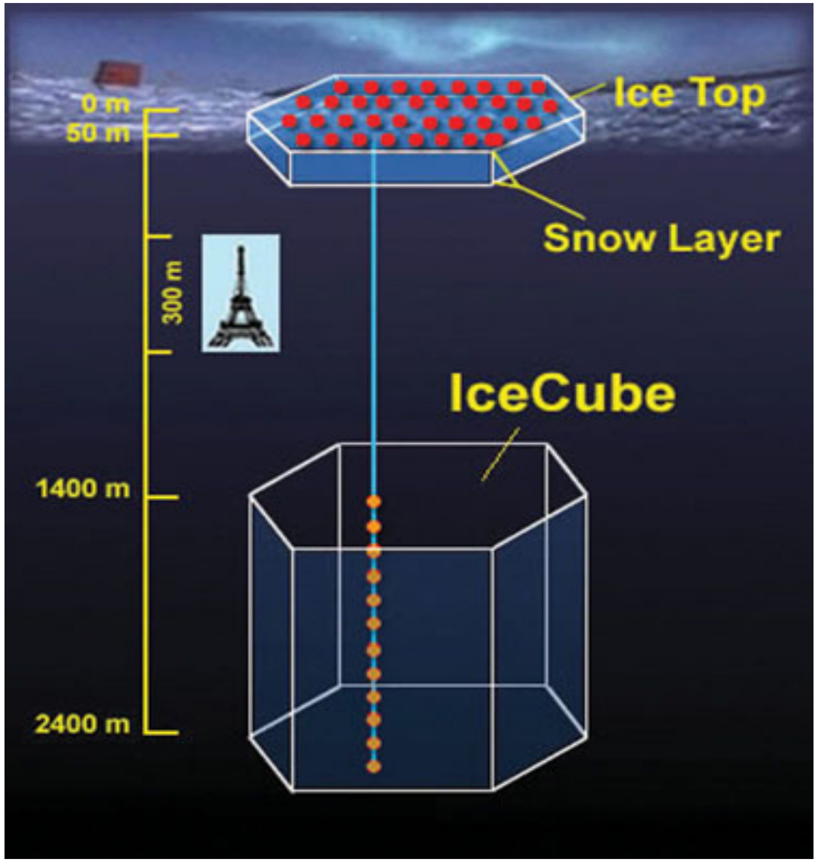
☞ detect correlated rate increase on top of PMT noise

Current SN ν detectors

IceCUBE

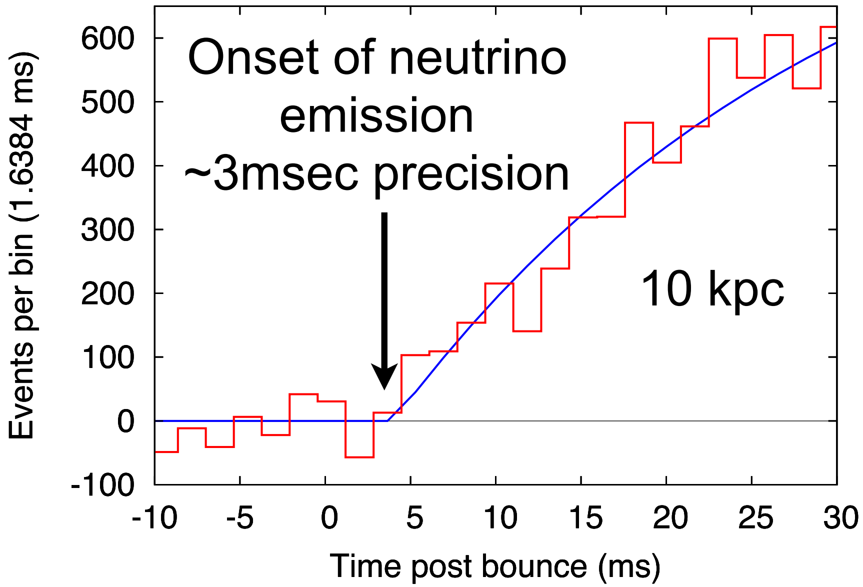
~km long string Water Cherenkov detector at the South Pole

Giga-ton detector



✓ Nominally multi-GeV energy threshold, but can see burst of low energy $\overline{\nu_e}$'s as increase in single PMT count rates.

✓ Cannot tag flavor, or other interaction info., overall rate and fine time structure.

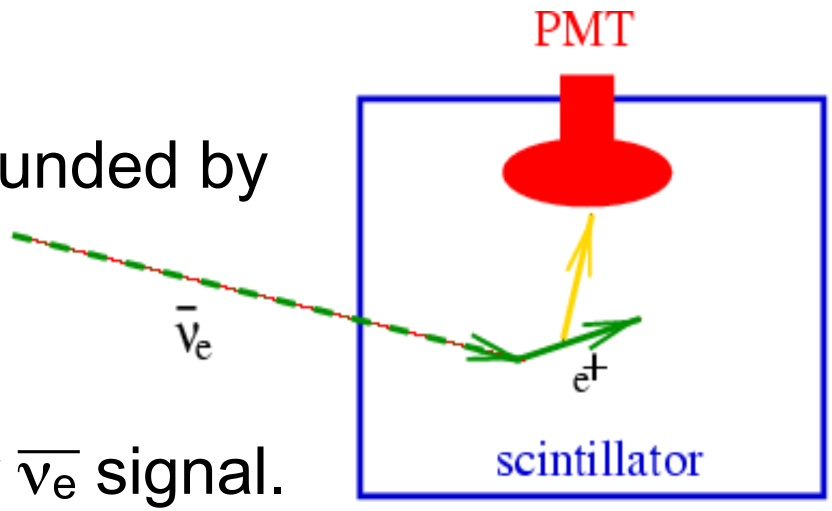


Halzen, Raffelt
arXiv : 0908.2317

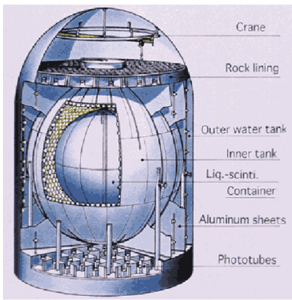
Current SN ν detectors

Scintillation detectors

✓ Liquid scintillator C_nH_{2n} volume surrounded by PMTs.
✓ Low energy threshold (O(100keV))
✓ Good neutron tagging using delayed coincidence technique → advantage for $\overline{\nu_e}$ signal.
✓ Poor directionality, since light is almost isotropic

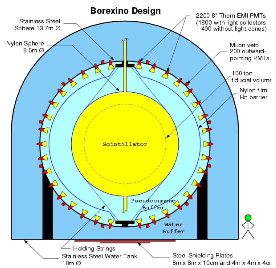


KamLAND (Japan)

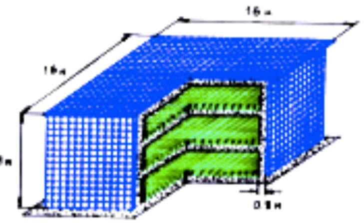


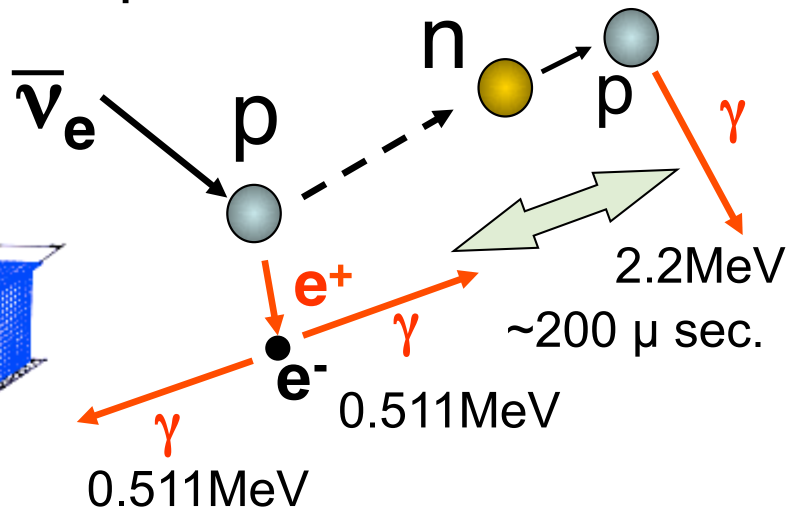
LVD (Italy)

Borexino (Italy)



Baksan (Russia)

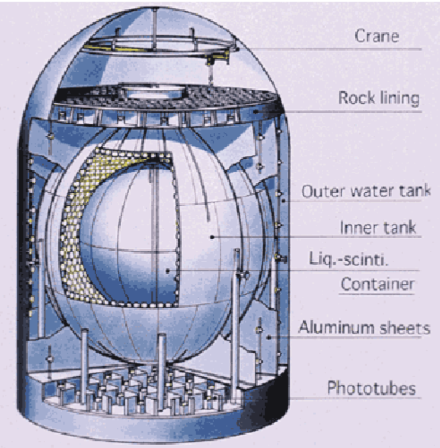




+Double Chooz, Daya Bay and RENO

Current SN ν detectors

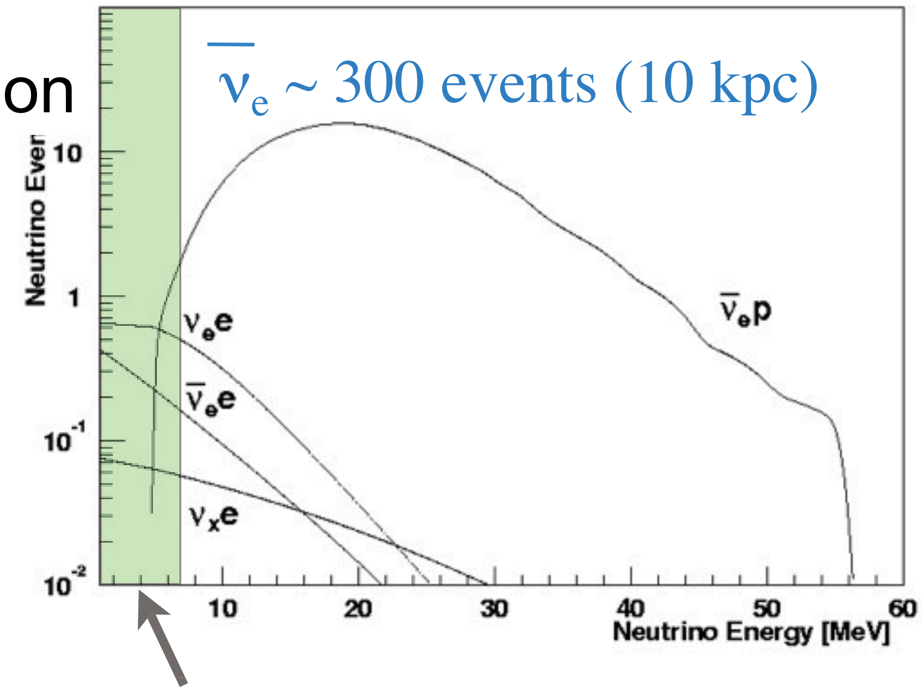
KamLAND 1000 ton Liquid scintillator at Kamioka



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

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

Spectrum



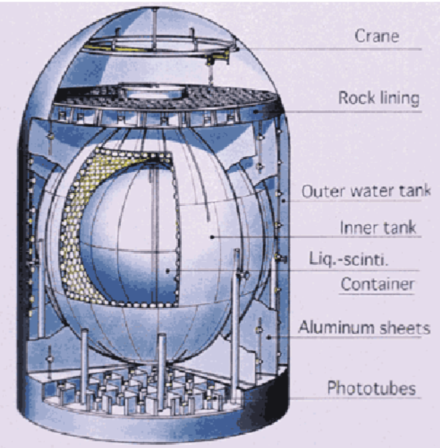
unique for KamLAND

<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 ($\nu+p\rightarrow\nu+p$)

Current SN ν detectors

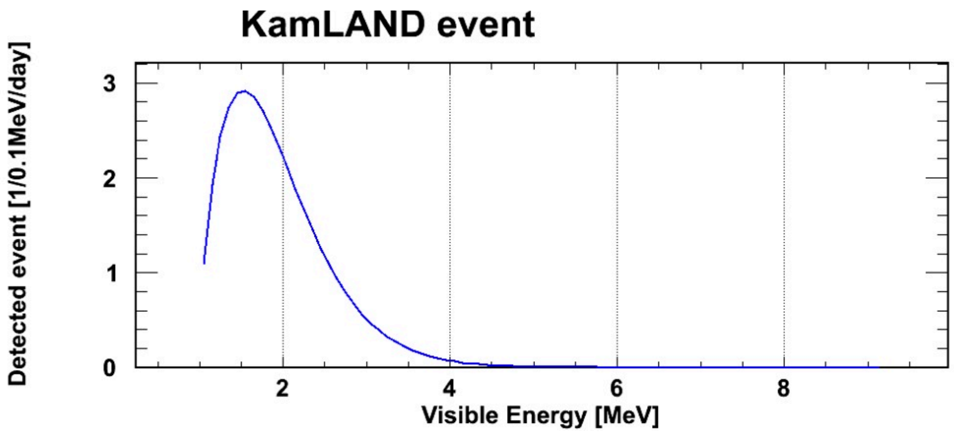
KamLAND 1000 ton Liquid scintillator at Kamioka



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

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

Prediction of SN by signal from Si burning



Expected number of event at 10kpc

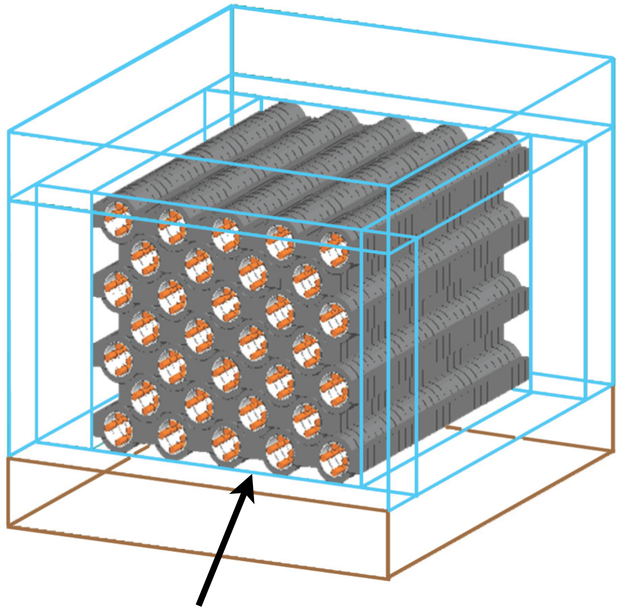
~300 ev (inverse beta decay)
~60 ev (^{12}C CC)
~20 ev (νe elastic scattering)
~300 ev (ν+p→ν+p)

~10 events/day for Betelgeuse

Ishidoshiro
(JPS meeting, March, 2013)

Current SN ν detectors

HALO Helium and Lead Observatory at SNO lab. (Canada)



^{3}He neutron counter
with lead target

CC
$\nu_e + {}^{208}Pb \rightarrow {}^{207}Bi + n + e^-$
$\nu_e + {}^{208}Pb \rightarrow {}^{206}Bi + 2n + e^-$

NC
$\nu_x + {}^{208}Pb \rightarrow {}^{207}Pb + n$
$\nu_x + {}^{208}Pb \rightarrow {}^{206}Pb + 2n$

- ✓ HALO-1 is using an available 76 tons of Pb
- ✓ 85 neutrons at SN @10kpc
  - 65 neutrons through CC
  - 20 neutrons through NC
- ✓ ~50% of detection efficiency
- ✓ Totally, ~40 events are expected
- ✓ HALO-2 is a future kton-scale detector

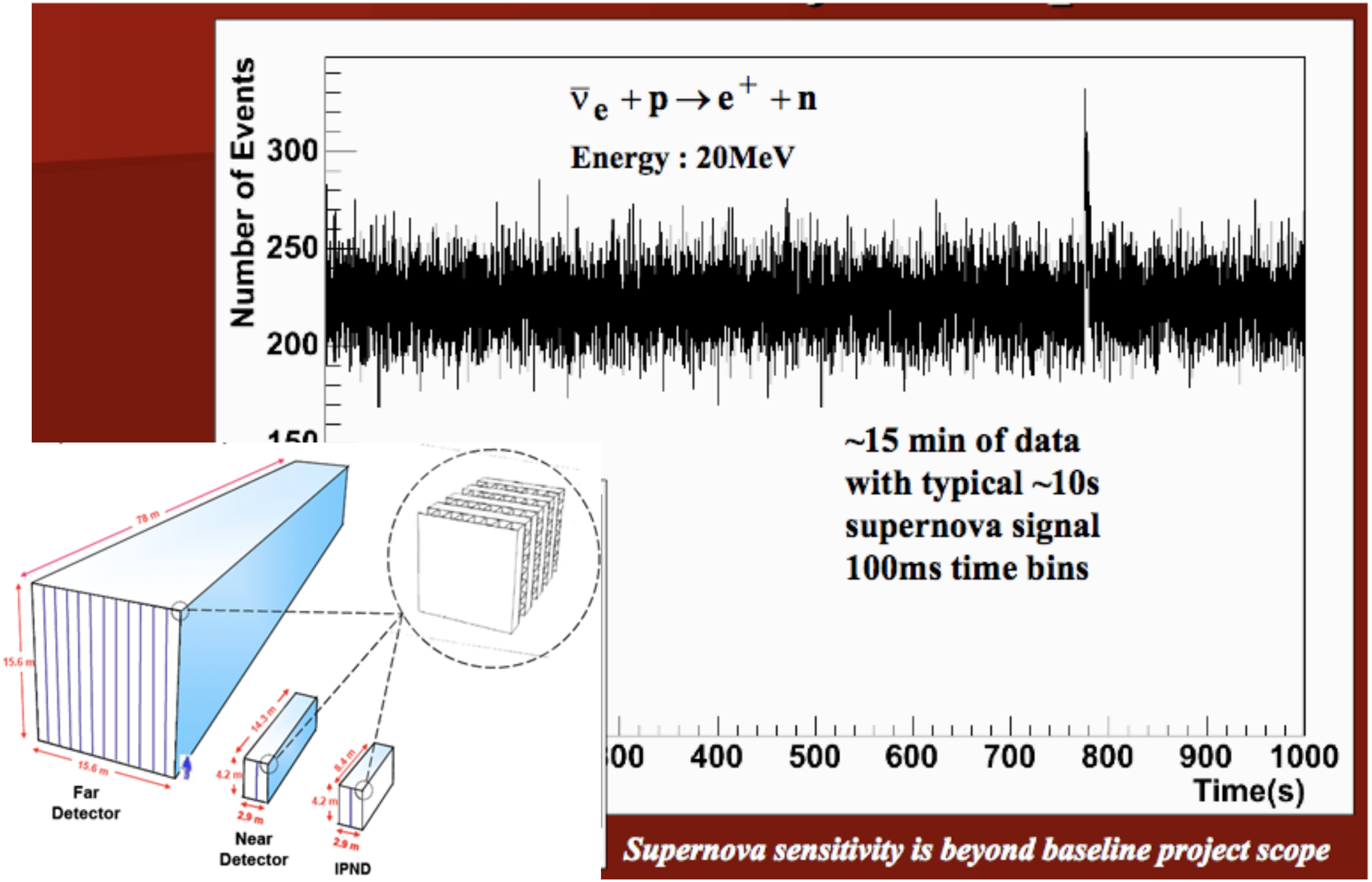
$^3He + n \rightarrow p + T$

Thermal neutron
Ionization by proton (573keV) and tritium (101keV)
Detection by proportional counter

Current SN ν detectors

NOνA

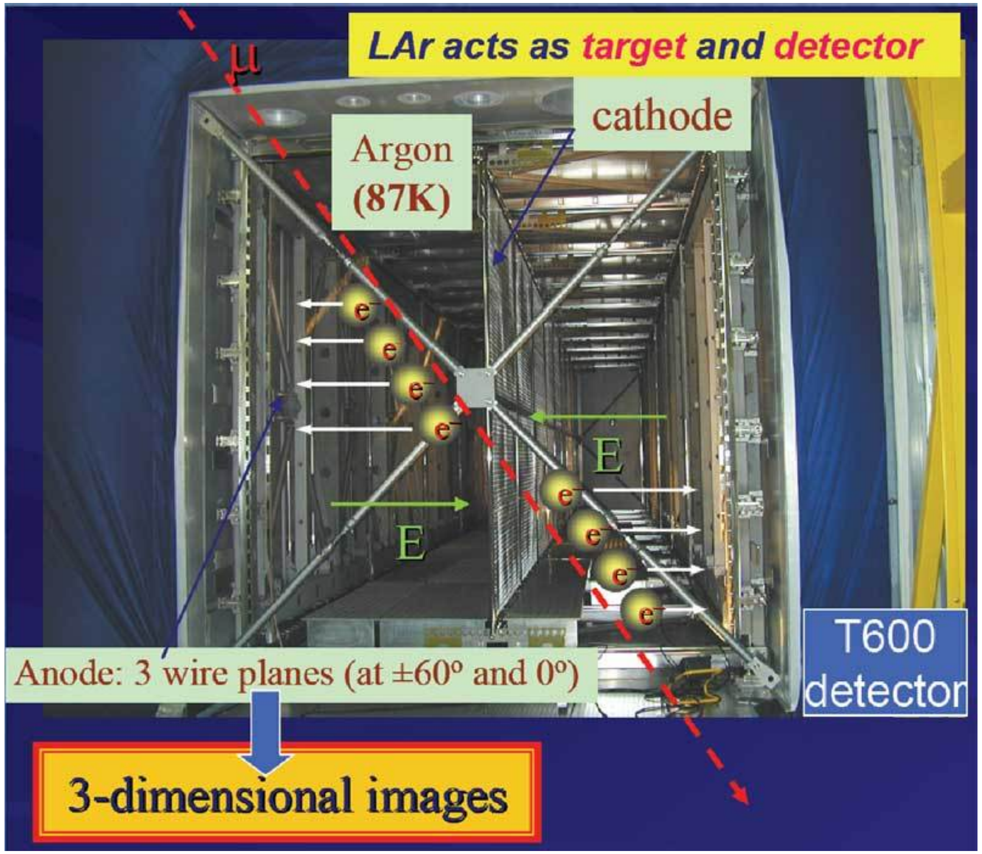
15kton scintillator near surface at Ash River (MN, USA)
for long baseline neutrino oscillation experiment



Current SN ν detectors

ICARUS

600 ton Liquid Argon in Gran Sasso (Italy)
(-> FNAL (USA))

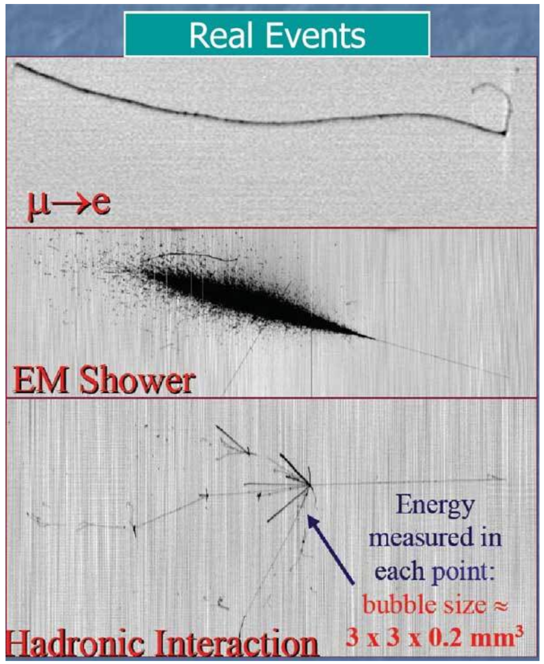


CC $\nu_e + {}^{40}Ar \rightarrow {}^{40}K^* + e^-$

$\nu_e + {}^{40}Ar \rightarrow {}^{40}Cl^* + e^+$

NC $\nu_x + {}^{40}Ar \rightarrow \nu_x + {}^{40}Ar^*$

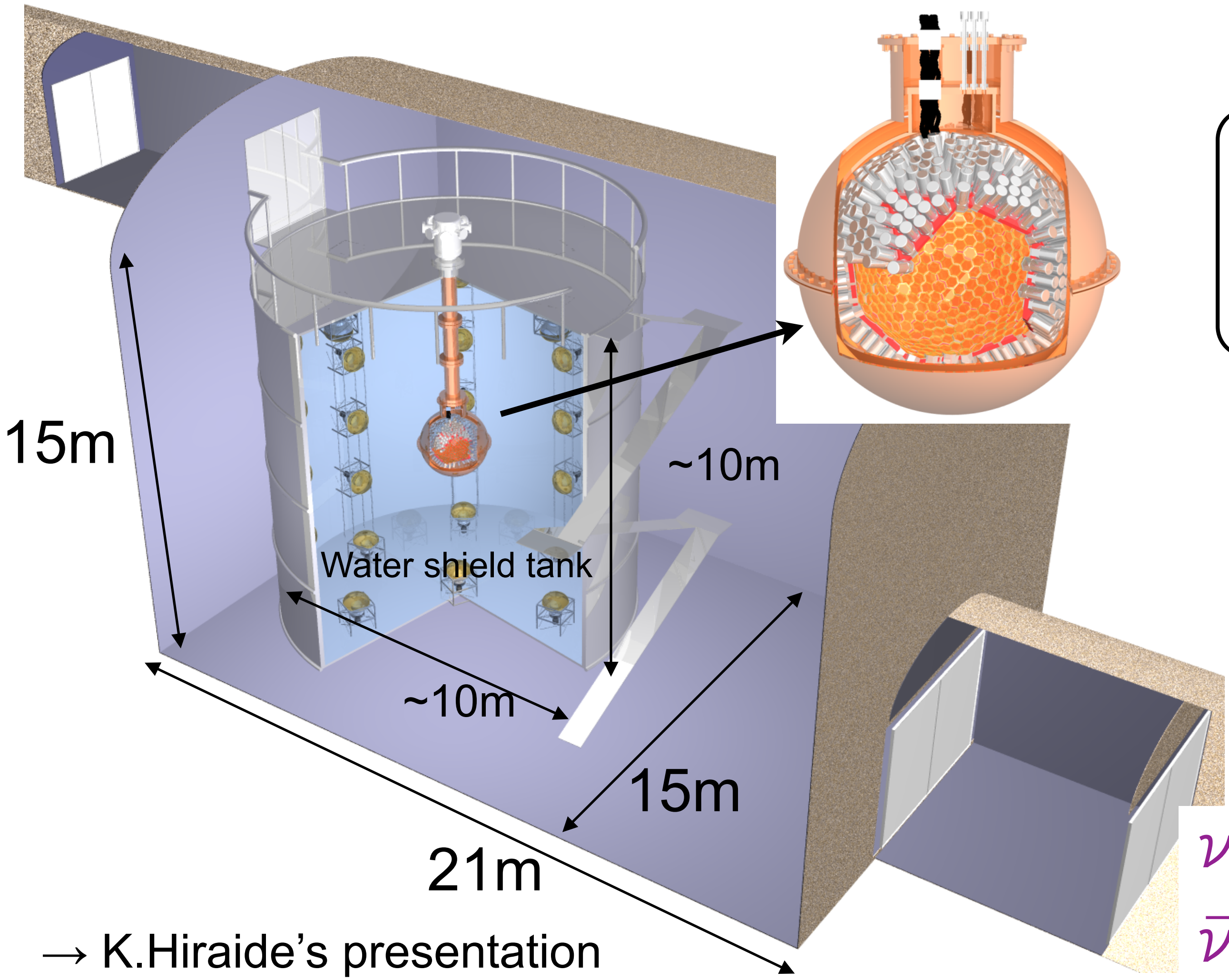
ES $\nu_{e,x} + e^- \rightarrow \nu_{e,x} + e^-$



Good electron neutrino sensitivity

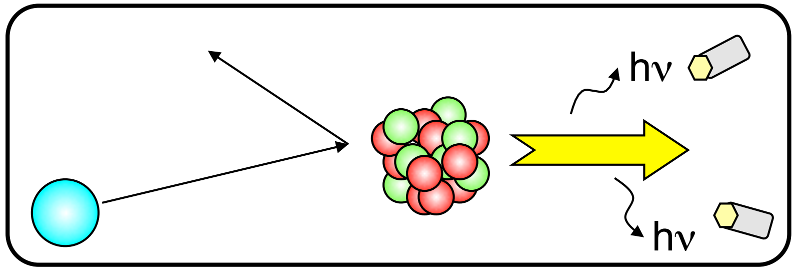
Current SN ν detectors

XMASS 800kg Liquid Xenon detector



→ K.Hiraide's presentation

Direct dark matter search



nuclear recoil interaction

Coherent elastic

ν_x + (N,Z) → ν_x + (N,Z)

CC interactions

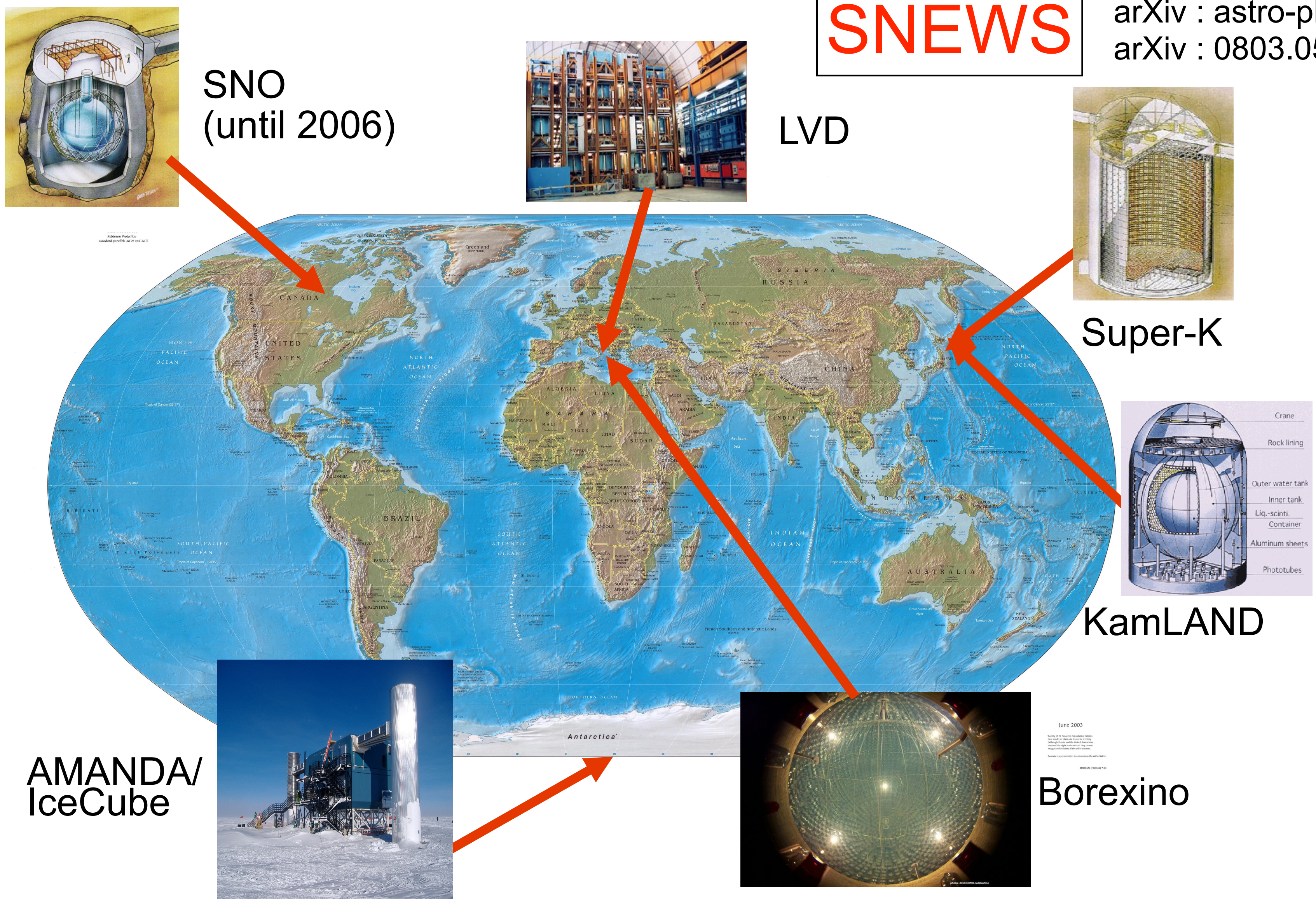
ν_e + (N,Z) → (N-1, Z+1) + e^-

$\overline{\nu}_e$ + (N,Z) → (N+1, Z-1) + e^+

SuperNova Early Warning System

SNEWS

arXiv : astro-ph/0406214
arXiv : 0803.0531

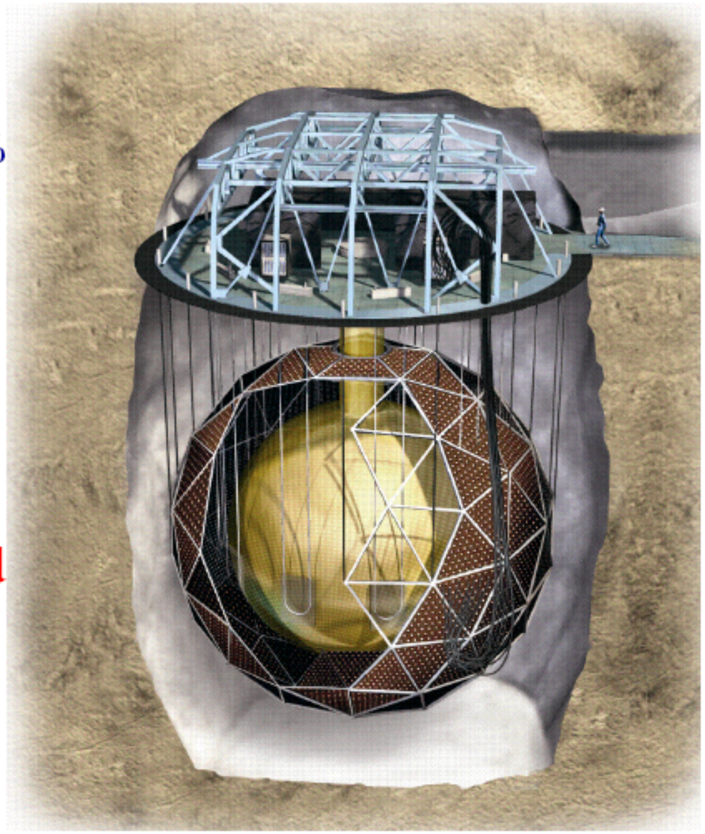


Future prospects

Future SN ν detectors

SNO+ Large liquid scintillator detector at SNO lab. (Canada)

- 1000 t of D_2O replaced by liquid scintillator
  - Neodymium-loaded at 0.1%
  - 780 kg of natural Nd
- 9000 PMTs
  - 3.5 % resolution at Nd endpoint (3.37 MeV)
- Water shield
  - 1700 + 5300 tons UPW
- New rope system to hold down the 6 m radius acrylic vessel



✓ Main purpose is searching for double-beta decay loaded ^{130}Te
✓ 780 tones of liquid scintillator.
✓ Good energy resolution
✓ Deep underground
- 6800mwe (2700 for Kamioka)

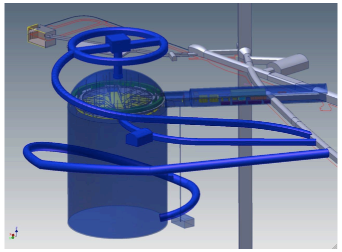
✓ For SN, similar ability as KamLAND is expected.

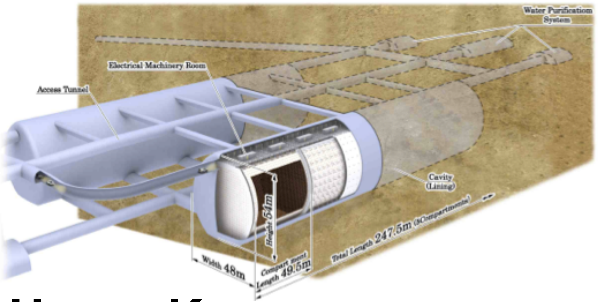
Coming soon

Future SN ν detectors

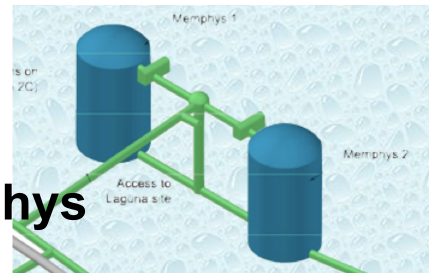
Large scale detectors

LBNE WCh



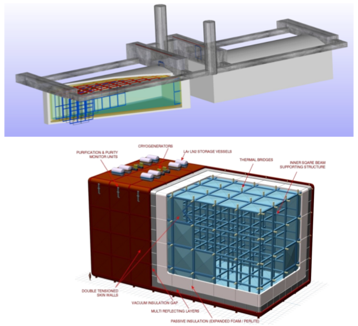


Hyper-K

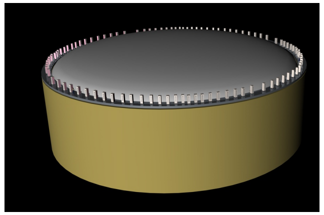


Memphys

Megaton-scale water detector concepts



5-100 kton-scale liquid argon concepts



LBNE LAr

GLACIER

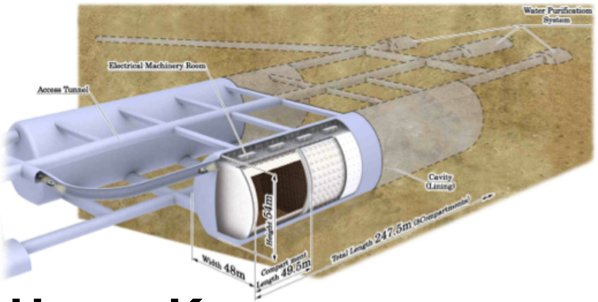
10-100 kton-scale scintillator detector concepts

LENA

Future SN ν detectors

Large scale detectors

LBNE
WCh



Hyper-K

Memphys

Megaton-scale water
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5-100 kton-scale
liquid argon
concepts

LBNE LAr GLACIER

10-100
kton-scale
scintillator
detector
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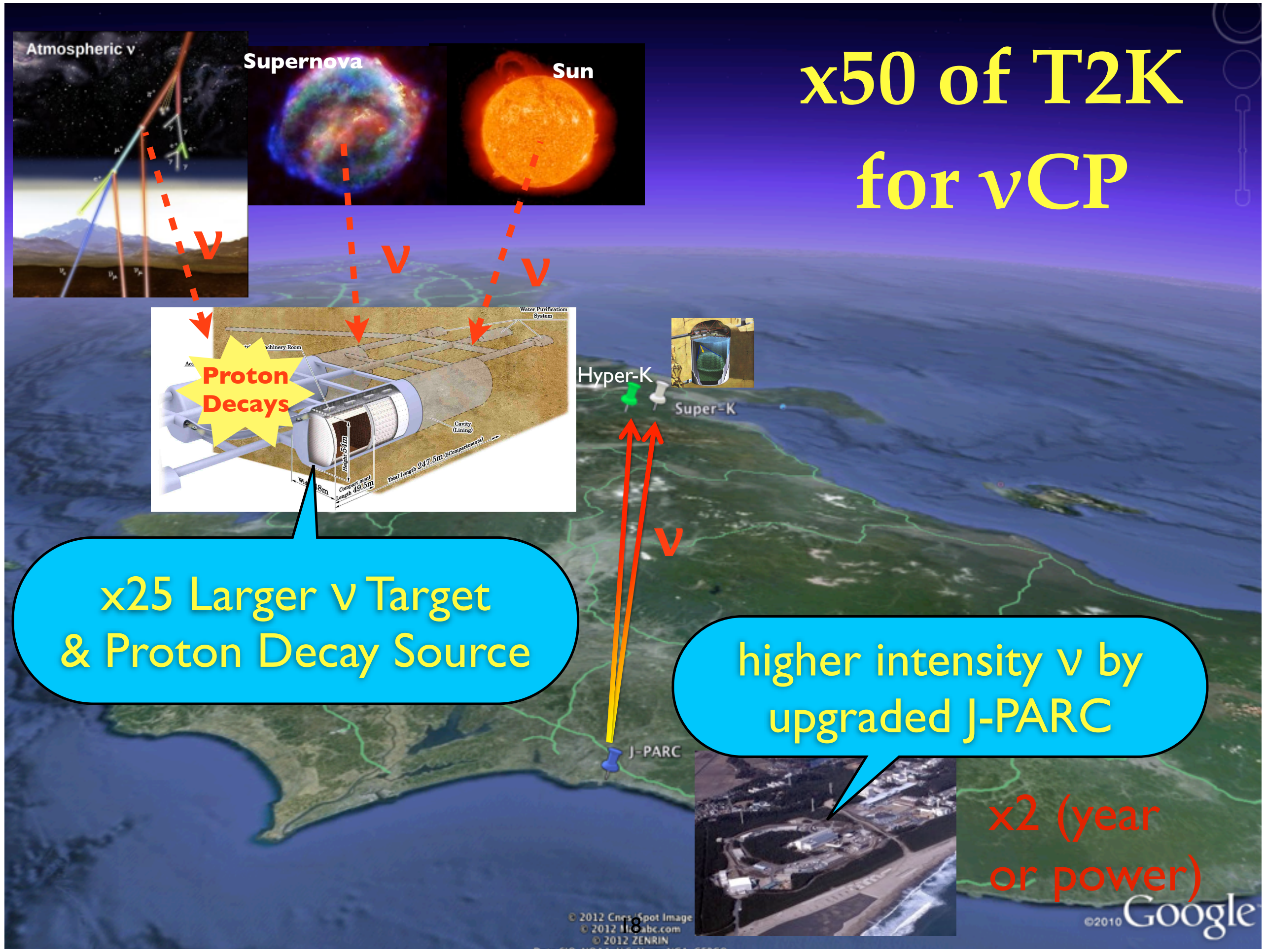
LENA

Future SN ν detectors

Hyper-Kamiokande

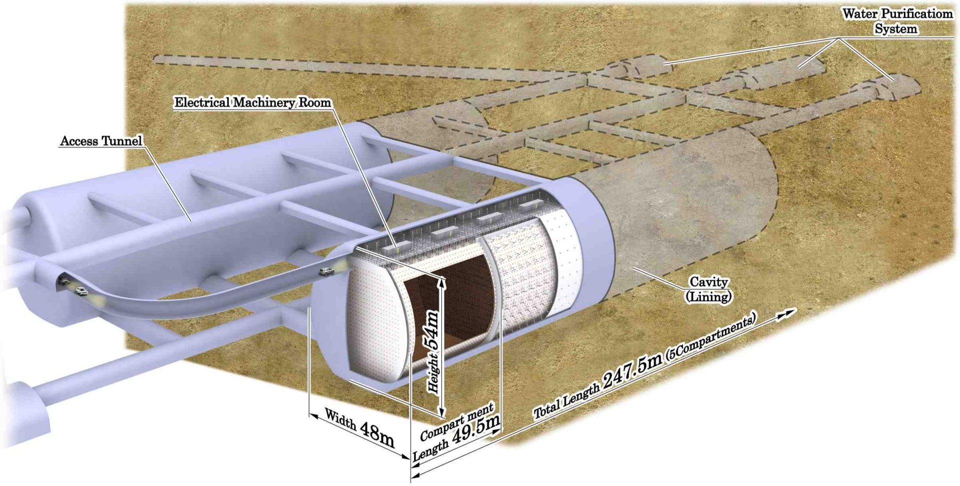


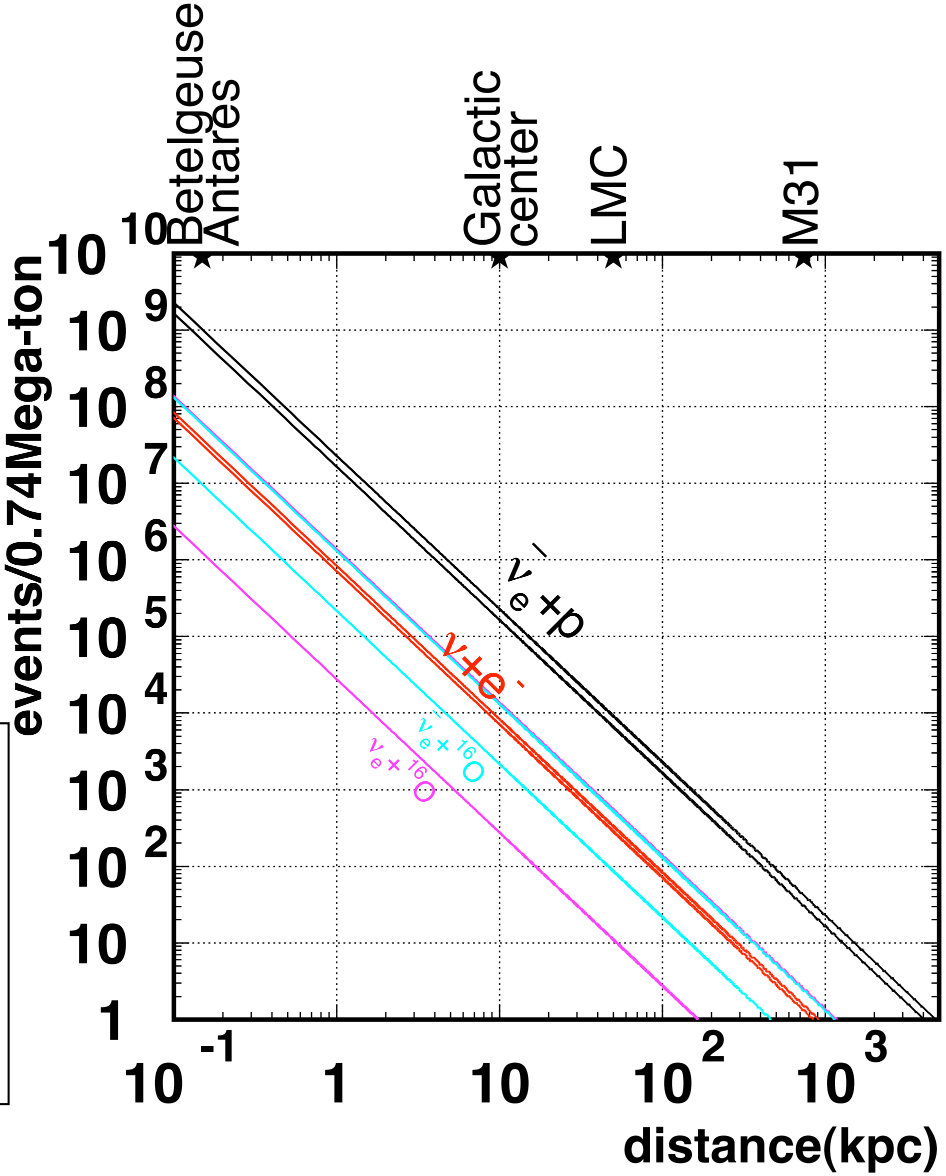
✓ Main purpose is searching for CP violation in lepton sector by long baseline experiment.
✓ Total volume ~ 1 Mton
✓ Fiducial volume : 0.56 Mton, 0.74 Mton for SN which is ~20 times as SK.
✓ Number of photo-sensors : ~99000

LoI
arXiv 1109.3262

Future SN ν detectors

Hyper-Kamiokande





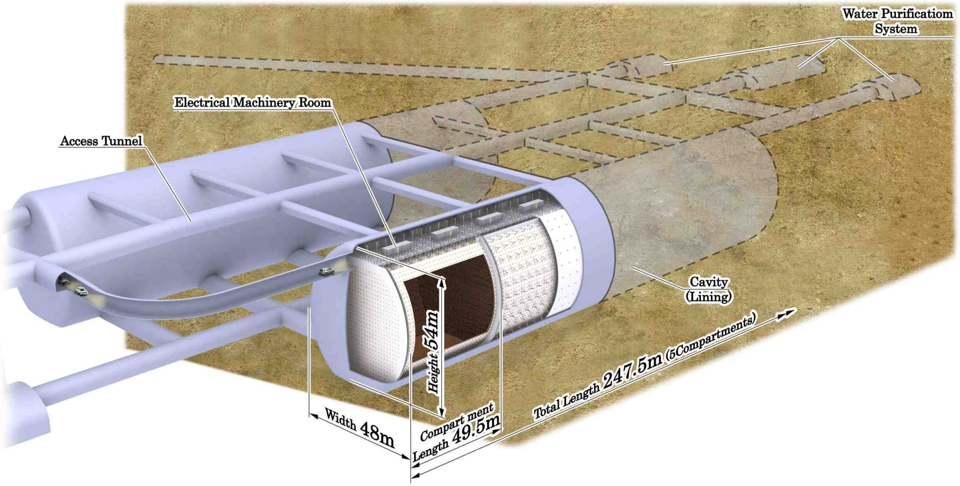
Expected number of event

~168000 ev (inverse beta decay)
~2300 ev (^{16}O CC)
~7000 ev (νe elastic scattering)
~8300 ev (^{16}O NC γ)

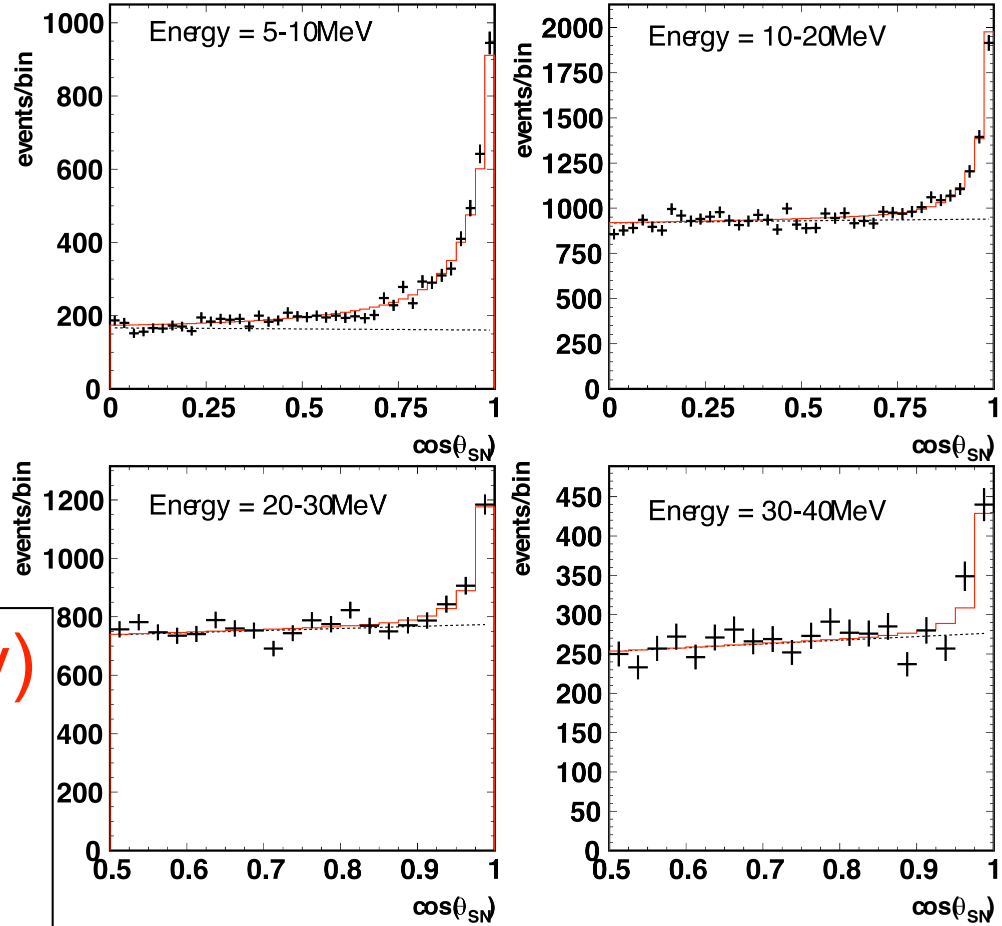
at 10kpc, 4.5MeV energy threshold

Future SN ν detectors

Hyper-Kamiokande



Angular distribution



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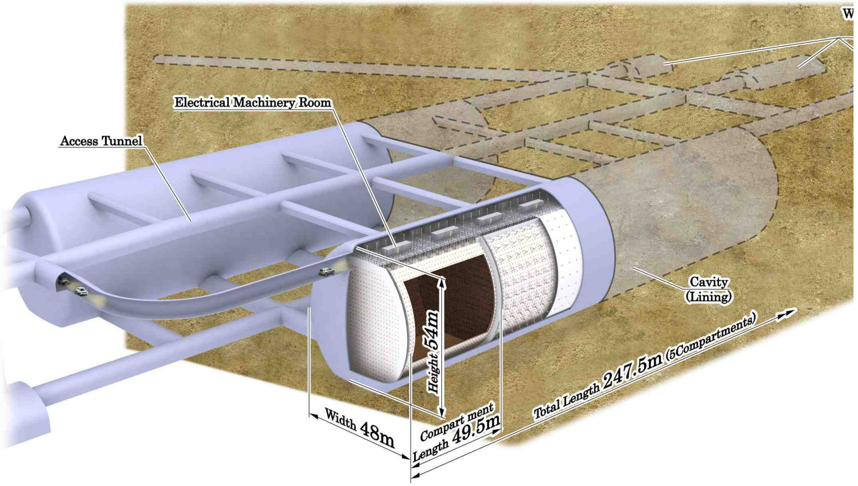
direction determination is with ~2 degree.

Future SN ν detectors

Hyper-Kamiokande



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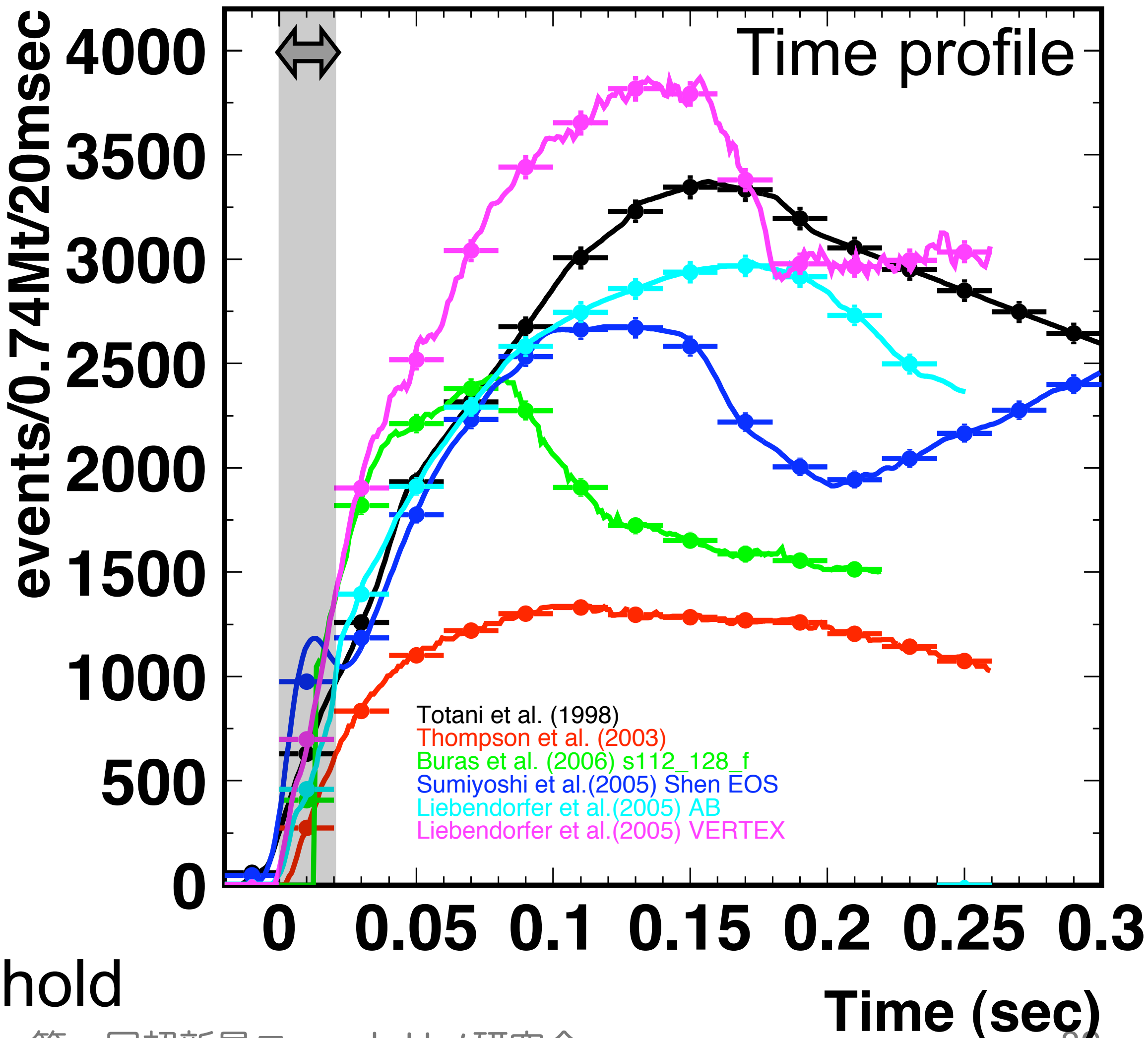
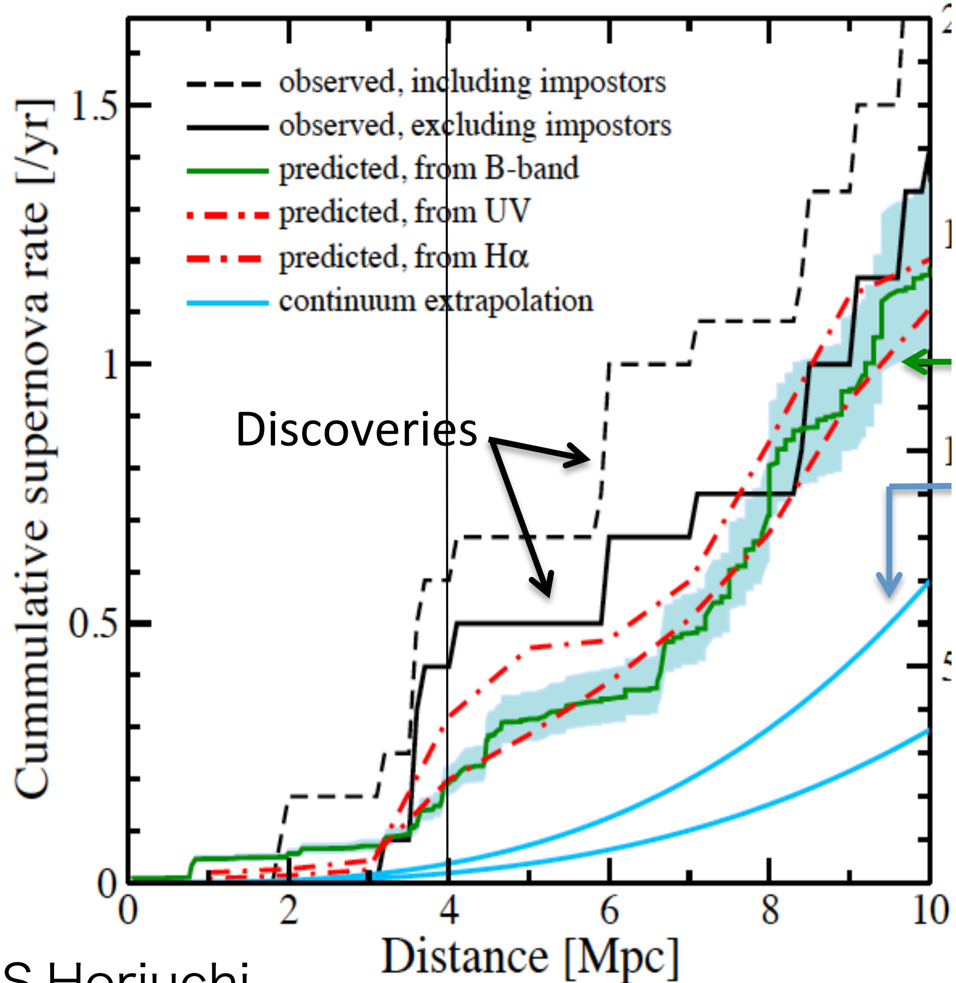
Determine starting time
with ~0.03 msec precision.



Future SN ν detectors

Hyper-Kamiokande



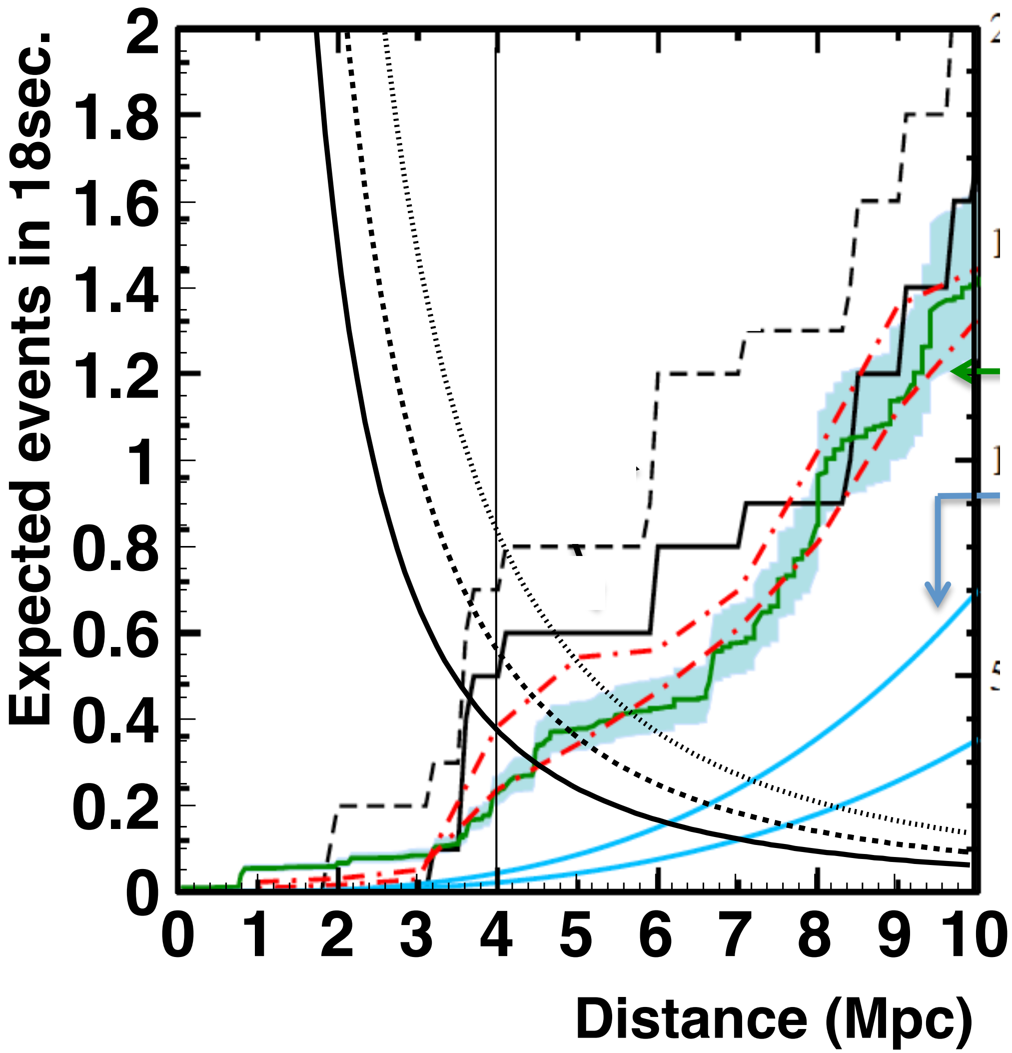
S.Horiuchi

Nearby galaxy

- ✓ 0.2~0.6 SN/year is expected at 4Mpc.
- ✓ If the analysis energy threshold for HK is set to 18MeV for reduce B.G., the # of expected events : 0.37~0.83 @4Mpc. While the expected accidental B.G. is 0.00656 events.
- ✓ The detection probability : 31~56% (N≧1) @4Mpc
- ✓ 1 event from SN@4Mpc (need another information e.g. GW) every 3~10 years is expected.

Future SN ν detectors

Hyper-Kamiokande



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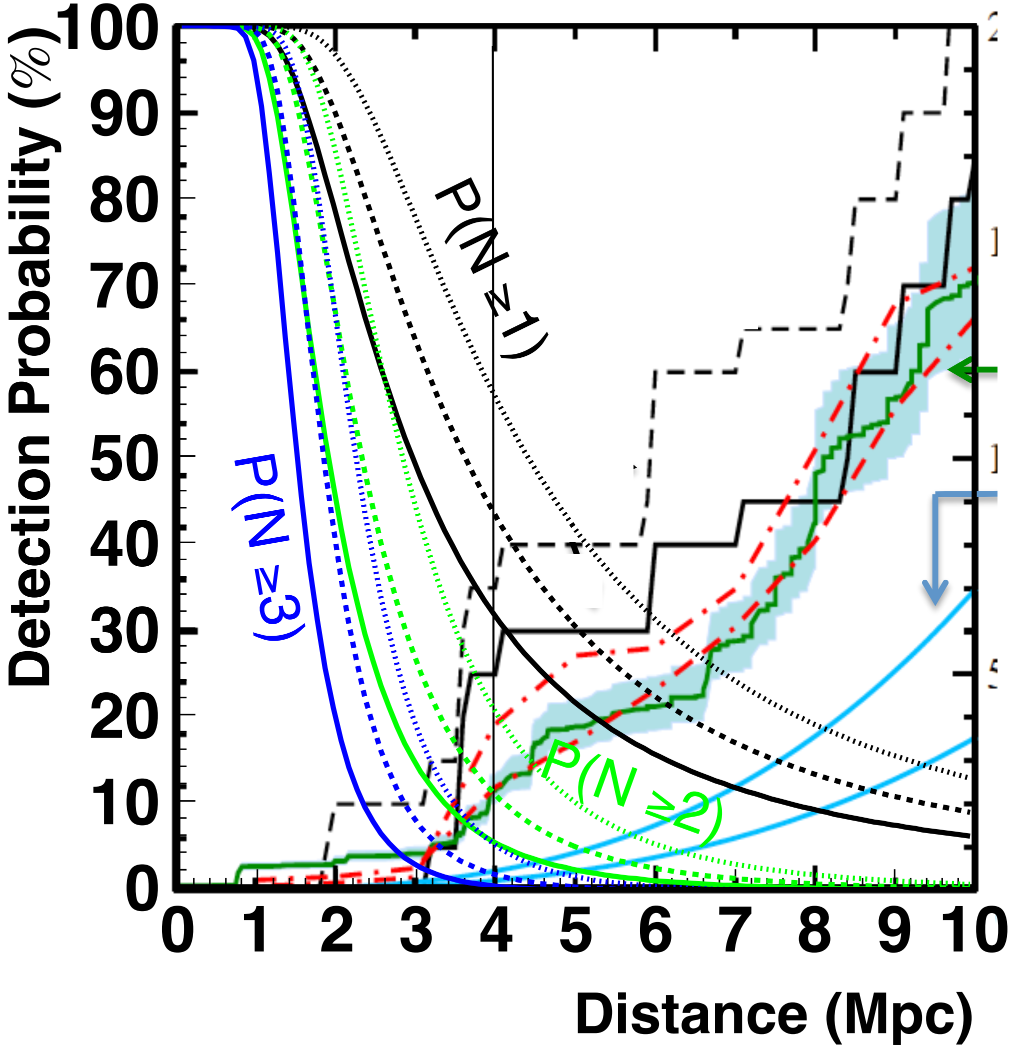
Future SN ν detectors

Hyper-Kamiokande



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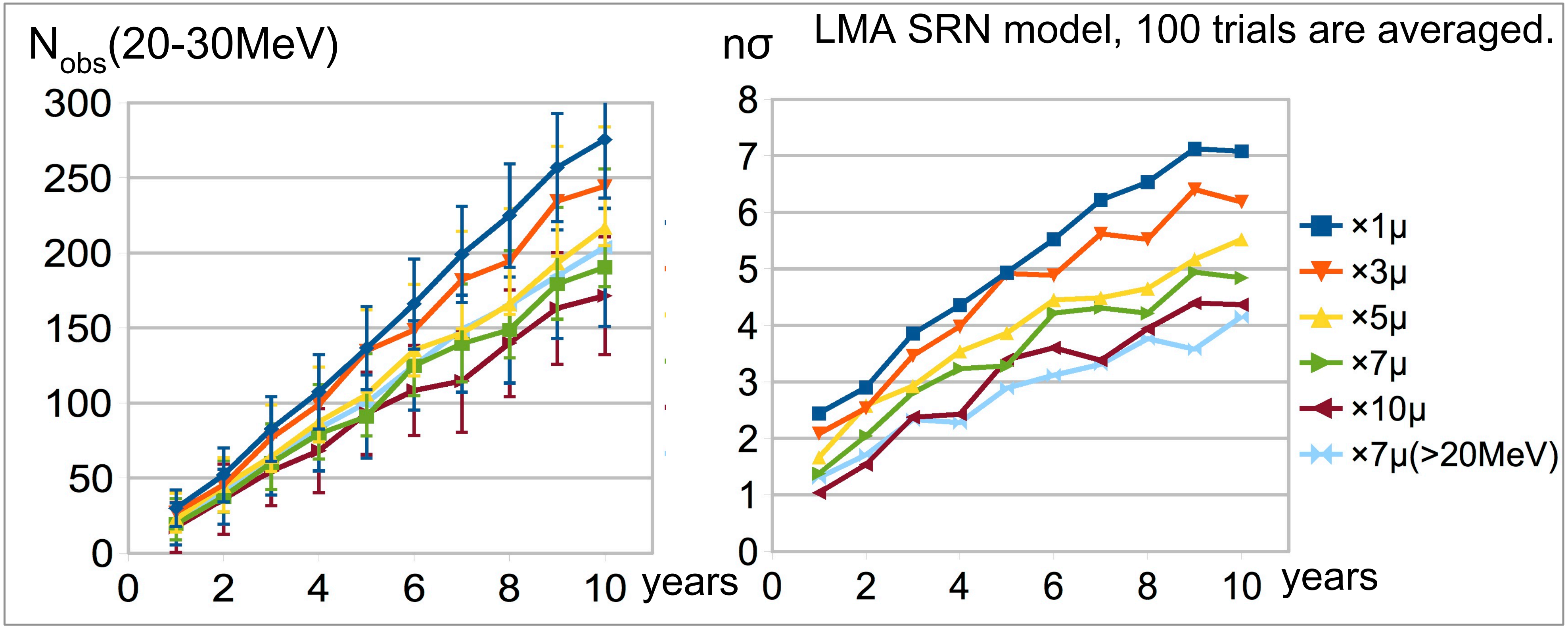
Future SN ν detectors

Hyper-Kamiokande

Sensitivity of Supernova Relic Neutrino
(w/o neutron tagging, w/ spectrum information)



Future SN ν detectors

Hyper-Kamiokande

研究会のお知らせ

「ハイパーカミオカンデにおける

宇宙ニュートリノ観測」

５月１８／１９日

神戸大学　瀧川記念学術交流会館

大会議室

Summary

Surprising recent theory improvement

Ready to observe by several neutrino detectors

Let's go supernova!

Thanks