NNN05, April 7, 2005

Low energy astrophysical neutrino observations with megaton class detector s

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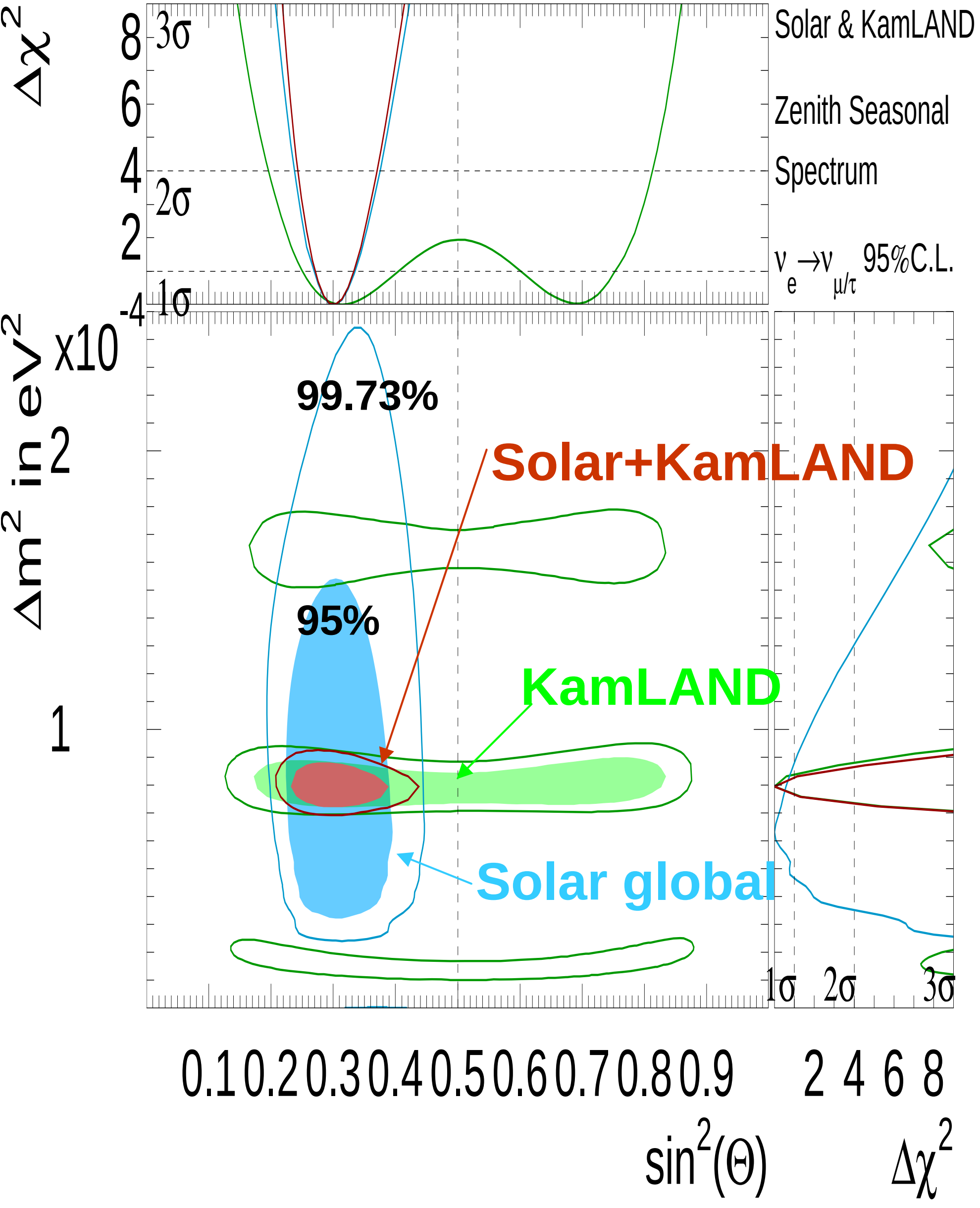
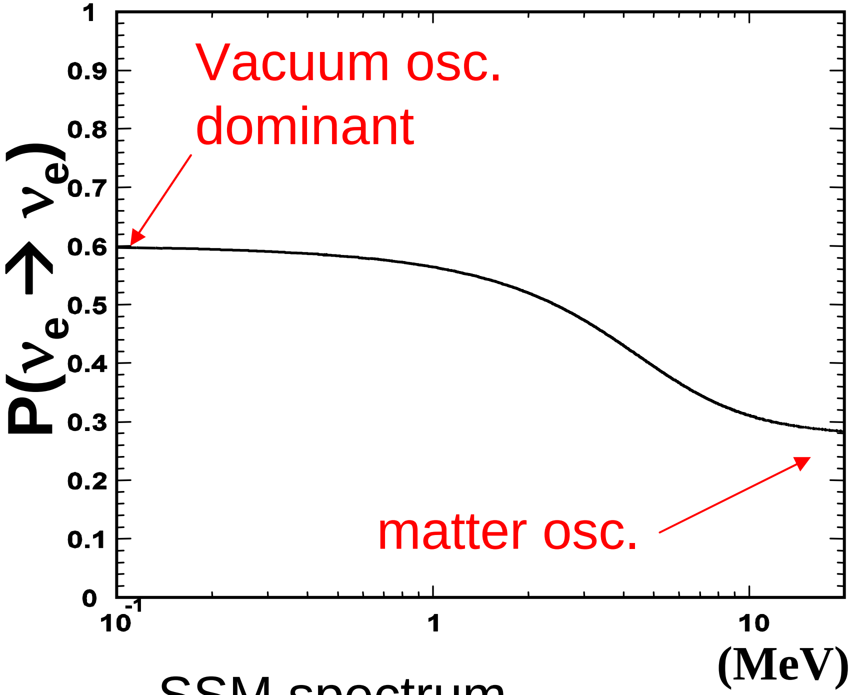
- ^{8}B solar neutrino measurement
- Supernova burst neutrino observation
- Supernova relic neutrino observation
- Conclusions

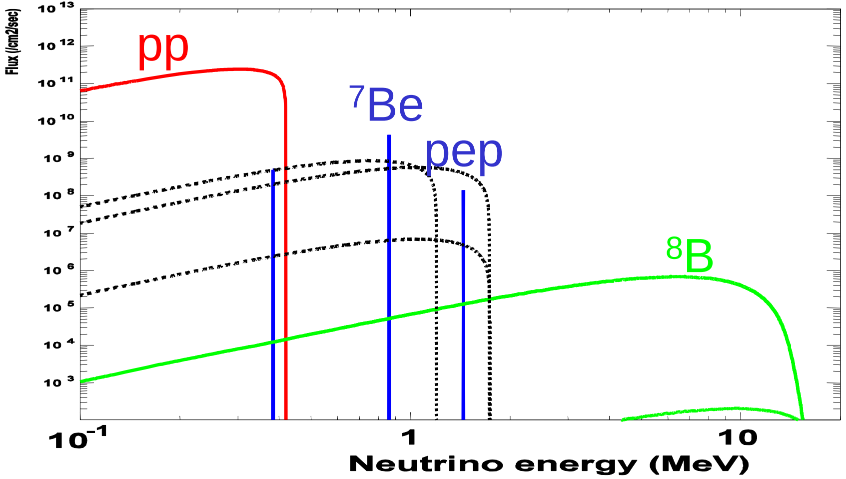
Current status of solar neutrino oscillations



Expected $P(\nu_e \to \nu_e)$ at best fit

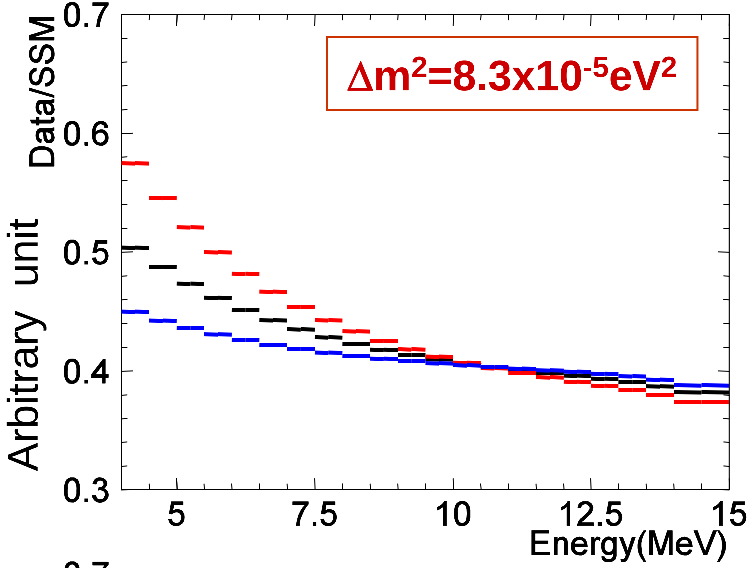


SSM spectrum

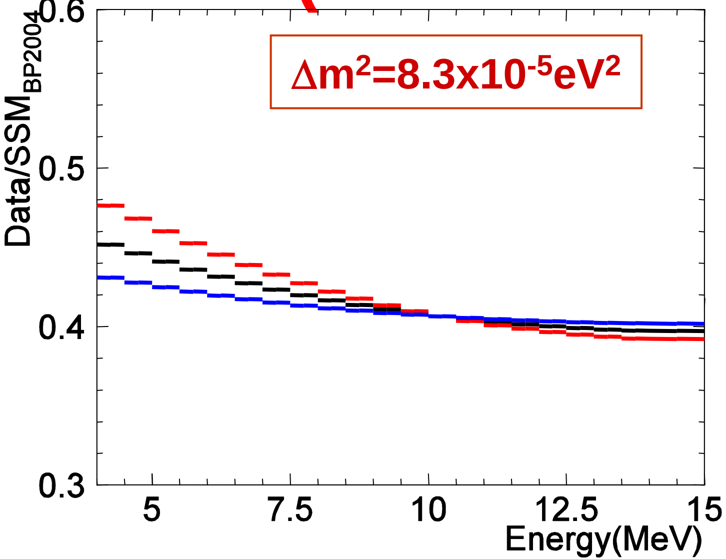


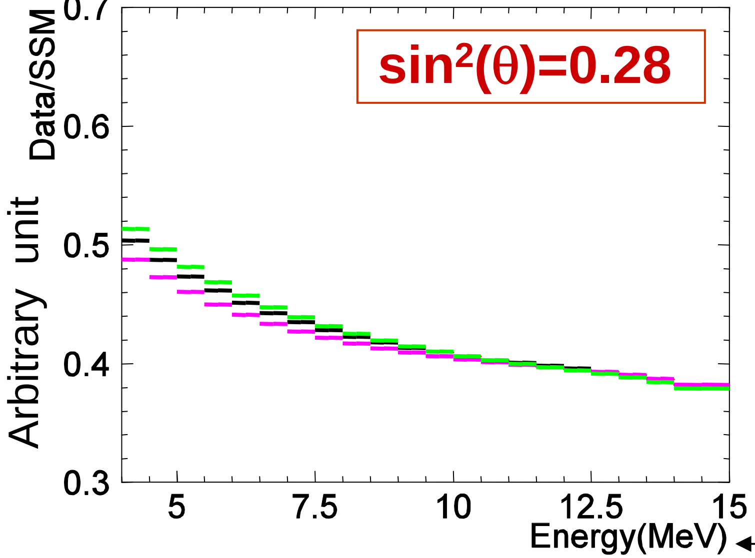
Expected low energy upturn (^{8}B)

SNO CC **SK (νe scattering)**

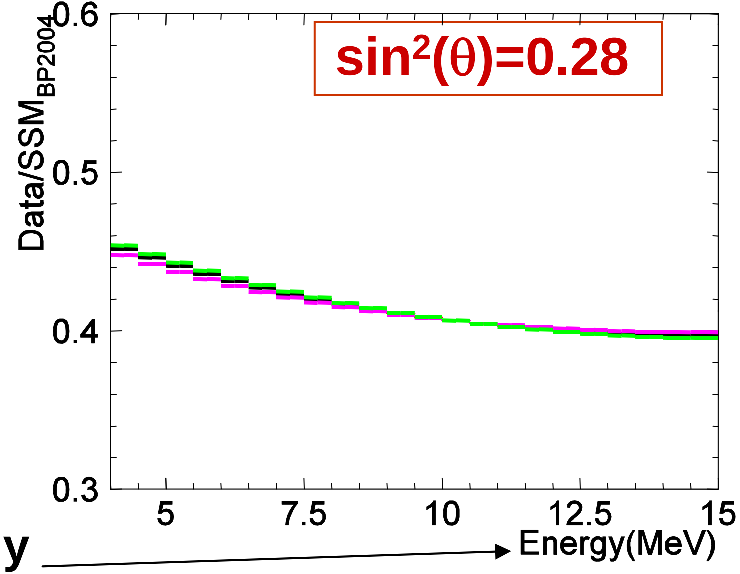


$\sin^2(\theta)$
0.22
0.28
0.35





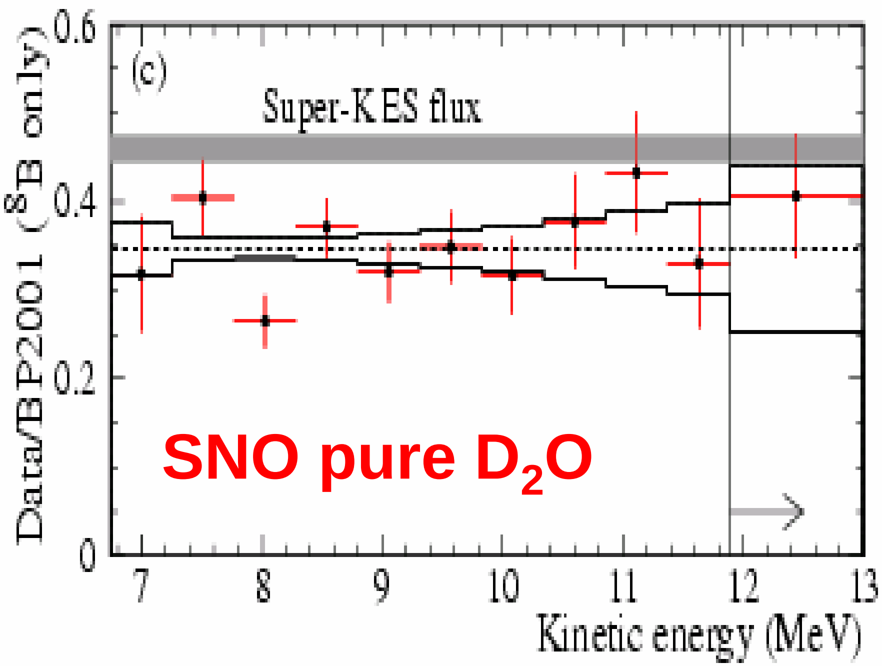
Δm^2 (eV^2)
9.1×10^{-5}
8.3×10^{-5}
7.4×10^{-5}

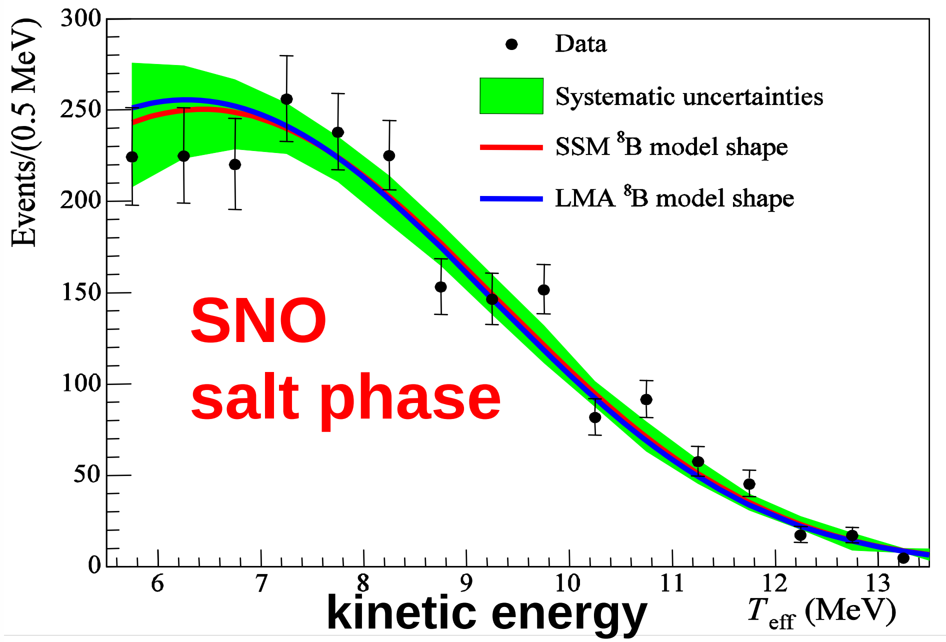


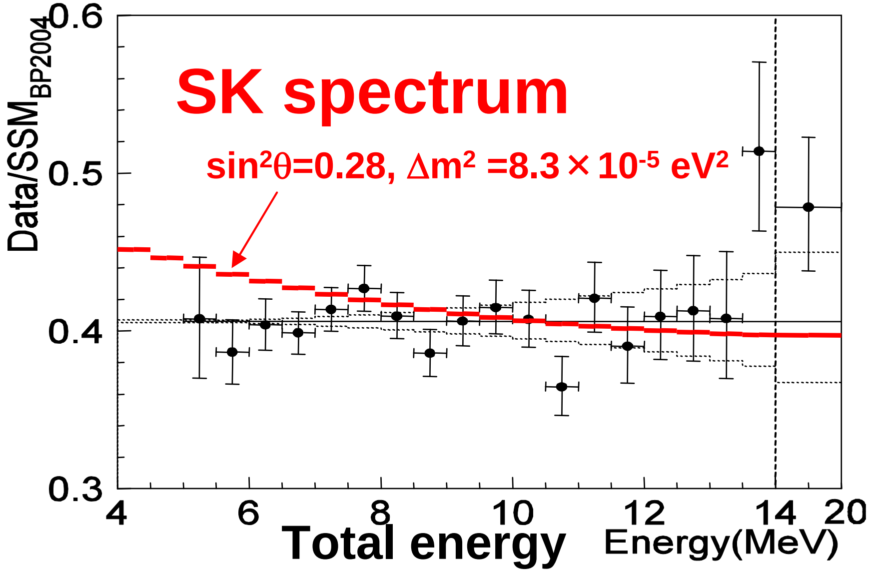
Total energy

~20% in SNO and ~10% in SK upturn is expected from 4 MeV to 15 MeV.

Measurements by SNO and SK so far







No spectrum distortion so far.

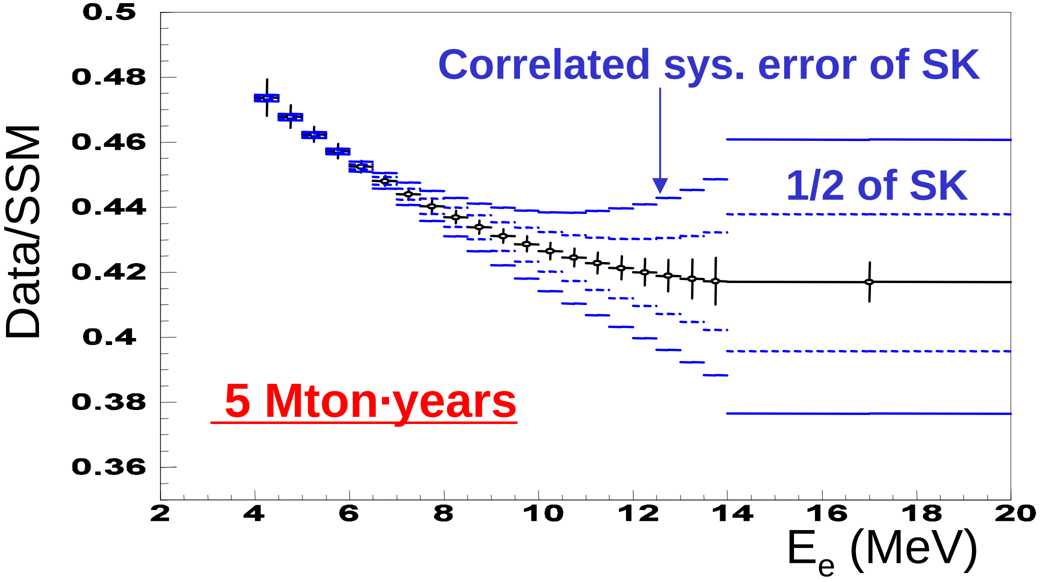
Current SK and SNO measurements are limited by statistics and systematic.

Need more statistics, lower threshold and make systematic errors smaller to test spectrum distortion.

Expected solar ν spectrum measurement by Mega-ton water cherenkov detector

^{8}B spectrum distortion

$\sin^2\theta = 0.28$, $\Delta m^2 = 8.3 \times 10^{-5}$ eV^2

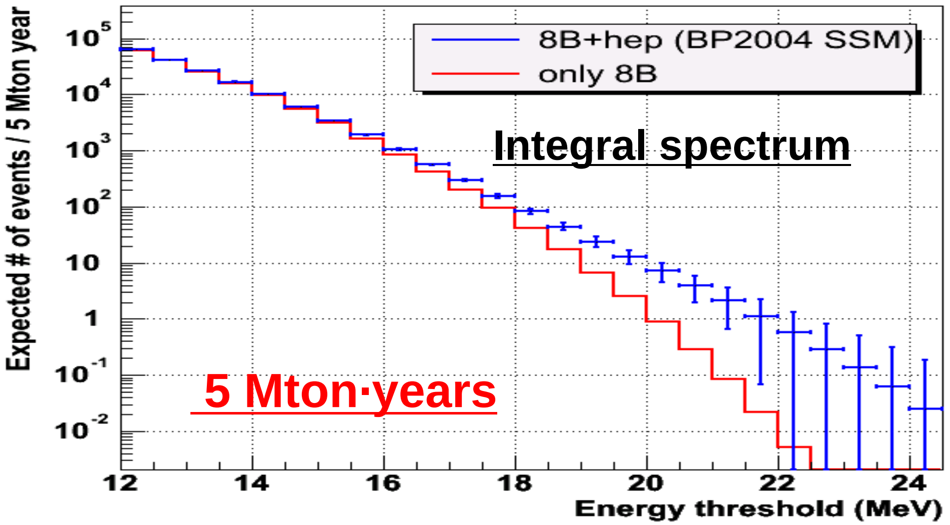


Enough statistics to see distortion.

Energy scale calibration should be better than ~0.3%.

(*)For the statistical error, SK background level above 5.5MeV and 70% reduction below 5.5 MeV are assumed.

hep neutrino



SSM(BP2004) flux:

hep: $7.88(1\pm0.16)\times10^3$ /cm^2/sec

= ~1/700 of ^{8}B

Statistically possible to measure hep neutrinos.

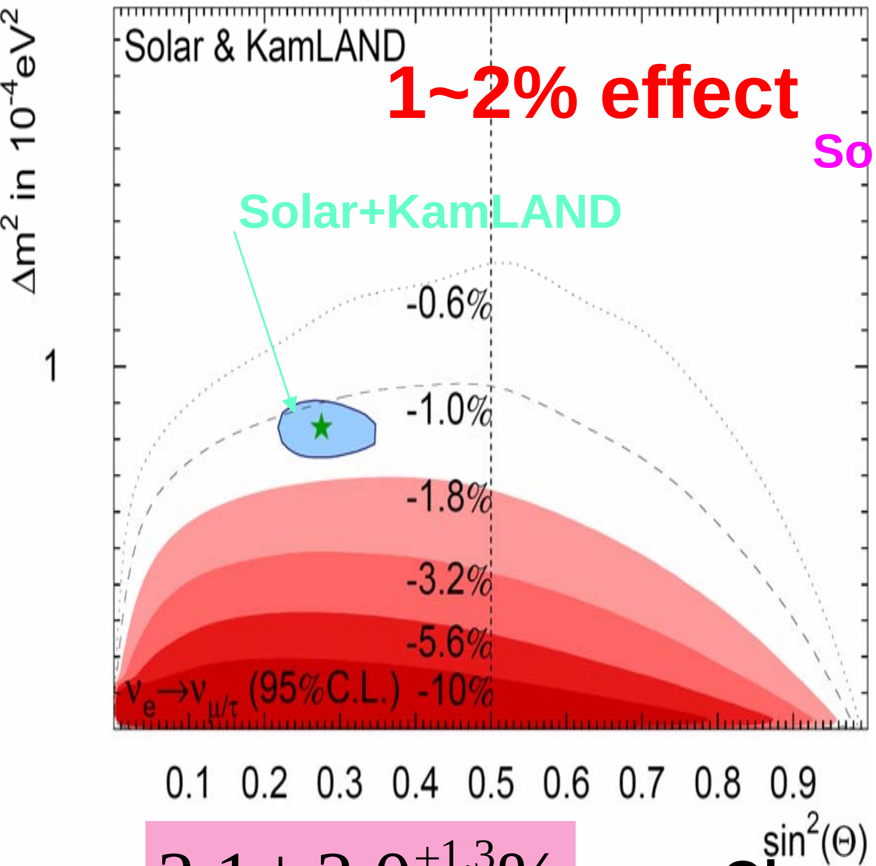
Precise calibration of energy resolution is necessary.

^{8}B -- Day-Night effect

- Not yet convincingly seen either in **SK** nor **SNO**

$$A_{ND} = \frac{\text{(Night-Day)}}{\text{(Night+Day)/2}} \text{ X100(\%)}$$

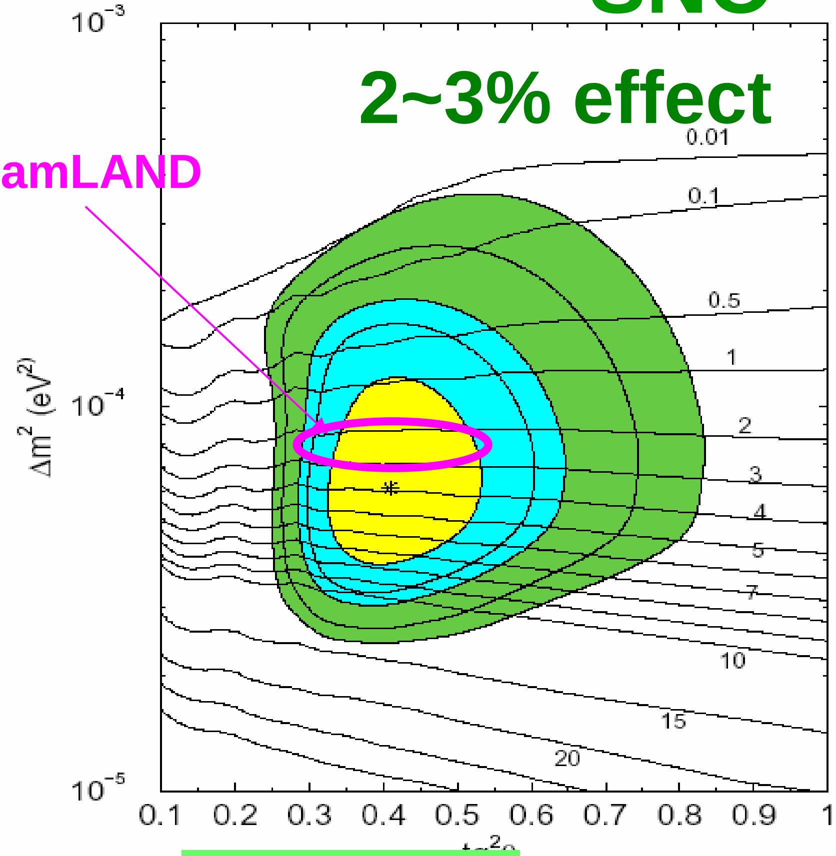
SK



1~2% effect

Solar+KamLAND

SNO



2~3% effect

Solar+KamLAND

$2.1 \pm 2.0^{+1.3}_{-1.2}\%$ ← **Observations** → $7.0 \pm 4.9^{+1.3}_{-1.2}\%$ (pure D_2O)

$-5.6 \pm 7.4 \pm 5.3\%$ (salt phase)

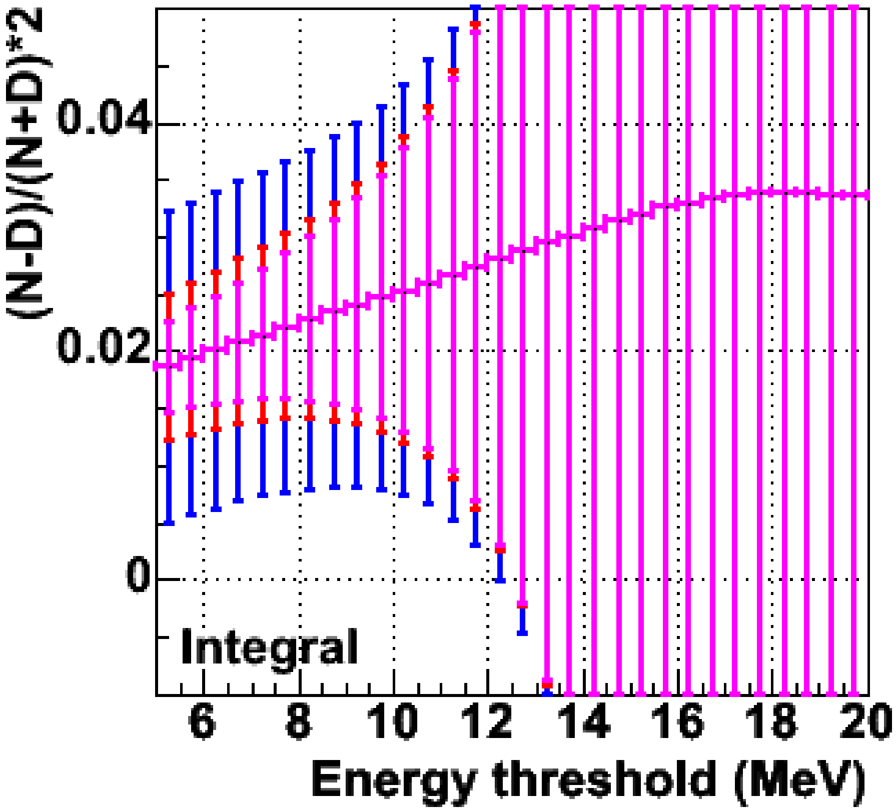
Day/night measurement by mega-ton detector

1 Mton year (0.5 Day & 0.5 Night) for no BG

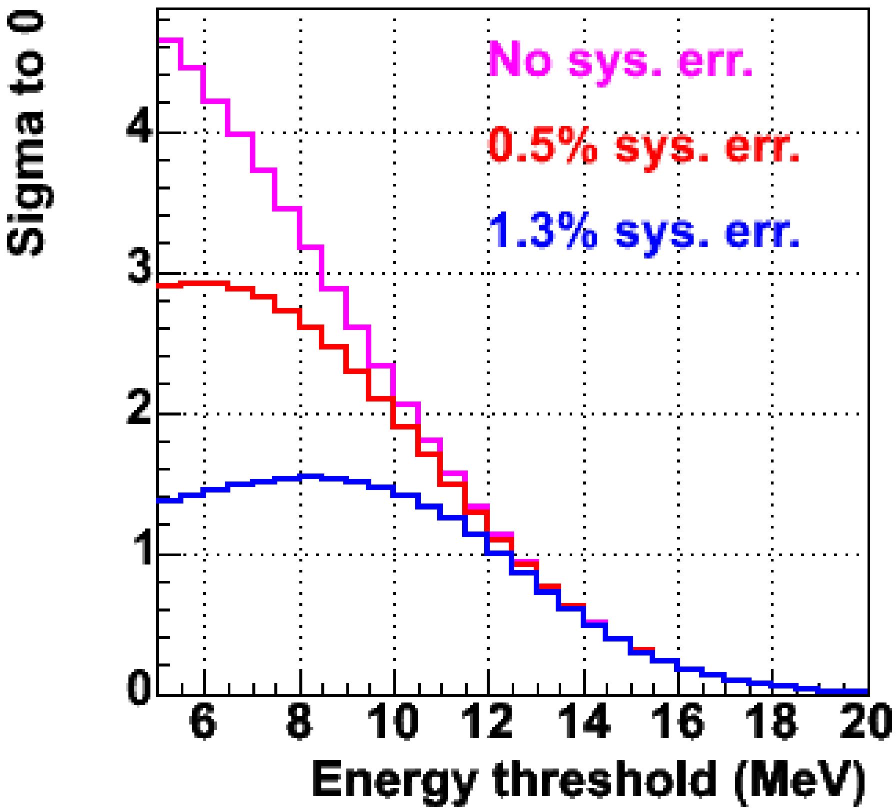
(2.4 Mton year (1.2 Day & 1.2 Night) for SK spallation B.G.)

$\Delta m^2 = 7.1\mathrm{x}10^{-5}\mathrm{eV}^2$, $\sin^2(\theta) = 0.28$

Day/night asymmetry



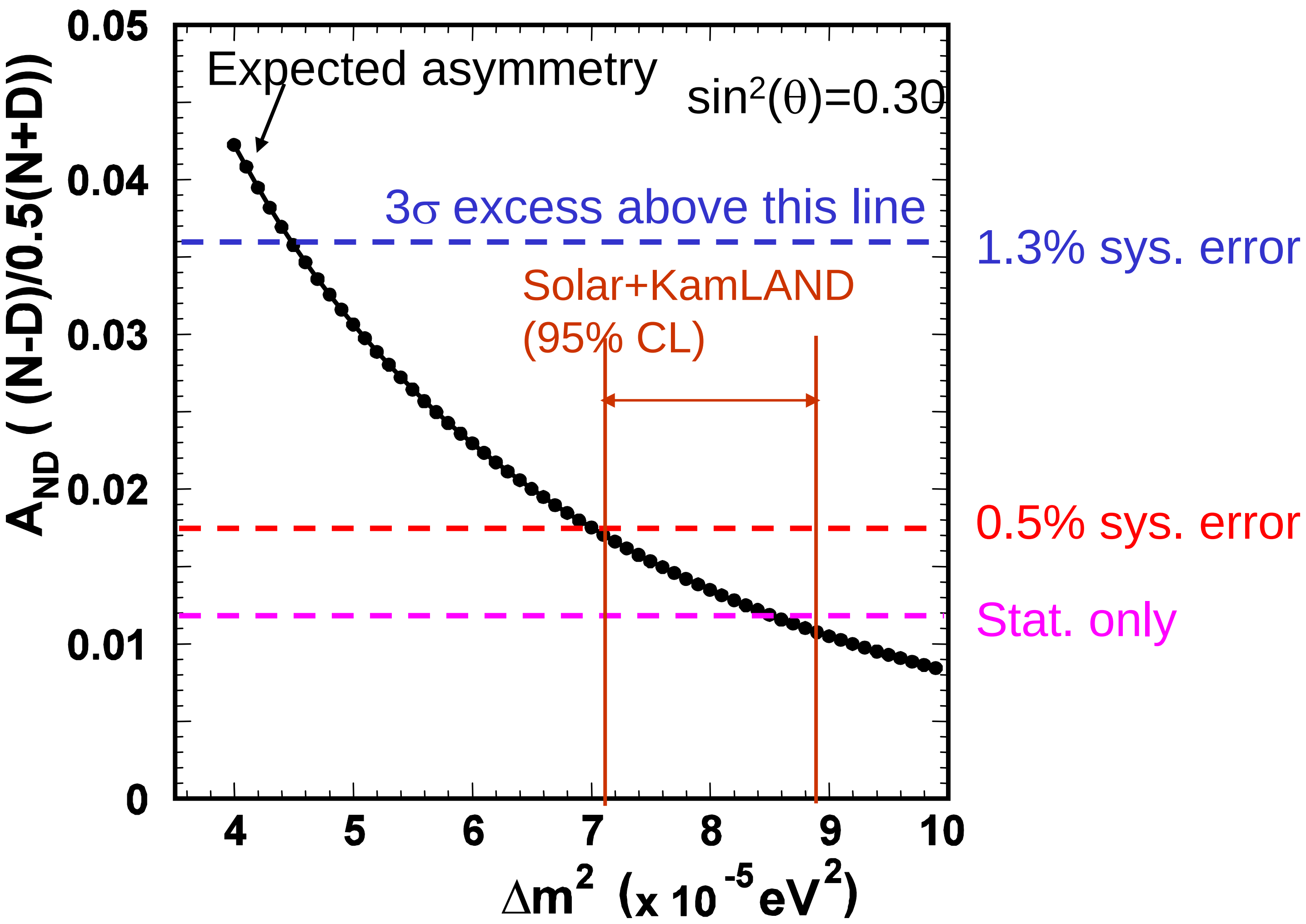
Statistical significance



3σ level can be achieved with 0.5% systematic error for this

Sensitivity of Day/Night Asymmetry

1 Mton year (0.5 Day & 0.5 Night) for no BG
(2.4 Mton year (1.2 Day & 1.2 Night) for SK spallation B.G.)

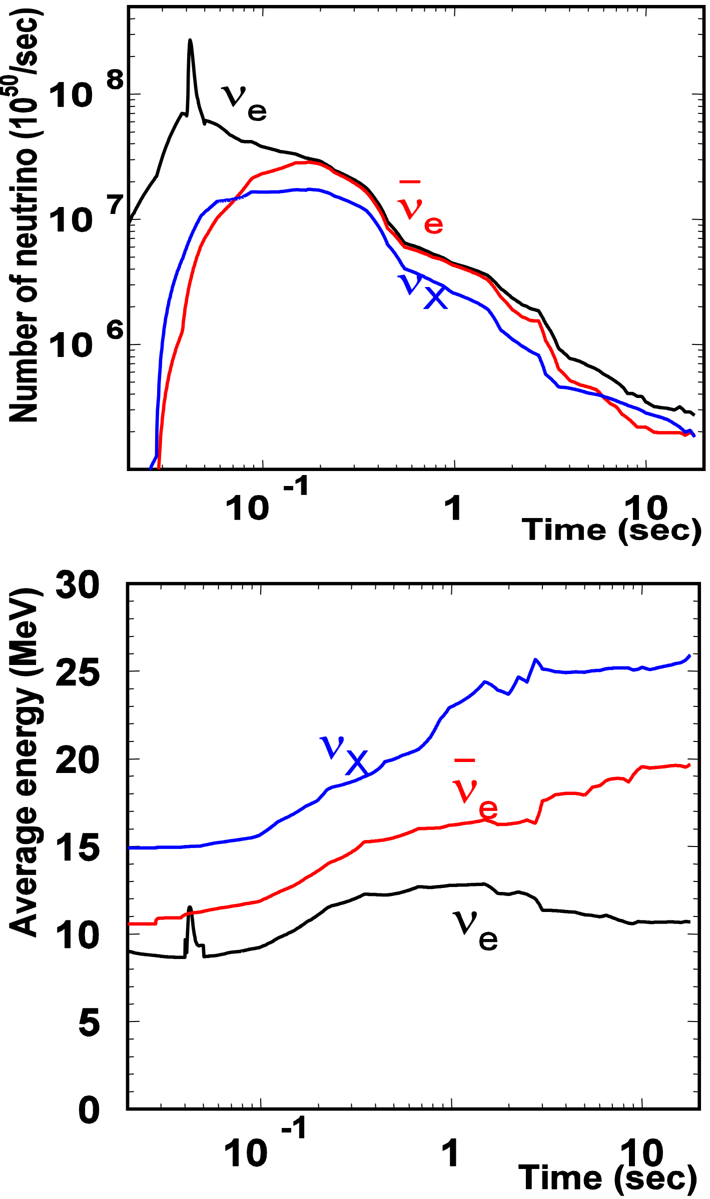


Systematic error must be less than

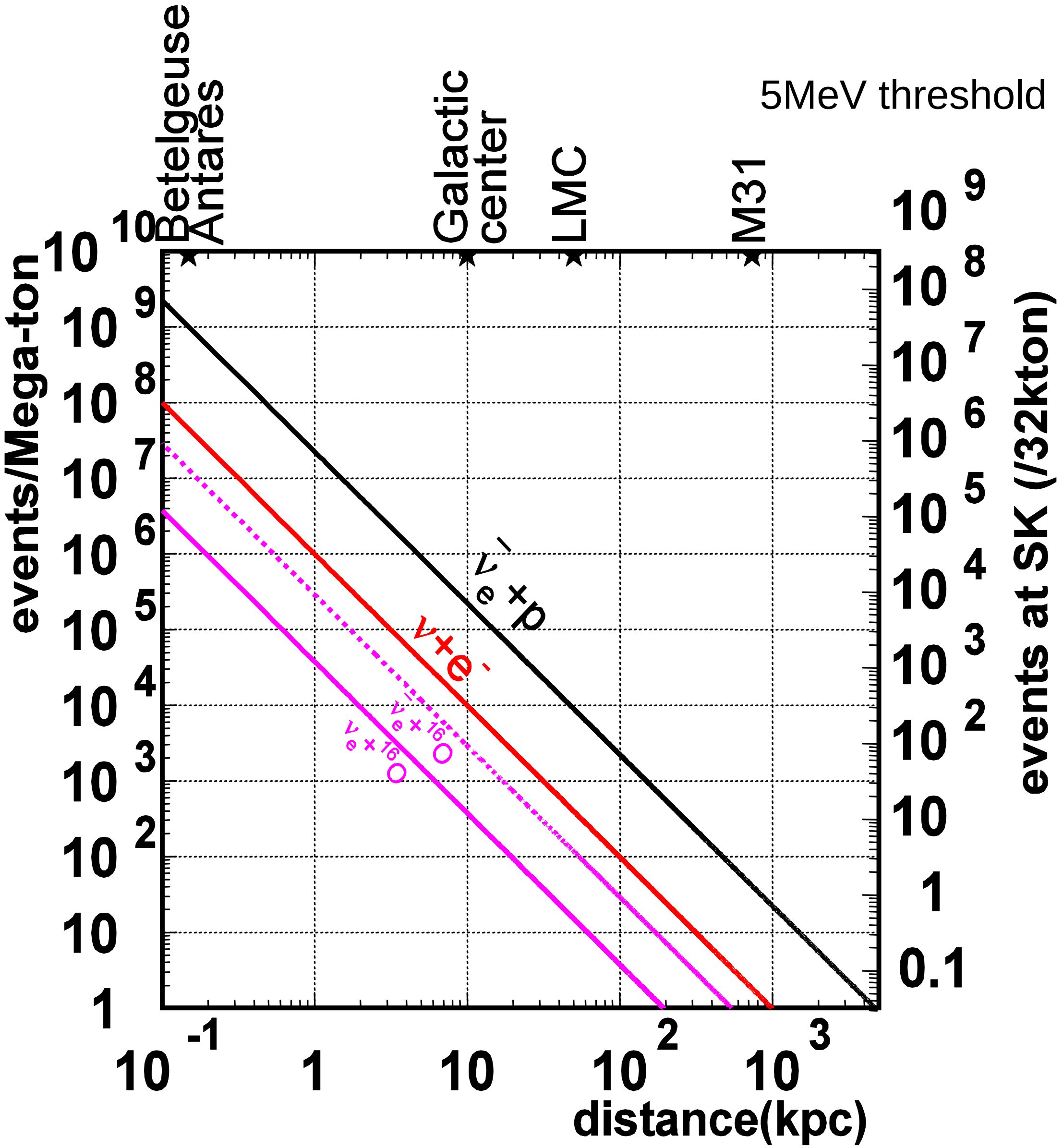
Supernova event rate in Mega-ton detector

Livermore simulation

(T.Totani et al., ApJ.496,216(1998))



Expected number of events

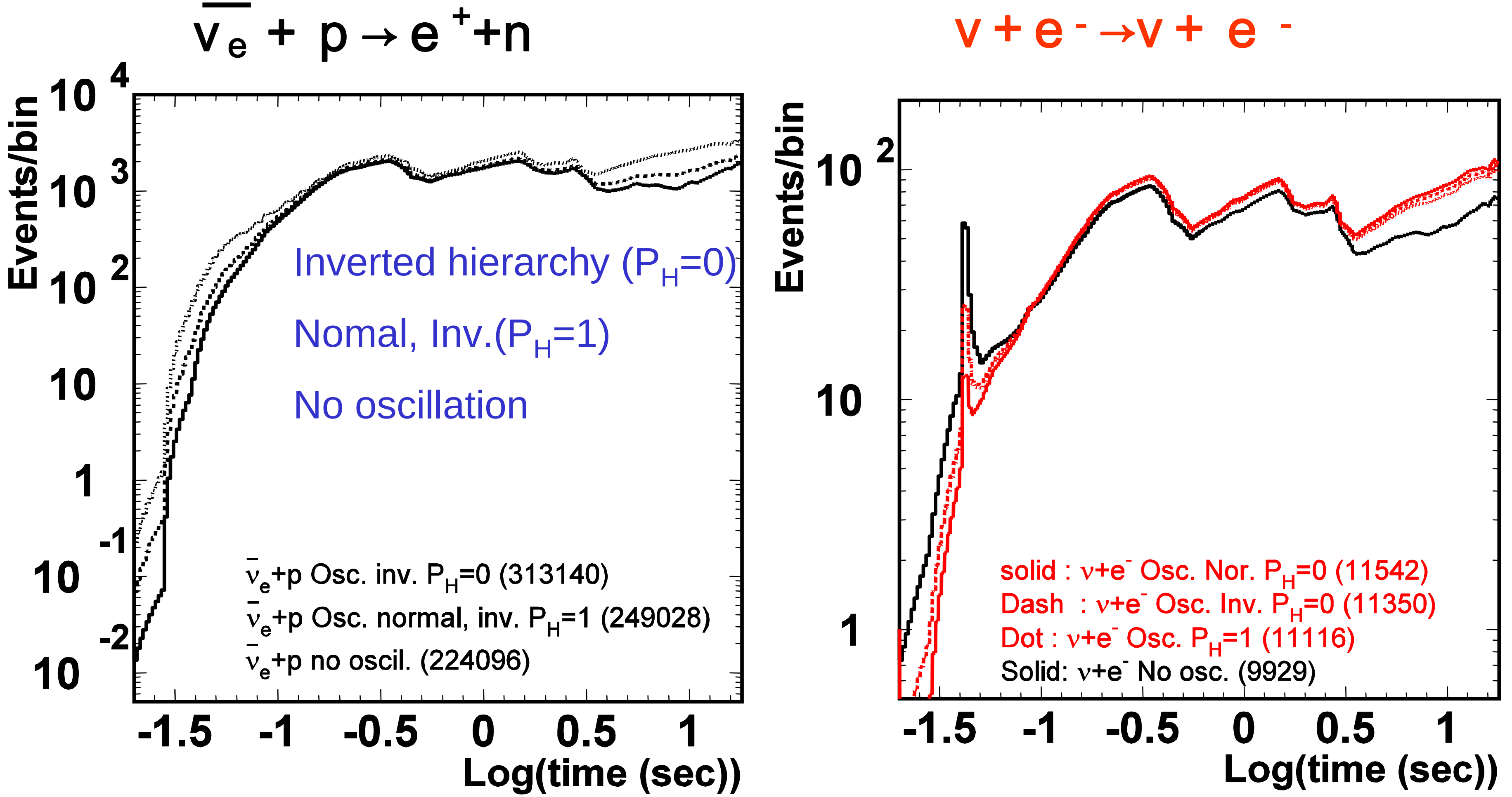


Time profile with neutrino oscillations

Total number of events in parentheses

SN at 10kpc, 1mega-ton

Time variation 200 log bins from 20msec to 18sec



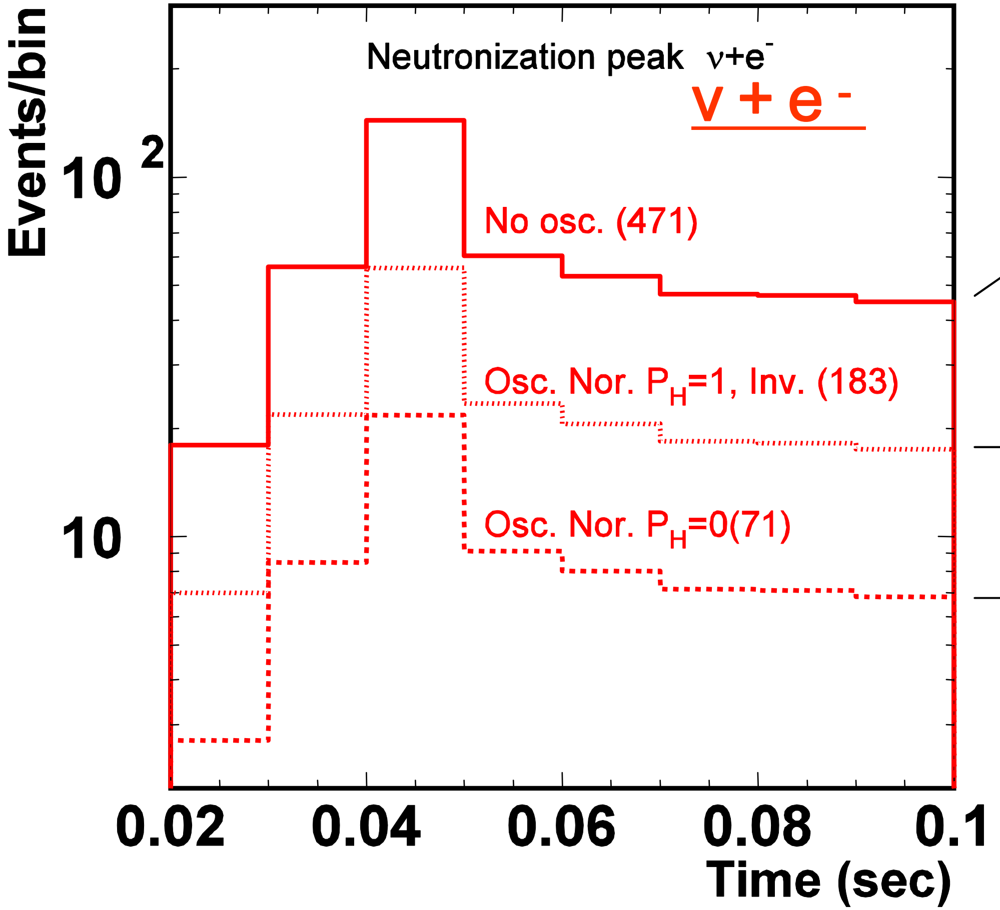
P_H: crossing probability at H resonance

(P_H=0: adiabatic)

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

SN at 10kpc, 1mega-ton

Number of events from 20msec to 0.1 sec (1bin=10msec)



No oscillation

Normal P_H=1 or
Inverted hierarchy

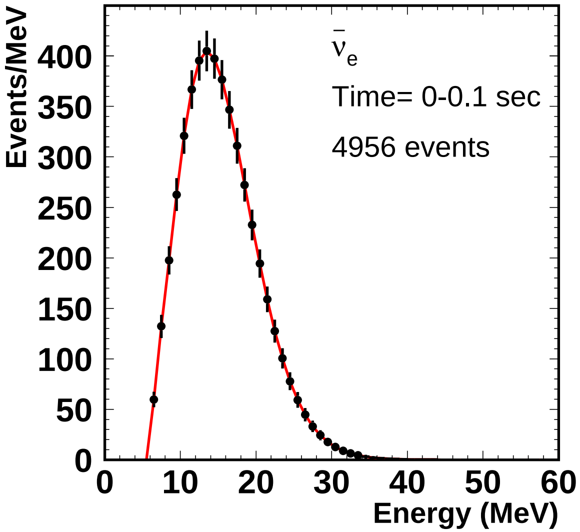
Normal hierarchy P_H=0

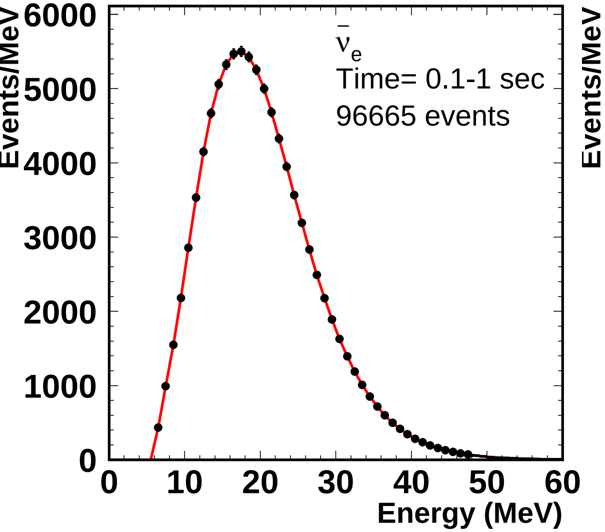
Neutronization burst can be observed even with neutrino oscillations.

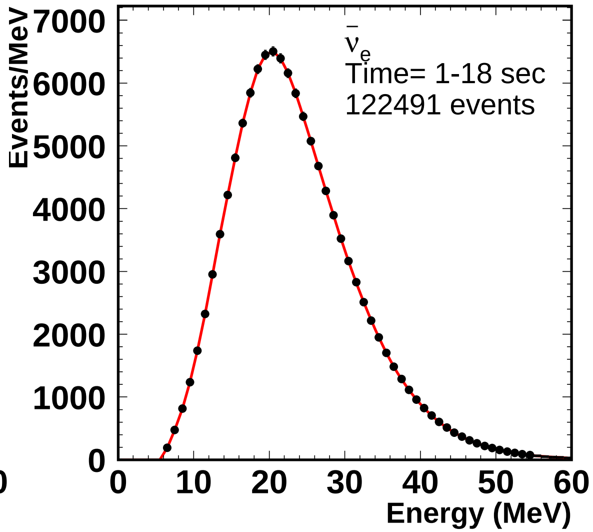
$\bar{\nu}_e$ energy spectrum measurement

SN at 10kpc, 1mega-ton

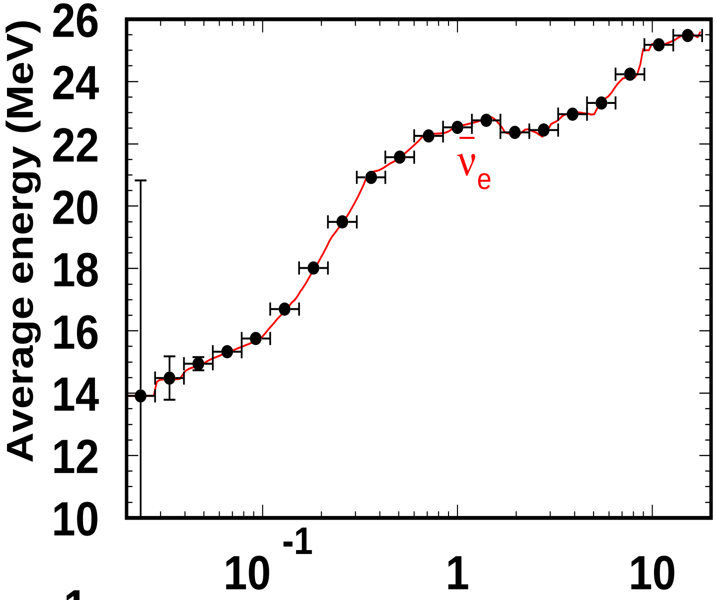
Visible energy spectrum in each time range range

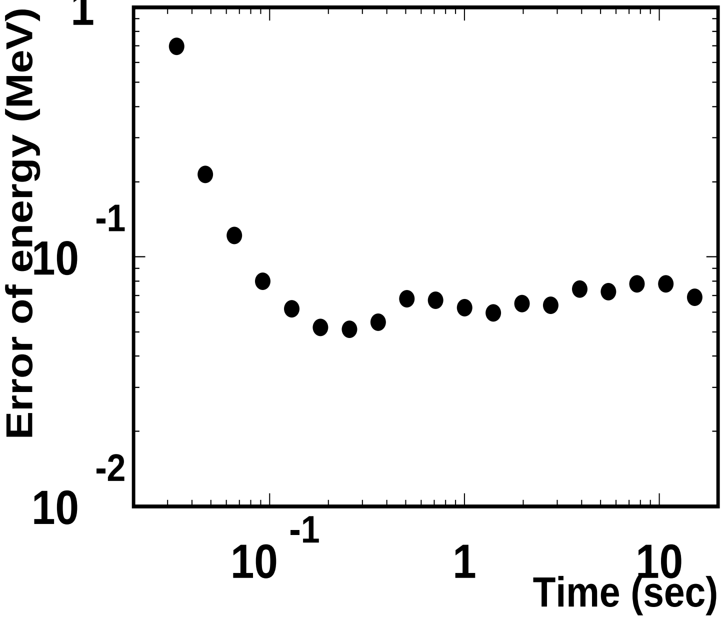




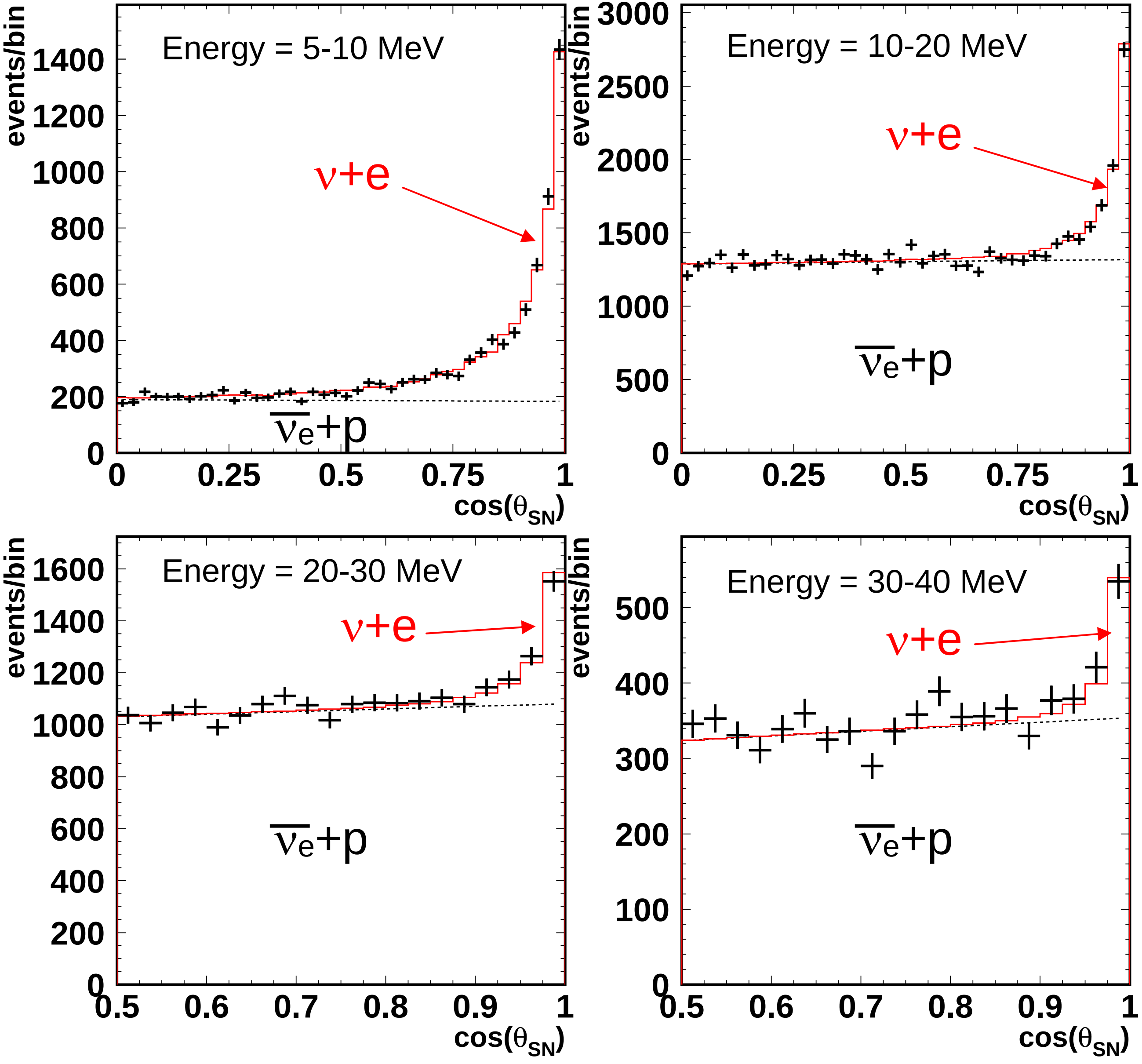


Time variation of average energy





Identification of νe scattering events by direction to supernova

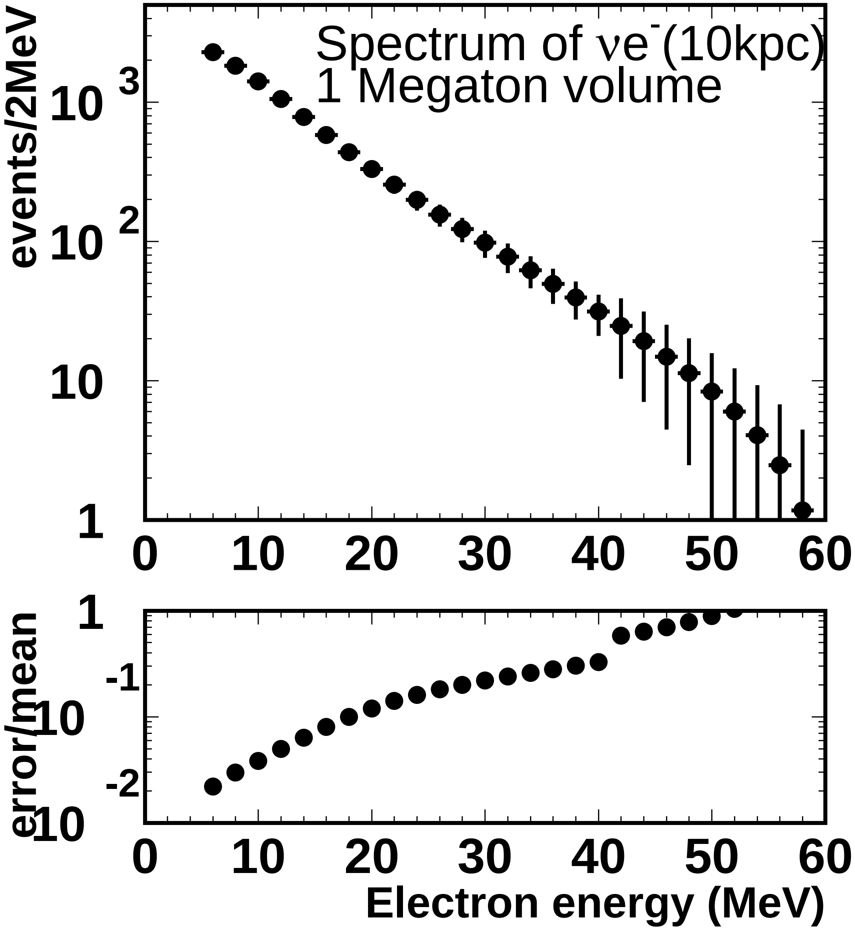


SN at 10kpc,
1 mega-ton

νe scattering events can be statistically extracted using the direction to supernova.

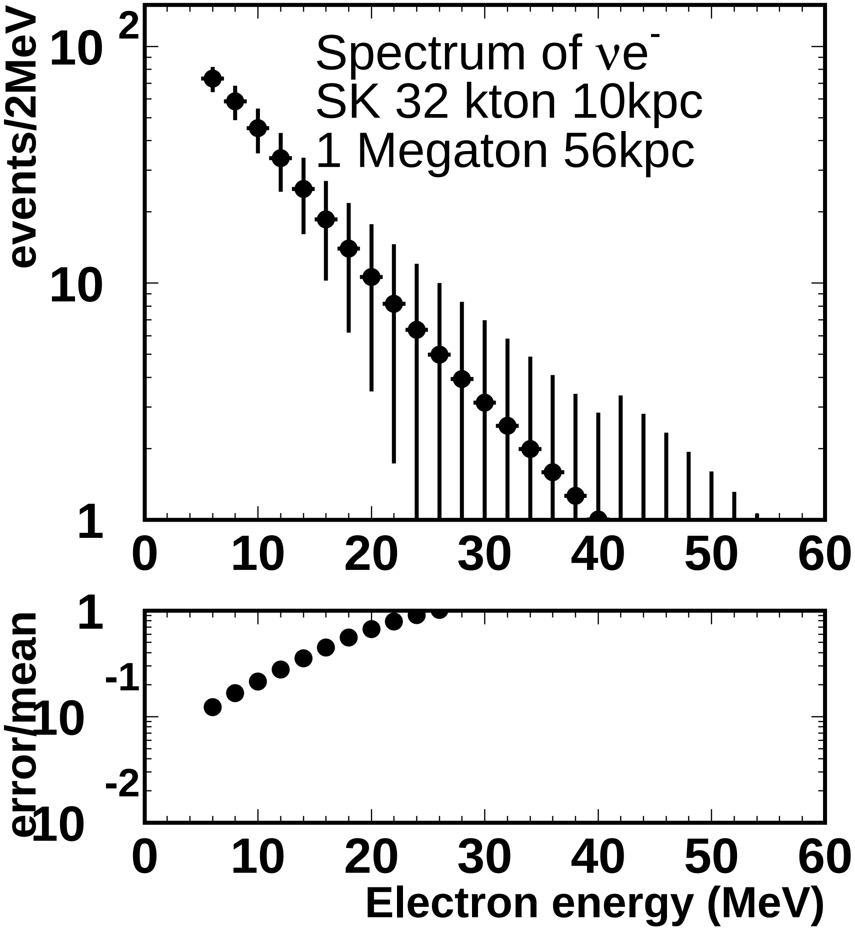
$\nu_e+\nu_x$ spectrum measurement by νe scattering

10kpc, 1 Mega-ton



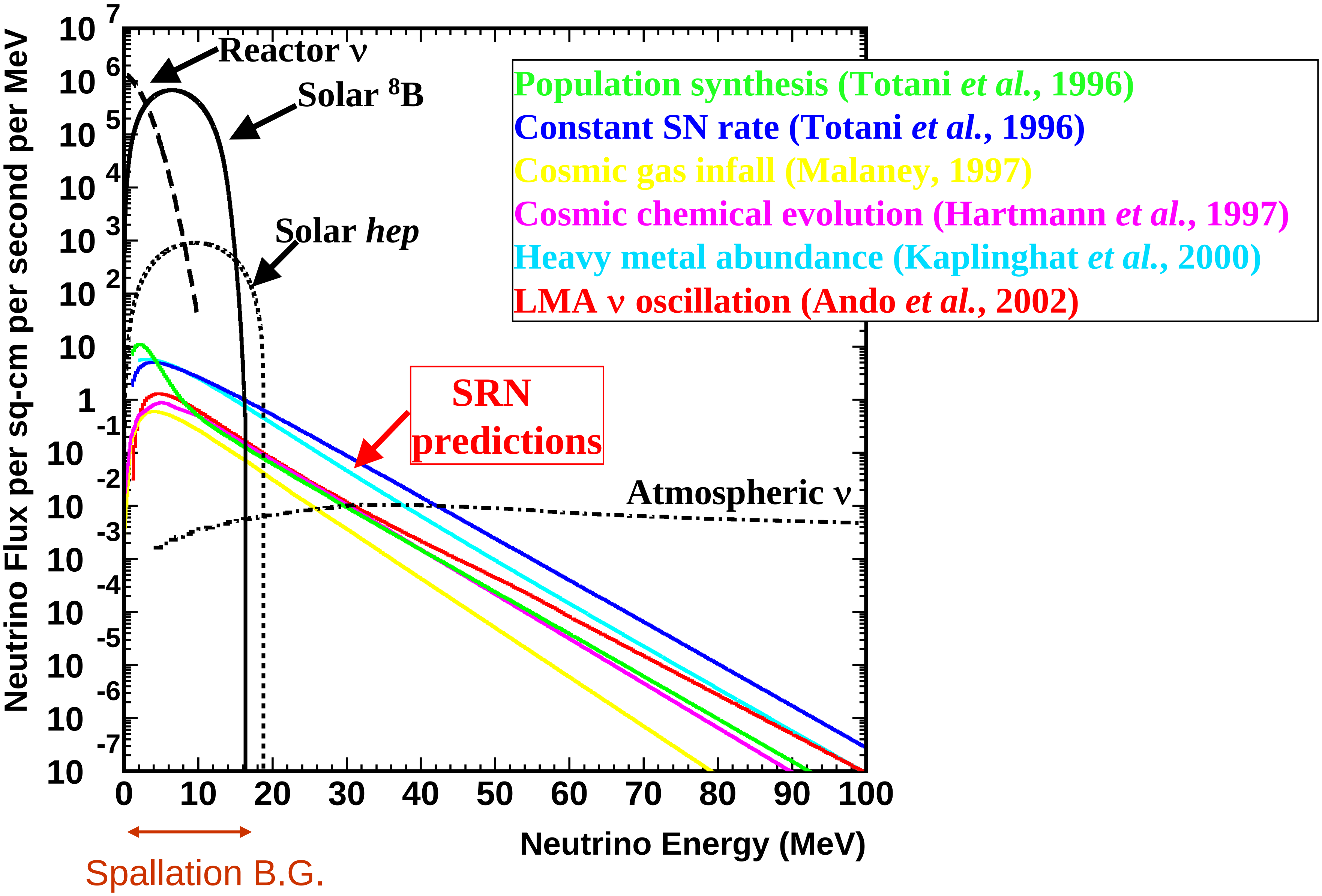
Spectrum measurement up to ~40MeV.

56kpc, 1 Mega-ton



Spectrum measurement up to ~20MeV.

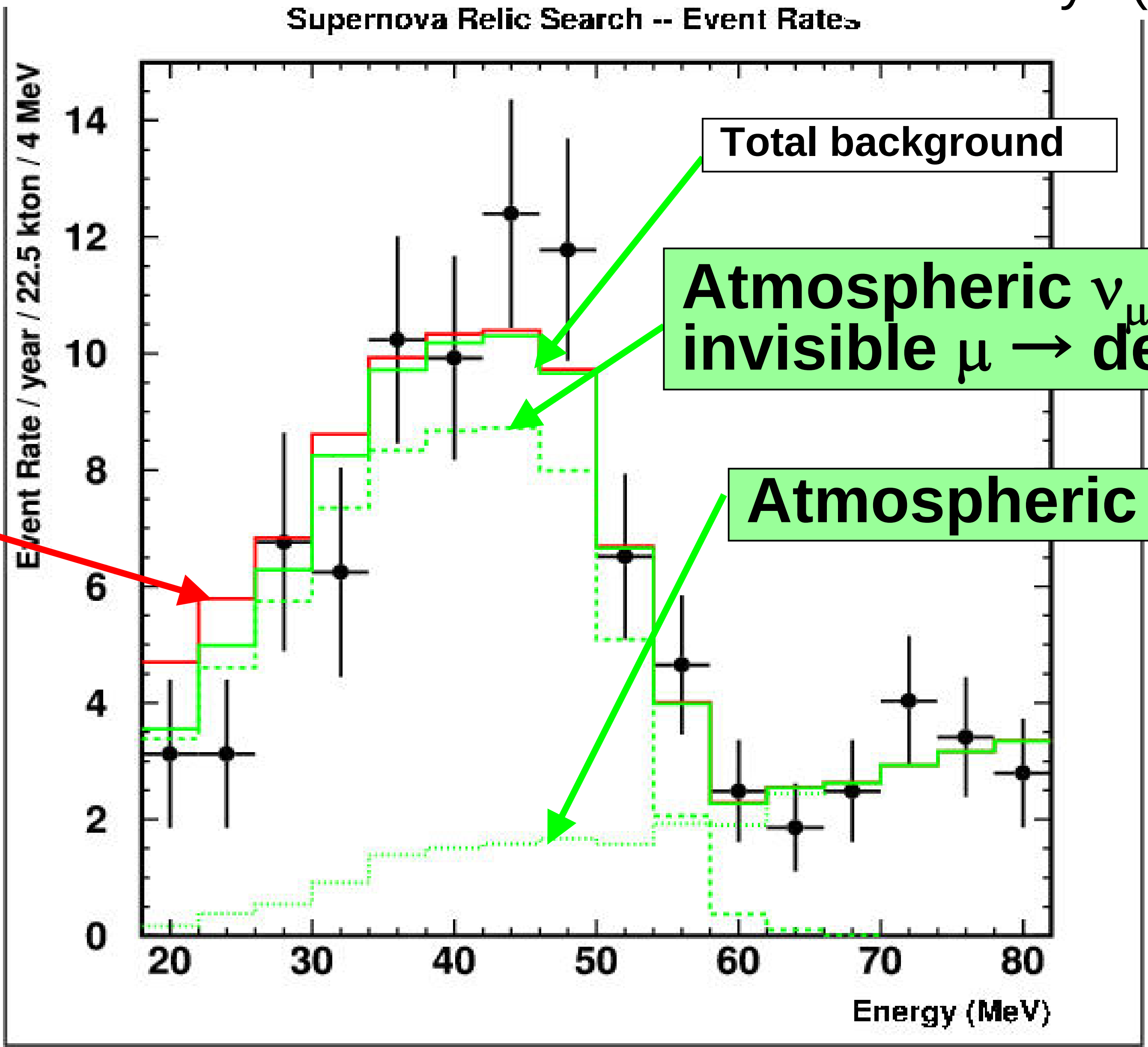
Search for supernova relic neutrinos(SRN)



SRN search in SK-I

Energy spectrum above 18 MeV

1496 days (SK-I)



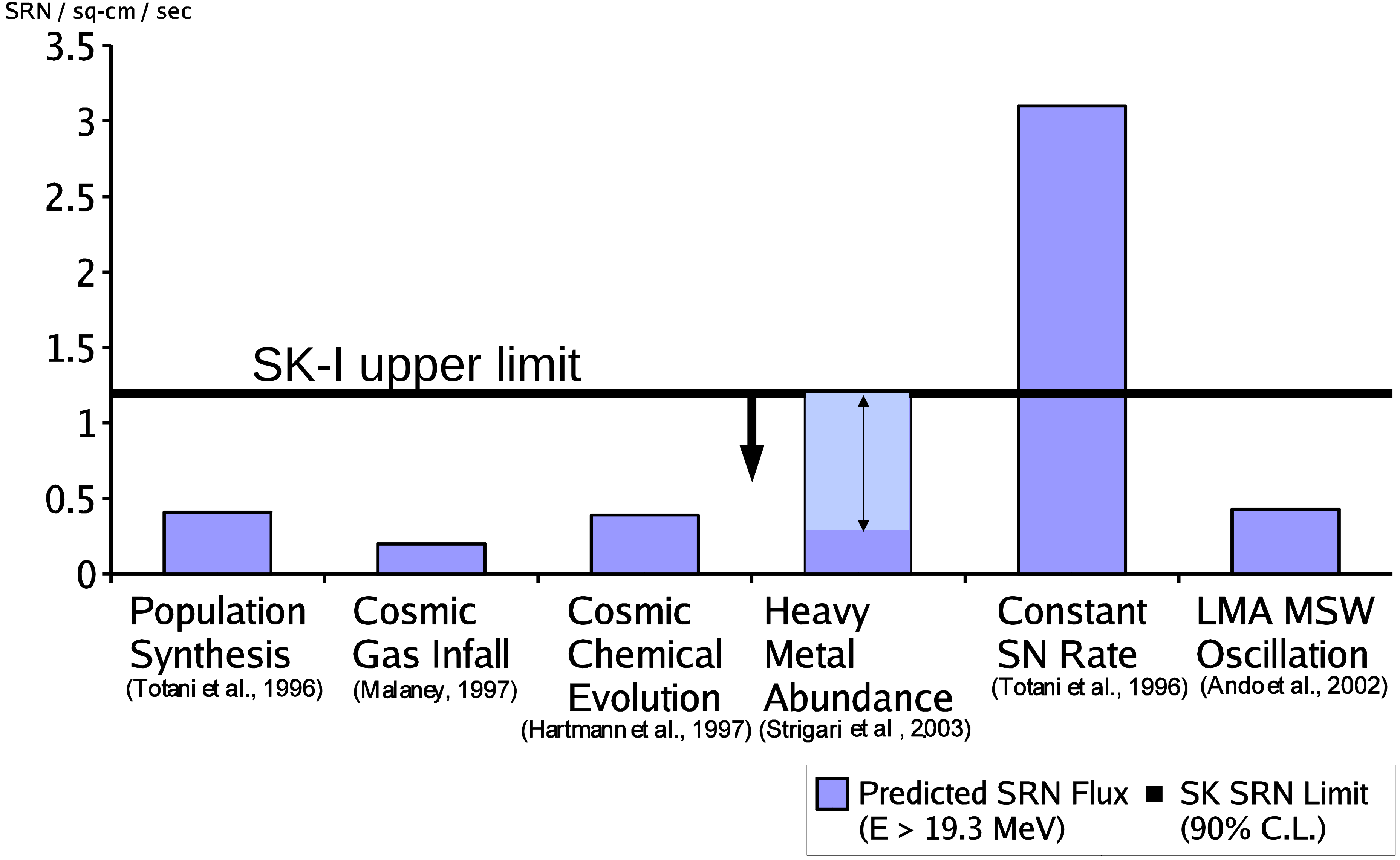
Total background

Atmospheric $\nu_\mu \rightarrow$ invisible $\mu \rightarrow$ decay e

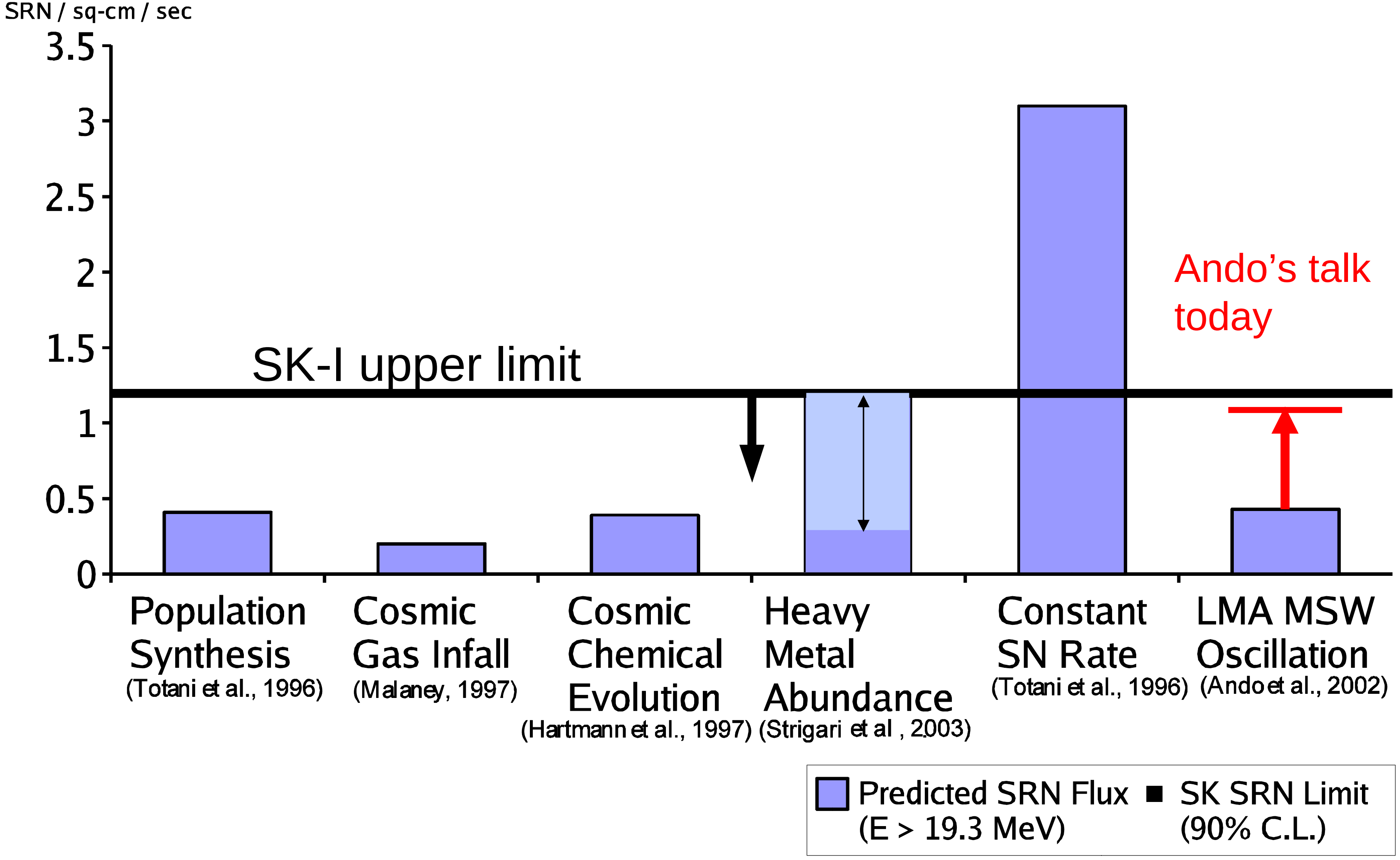
Atmospheric ν_e

90% CL limit of SRN

SK SRN Flux Limits vs. Theoretical Predictions
(E_ν> 19.3 MeV)

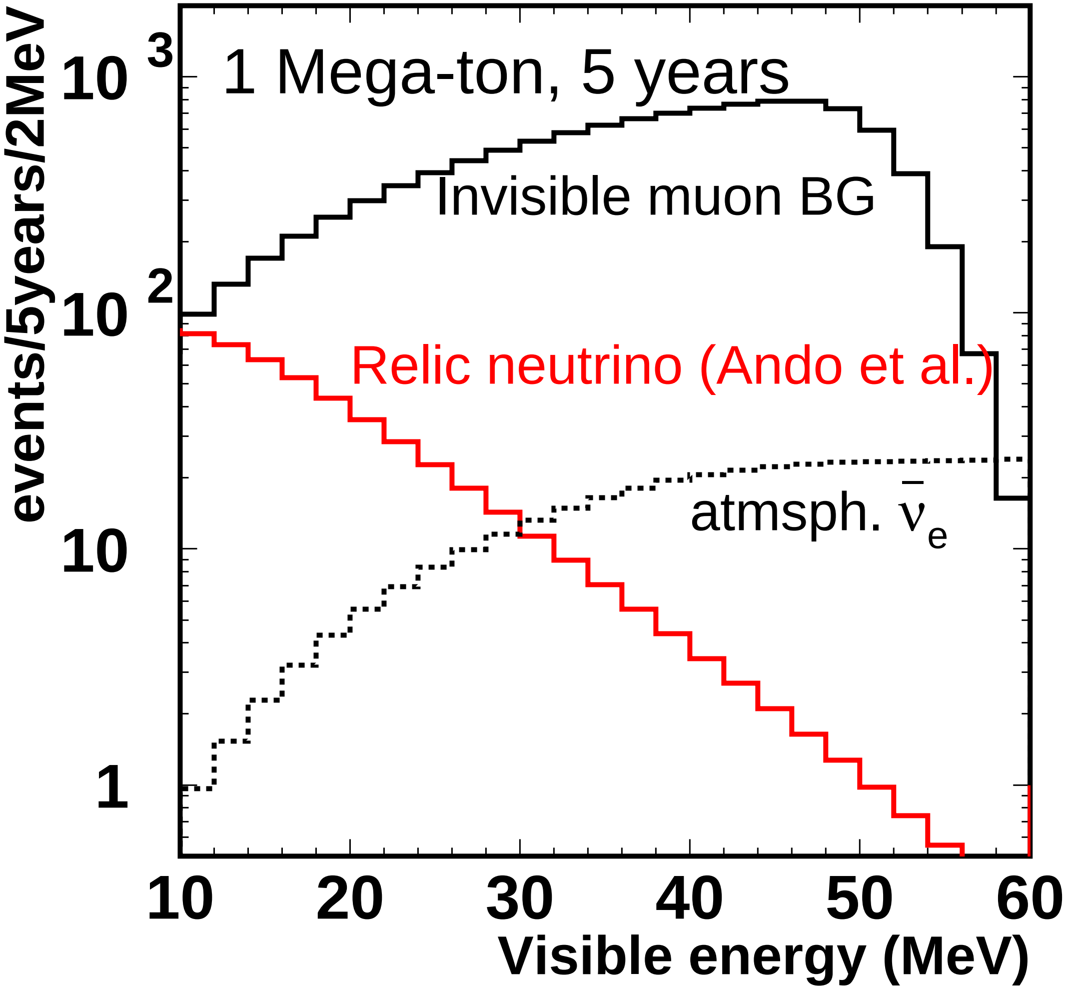


SK SRN Flux Limits vs. Theoretical Predictions
(E_ν> 19.3 MeV)



SRN event rate in Mega-ton detector

Relic model: S.Ando, K.Sato, and T.Totani, Astropart.Phys.18, 307(2003).



SRN signal:
~630
(Ando's talk today)

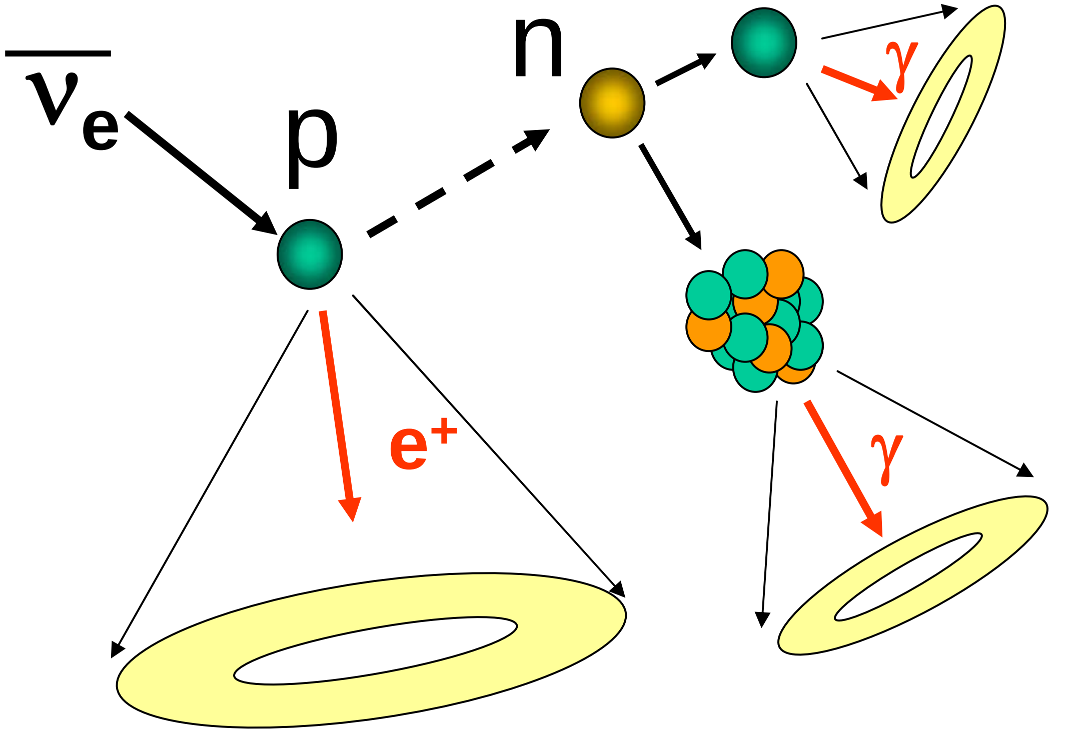
~~**SRN signal: 246**~~

Background: 2518

in 15-30 MeV

Invisible muon BG must be reduced.

Possibilities of $\overline{\nu}_e$ tagging



Positron and gamma ray vertices are within ~50cm.

Possibility 1

n+p→d + γ

2.2MeV γ-ray

ΔT = ~ 200 μsec

Nhit=~6 for 40% coverage and 20% peak QE

Possibility 2

n+Gd →~8MeV γ

ΔT = several 10th μsec

(→ M.Vagins’ talk)

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

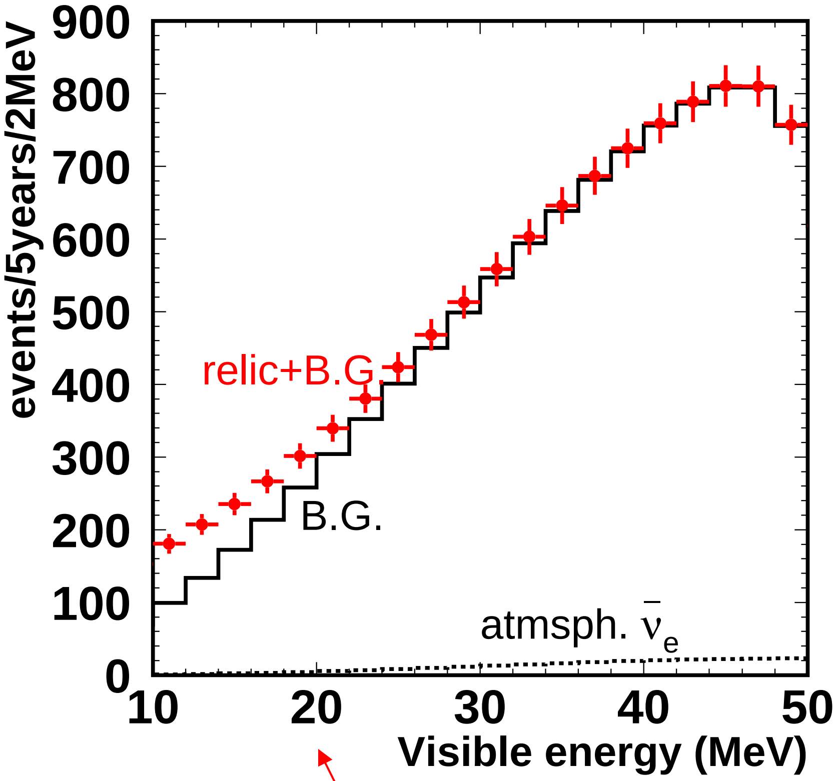
Possibility of SRN detection

Relic model: S.Ando, K.Sato, and T.Totani, Astropart.Phys.18, 307(2003).

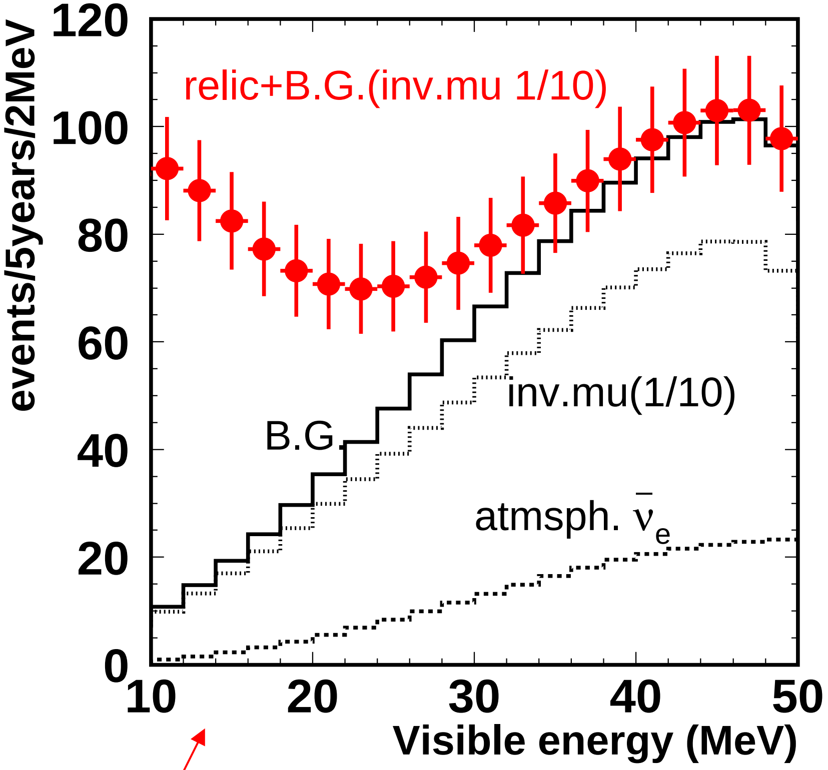
Signal yield will be factor ~2.6 larger if today's Ando's value is used.

1 Mega-ton, 5 years

No B.G. reduction



B.G. reduction by neutron tagging



Statistically 4.6σ excess
(E_{vis} > 15 MeV)

Assuming 90% of invisible muon B.G. can be reduced by neutron tagging.

Conclusions

- Precise measurements of ^{8}B solar neutrino spectrum and day/night asymmetry by Mega-ton detectors are still important for further study of solar neutrino oscillation.
- Quite high statistics of supernova events is expected for galactic supernova. It enables us to measure
  - Precise nu_e_bar spectrum and time variation
  - nu_e and nu_x spectrum measurement by νe scattering
- Expected number of SRN event is ~250/5yr/Megaton. Delayed coincidence method to tag nu_e_bar is important to discover SRN neutrinos.