Low-energy neutrino observation at Super-Kamiokande-III

Yasuo Takeuchi

Kamioka Observatory, ICRR, Univ. of Tokyo

Outline

- SK detector
- Update of the supernova neutrino observation in SK-I & SK-II
  - Supernova burst neutrino
  - Supernova relic neutrino NEW
- Solar neutrino observation in SK-III
  - Expected sensitivity
  - Current status NEW

Super-Kamiokande Collaboration

J.Hosaka,[1] K.Ishihara,[1] J.Kameda,[1] Y.Koshio,[1] A.Minamino,[1] C.Mitsuda,[1] M.Miura,[1] S.Moriyama,[1] M.Nakahata,[1] T.Namba,[1] Y.Obayashi,[1] M.Shiozawa,[1] Y.Suzuki,[1] A.Takeda,[1] Y.Takeuchi,[1] S.Yamada,[1] I.Higuchi,[2] M.Ishitsuka,[2] T.Kajita,[2] K.Kaneyuki,[2] G.Mitsuka,[2] S.Nakayama,[2] H.Nishino,[2] A.Okada,[2] K.Okumura,[2] C.Saji,[2] Y.Takenaga,[2] S.Clark,[3] S.Desai,[3,*] E.Kearns,[3] S.Likhoded,[3] J.L.Stone,[3] L.R.Sulak,[3] W.Wang,[3] M.Goldhaber,[4] D.Casper,[5] J.P.Cravens,[5] W.R.Kropp,[5] D.W.Liu,[5] S.Mine,[5] C.Regis,[5] M.B.Smy,[5] H.W.Sobel,[5] C.W.Sterner,[5] M.R.Vagins,[5] K.S.Ganezer,[6] J.E.Hill,[6] W.E.Keig,[6] J.S.Jang,[7] J.Y.Kim,[7] I.T.Lim,[7] K.Scholberg,[8] C.W.Walter,[8] R.Wendell,[8] R.W.Ellsworth,[9] S.Tasaka,[10] E.Guillian,[11] A.Kibayashi,[11] J.G.Learned,[11] S.Matsuno,[11] M.D.Messier,[12] Y.Hayato,[13,†] A.K.Ichikawa,[13] T.Ishida,[13] T.Ishii,[13] T.Iwashita,[13] T.Kobayashi,[13] T.Nakadaira,[13] K.Nakamura,[13] K.Nitta,[13] Y.Oyama,[13] Y.Totsuka,[13] A.T.Suzuki,[14] M.Hasegawa,[15] I.Kato,[15,‡] H.Maesaka,[15] T.Nakaya,[15] K.Nishikawa,[15] T.Sasaki,[15] H.Sato,[15] S.Yamamoto,[15] M.Yokoyama,[15] T.J.Haines,[16,5] S.Dazeley,[17] S.Hatakeyama,[17] R.Svoboda,[17] E.Blaufuss,[18] J.A.Goodman,[18] G.W.Sullivan,[18] D.Turcan,[18] J.Cooley,[19] A.Habig,[20] Y.Fukuda,[21] T.Sato,[21] Y.Itow,[22] C.K.Jung,[23] T.Kato,[23] K.Kobayashi,[23] M.Malek,[23] C.Mauger,[23] C.McGrew,[23] A.Sarrat,[1,23] C.Yanagisawa,[23] N.Tamura,[24] M.Sakuda,[25] Y.Kuno,[26] M.Yoshida,[26] S.B.Kim,[27] J.Yoo,[27] T.Ishizuka,[28] H.Okazawa,[29] Y.Choi,[30] H.K.Seo,[30] Y.Gando,[31] T.Hasegawa,[31] K.Inoue,[31] J.Shirai,[31] A.Suzuki,[31] K.Nishijima,[32] H.Ishino,[33] Y.Watanabe,[33] M.Koshiba,[34] D.Kielczewska,[35,5] J.Zalipska,[35] H.G.Berns,[36] R.Gran,[36,20] K.K.Shiraishi,[36] A.Stachyra,[36] K.Washburn,[36] and R.J.Wilkes[36]

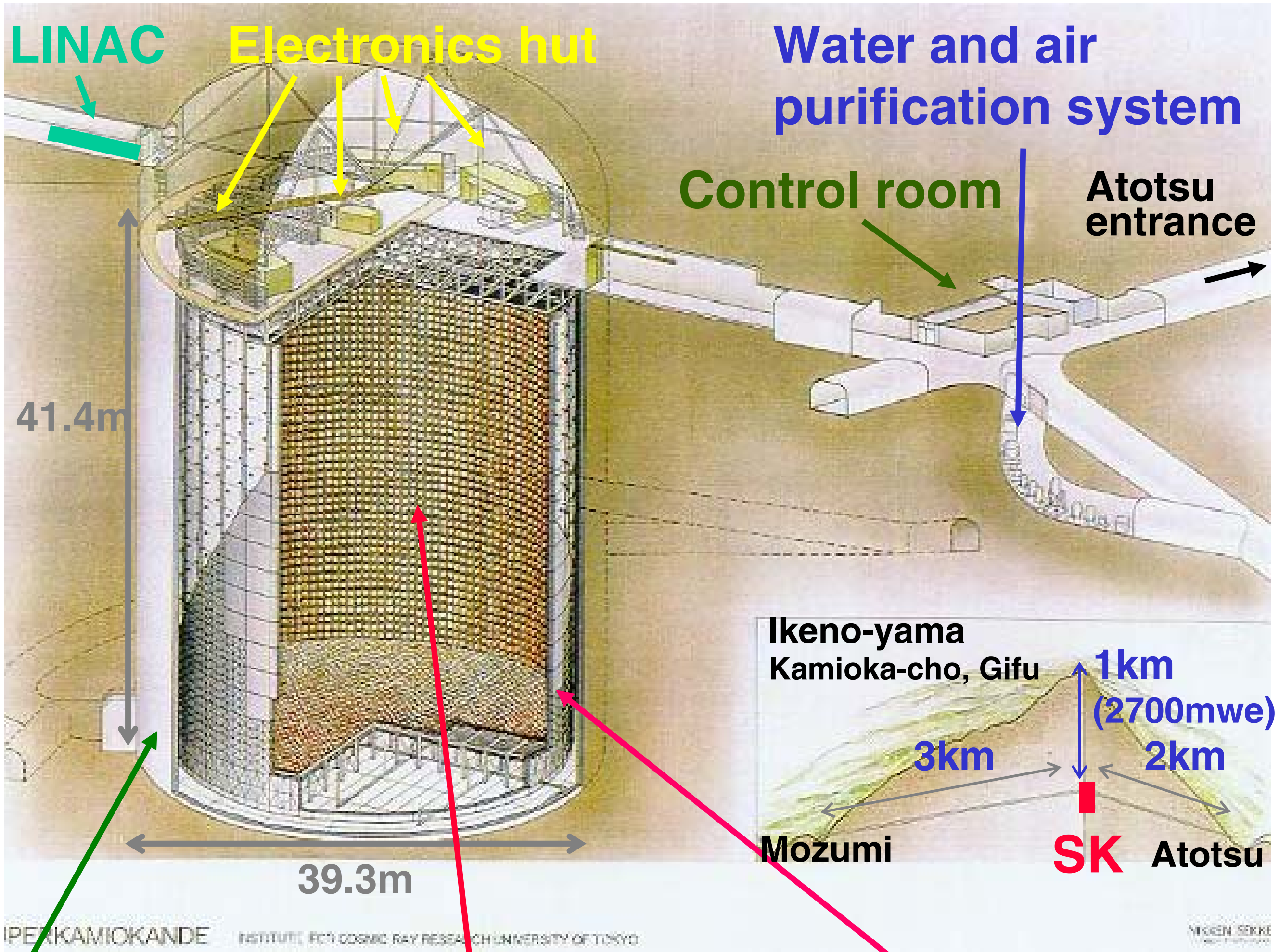
1 Kamioka Observatory, ICRR, Univ. of Tokyo, Japan
2 RCCN, ICRR, Univ. of Tokyo, Japan
3 Boston University, USA
4 Brookhaven National Laboratory, USA
5 University of California, Irvine, USA
6 California State University, Dominguez Hills, USA
7 Chonnam National University, Korea
8 Duke University, USA
9 George Mason University, USA
10 Gifu University, Japan
11 University of Hawaii, USA
12 Indiana University, USA
13 KEK, Japan
14 Kobe University, Japan
15 Kyoto University, Japan
16 Los Alamos National Laboratory, USA
17 Louisiana State University, USA
18 University of Maryland, College Park, USA
19 Massachusetts Institute of Technology, USA
20 University of Minnesota, Duluth, USA
21 Miyagi University of Education, Japan
22 Nagoya University, Japan
23 SUNY, Stony Brook, USA
24 Niigata University, Japan
25 Okayama University, Japan
26 Osaka University, Japan
27 Seoul National University, Korea
28 Shizuoka University, Japan
29 Shizuoka University of Welfrare, Japan
30 Sungkyunkwan University, Korea
31 RCNS, Tohoku University, Japan
32 Tokai University, Japan
33 Tokyo Institute for Technology, Japan
34 University of Tokyo, Japan
35 Warsaw University, Poland
36 University of Washington, USA

~130 collaborators
33 institutions
5 countries
(as of Sep. 2007)

Tsinghua Univ., China (June, 2005~)

Super-Kamiokande

NIM A501(2003)418



50000 ton
stainless steel tank

Inner Detector (ID)
11129 of 20 inch PMTs
(SK-III)

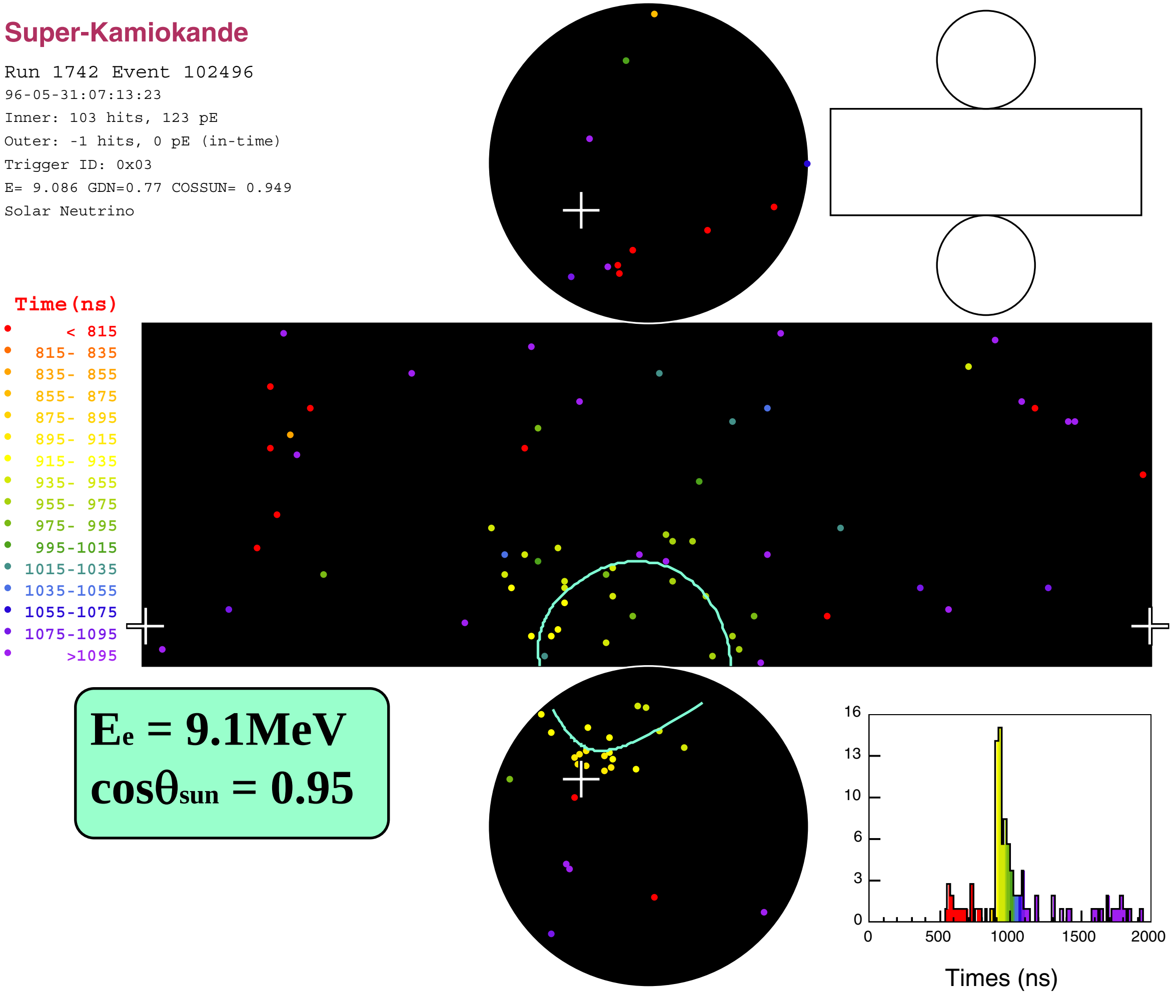
Outer Detector (OD)
1885 of 8 inch PMTs
(SK-III)

- SK-I (1996~2001)
- 50000ton water
- ~11200 of 20inch PMTs
- Fid. vol. 22.5kt
- Photo coverage 40%
- Stopped by the accident in Nov. 2001

- SK-II (2002~2005)
- ~5200 of 20inch PMTs
- Photo coverage 19%

- SK-III (Jul. 2006~)
- 40% coverage
- OD Segmentation

Typical low-energy event



$E_e = 9.1\text{MeV}$
$\cos\theta_{sun} = 0.95$

$\nu + e^- \rightarrow \nu + e^-$

(for solar neutrinos)

Sensitive to ν_e, ν_μ, ν_τ

$\sigma(\nu_{\mu(\tau)}e^-) =\sim 0.15\times\sigma(\nu_e e^-)$

- **Timing information**
  ➡ **vertex position**
- **Ring pattern**
  ➡ **direction**
- **Number of hit PMTs**
  ➡ **energy**

Resolutions (for 10MeV electron in SK-I)
Energy: 14% **Vertex: 87cm** **Direction: 26°**

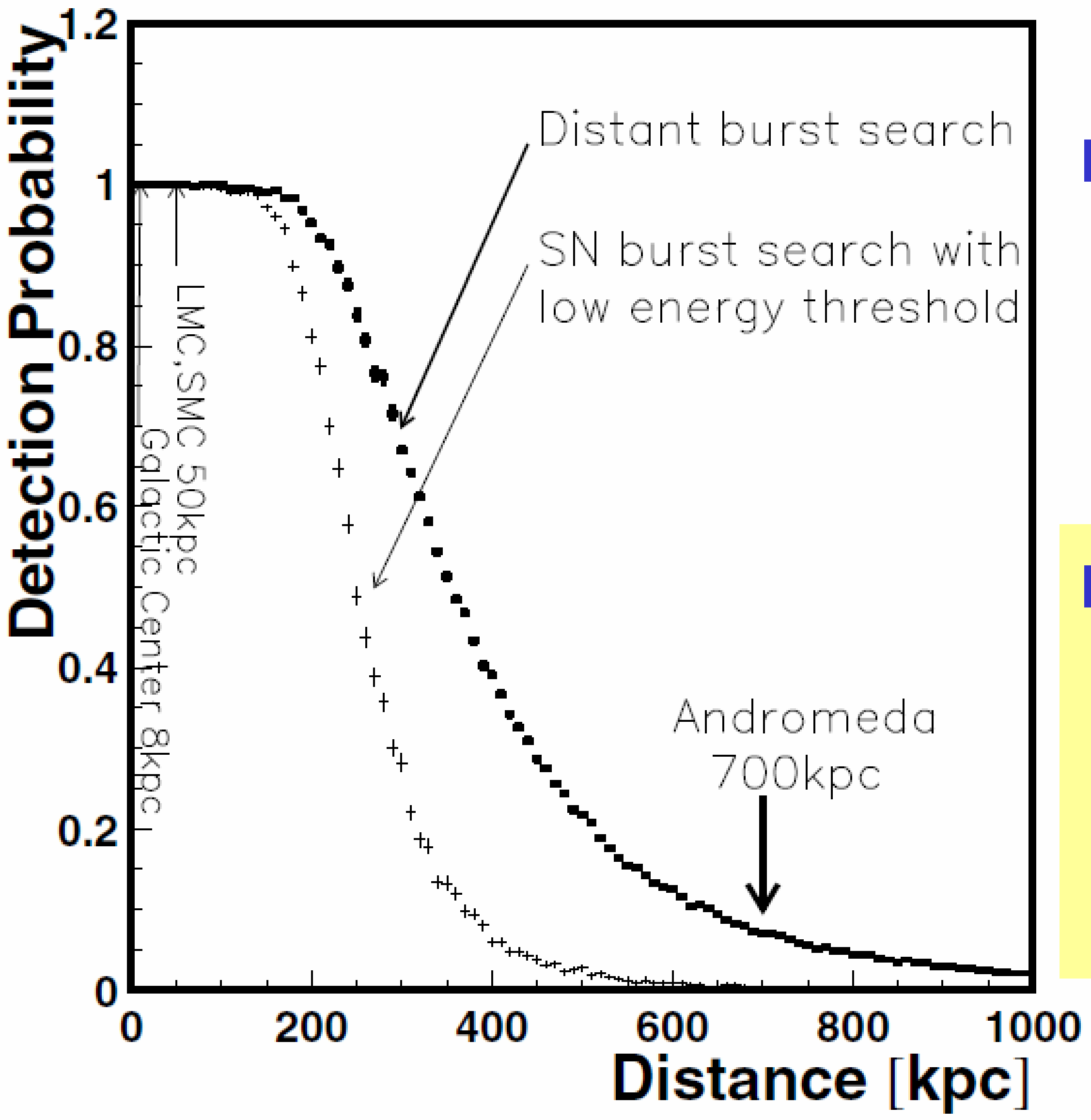
Supernova neutrinos

Supernova burst neutrino

(arXive:0706.2283 [hep-ex], accepted by ApJ)

- Live time: 2589.2 days in SK-I and SK-II
- R_{mean}>10m (average distance among vertices)
  - To reject spallation events, flasher events, etc.
- 3 searches are done in SK-I and SK-II
  - Distant search
    - 2 events / 20sec., E >17MeV
  - Low-energy threshold search
    - 3ev/0.5sec, 4ev/2sec, or 8ev/10sec.
    - E > 6.5MeV (SK-I) or 7MeV (SK-II)
  - Neutronization burst search
    - 2ev/1msec, 2ev/10msec, or 2ev/100msec.
    - ν_e-e scattering with direction cut
- No significant burst was found

Supernova burst neutrino



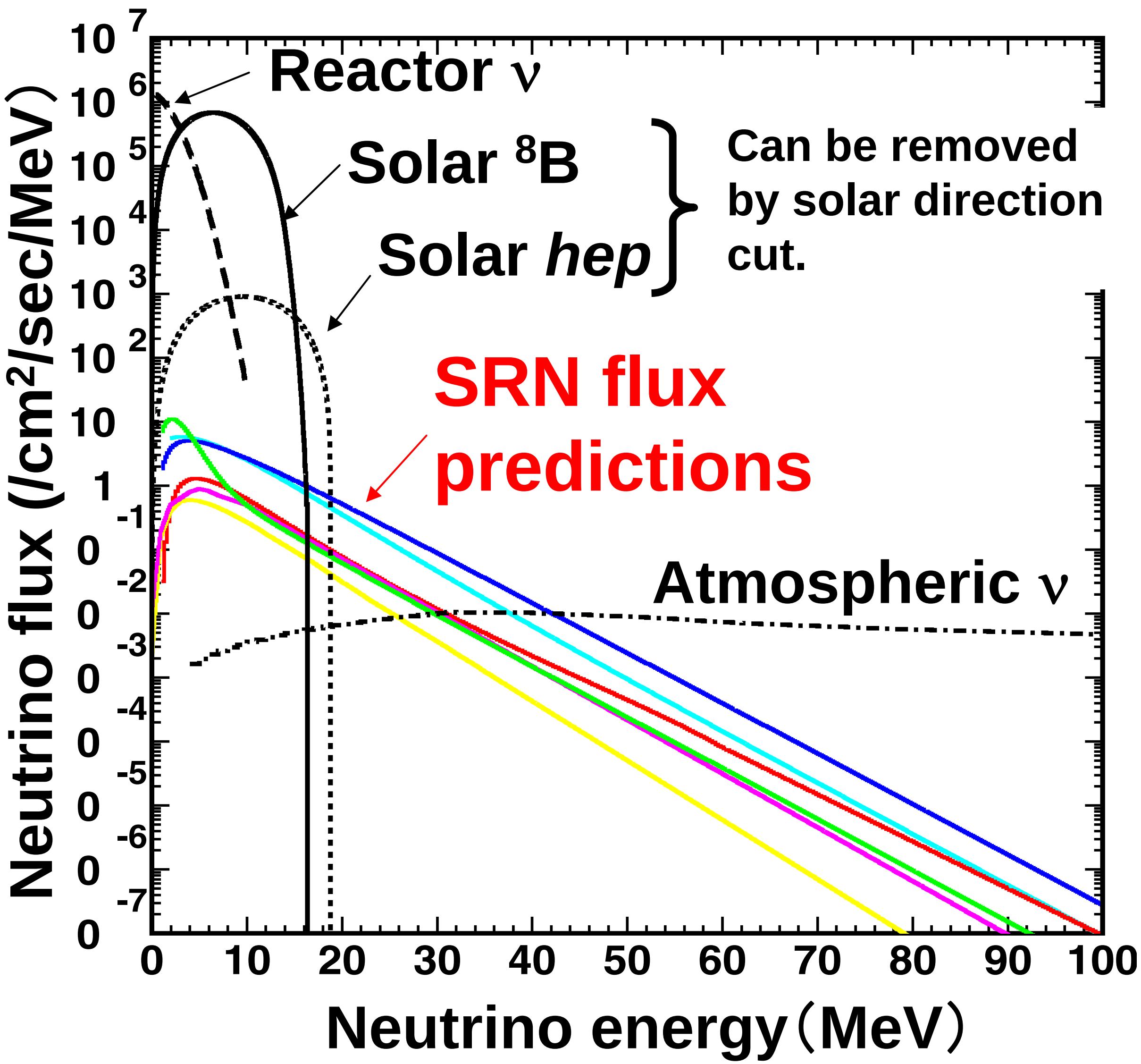
- ~10% probability at Andromeda was achieved in the distant search

- Upper limit: (90%CL)

  0.32 SN/year in100kpc

Supernova relic neutrino

Previous analysis in SK-I: PRL90(2003)061101



- **Reaction in SK:**

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

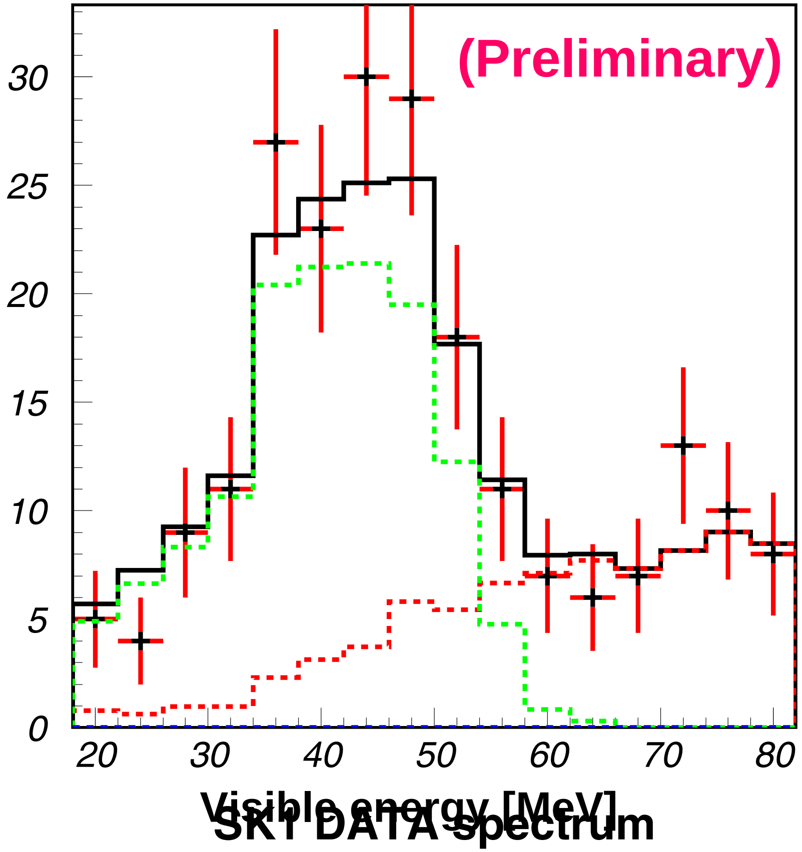
- **SRN measurement will enable us to investigate the history of past supernova. For example, the flux of SRN would show the star formation rate and supernova rate in galaxies.**

SRN observation in SK-I & II

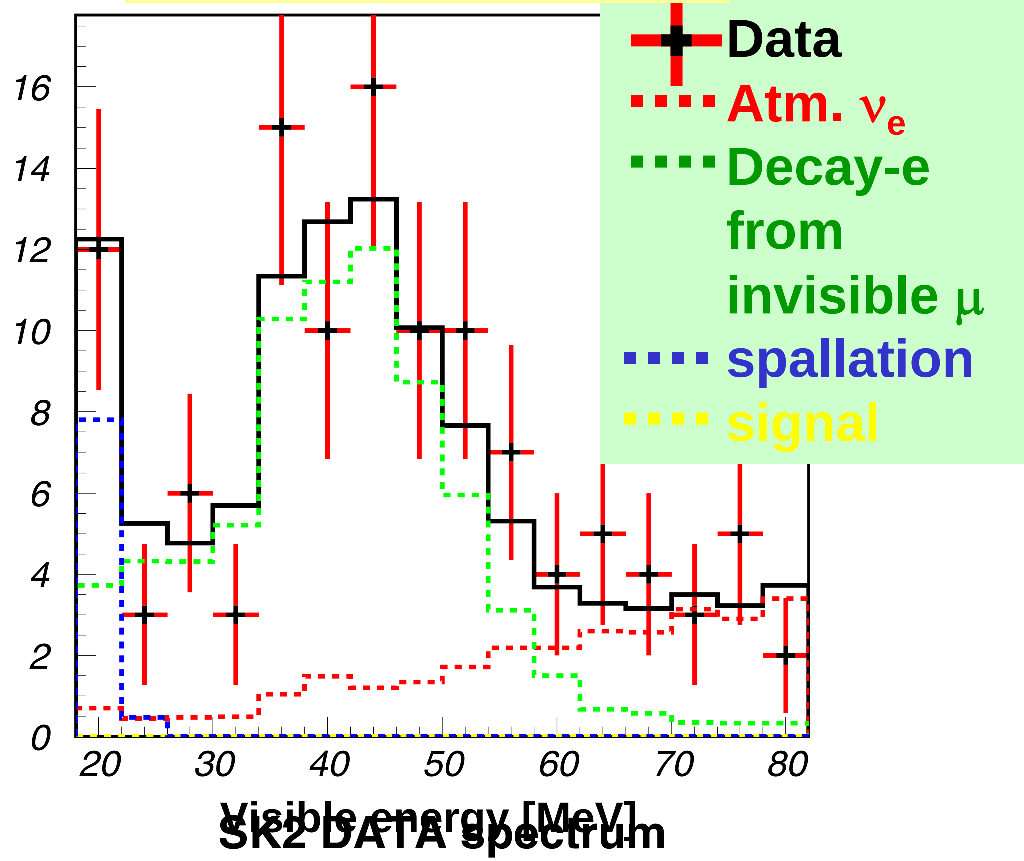
- The **latest analysis tools** are applied to both SK-I and -II
- Use **new cross section:** A.Strumia - F.Vissani PLB564 (2003)

Expected number of SRN event	SK-I: 5.7 event /1496days
	SK-II: 2.9 event /791days

SK-I new spectrum fit



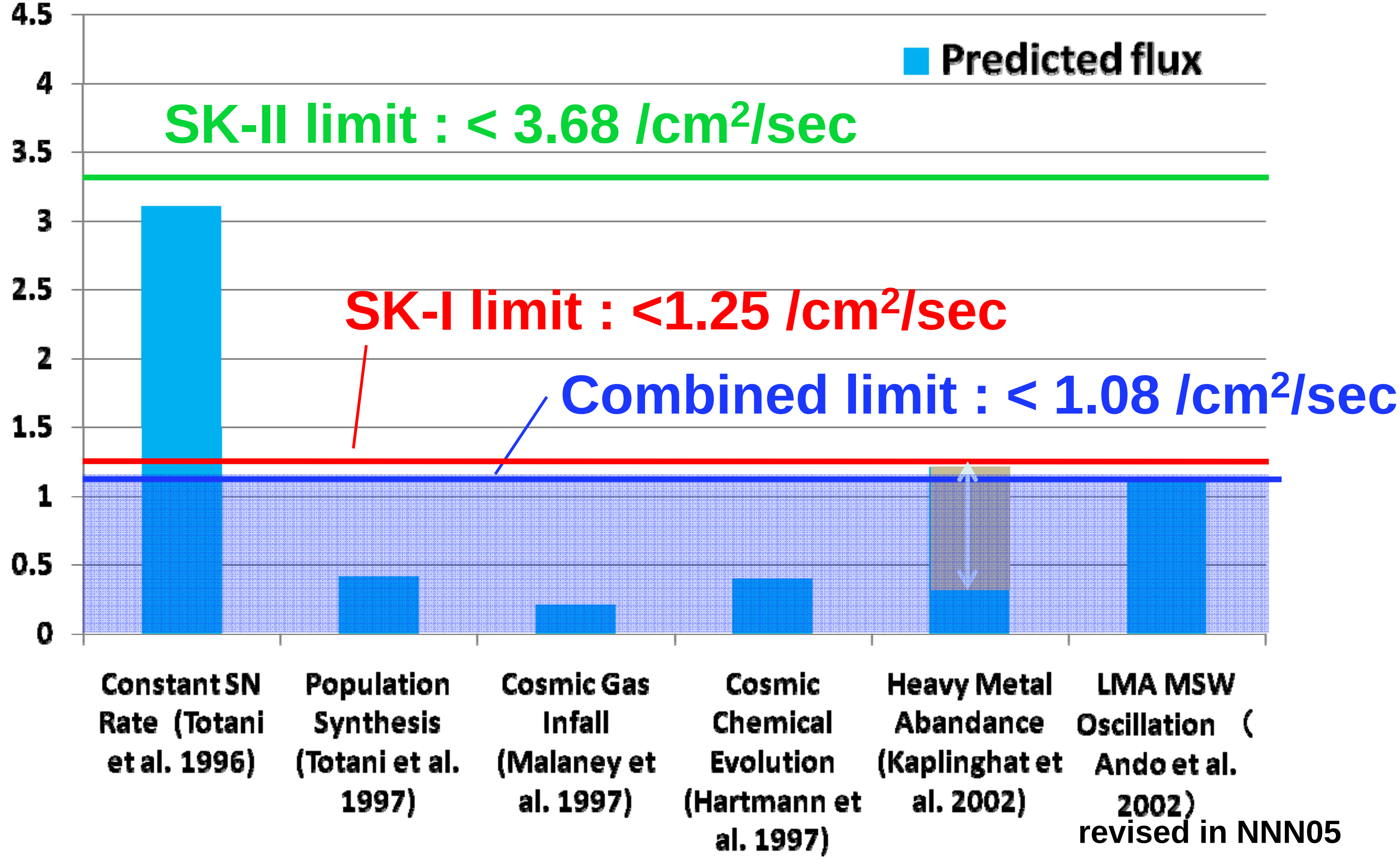
SK-II spectrum fit



SK flux limit vs predictions

- New flux limits (90%C.L.):
  SK-I : < 1.25 /cm^2 /sec
  SK-II : < 3.68 /cm^2/sec

SK-I + II: < 1.08 /cm^2/s
Preliminary

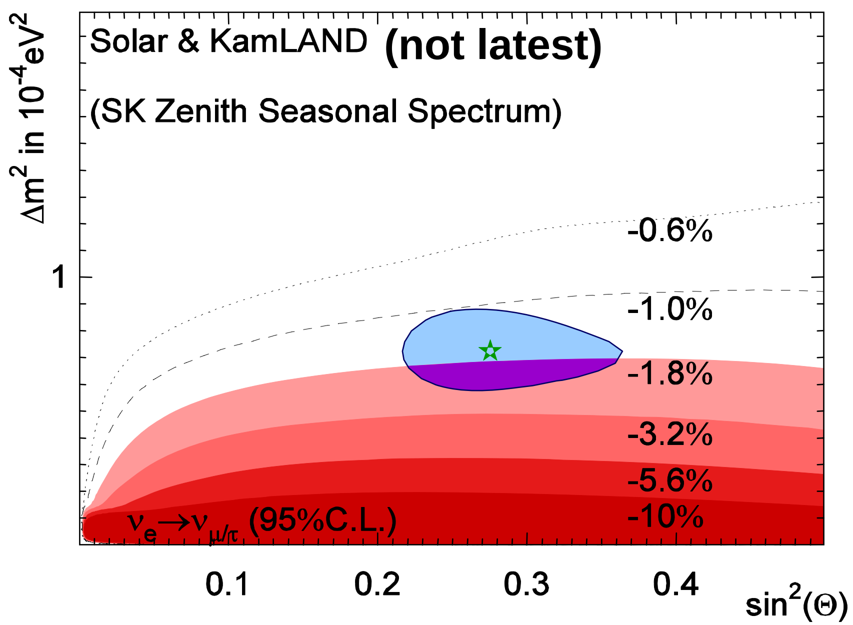


Solar neutrinos

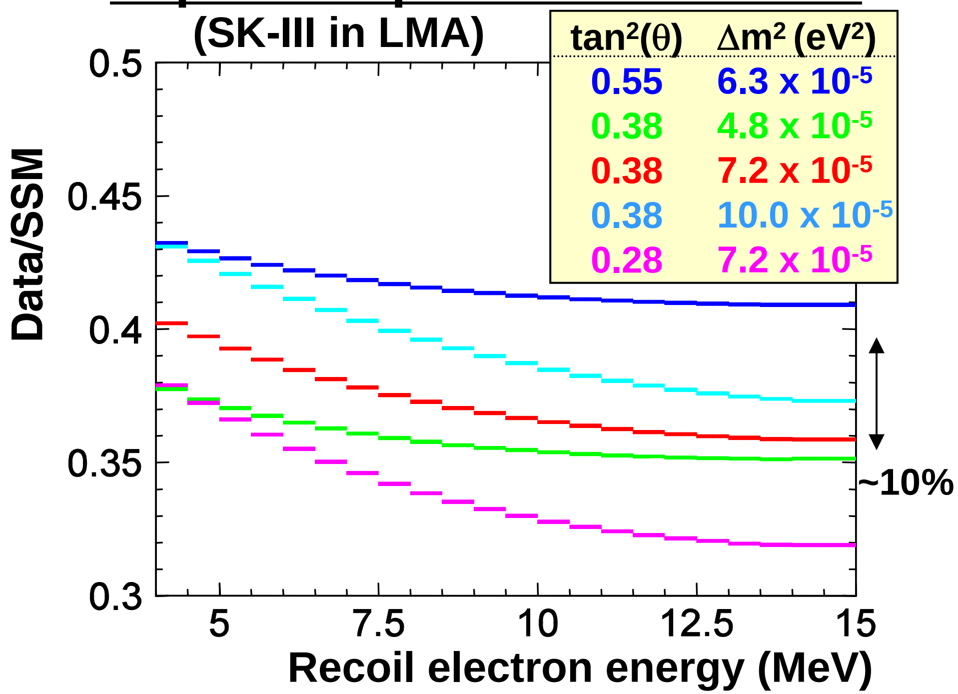
Solar neutrino measurements in

- **High statistics** ~15events/day with E_e > 5MeV, ^{8}B(+hep)
- **Time variations** (Day/Night, Seasonal, 5days each, etc.)
- **Energy spectrum** (Sensitive to ν oscillation parameters)
- **Precise energy calibration** by electron LINAC and ^{16}N
- **Flux independent analysis** (Time variation, Energy spectrum)

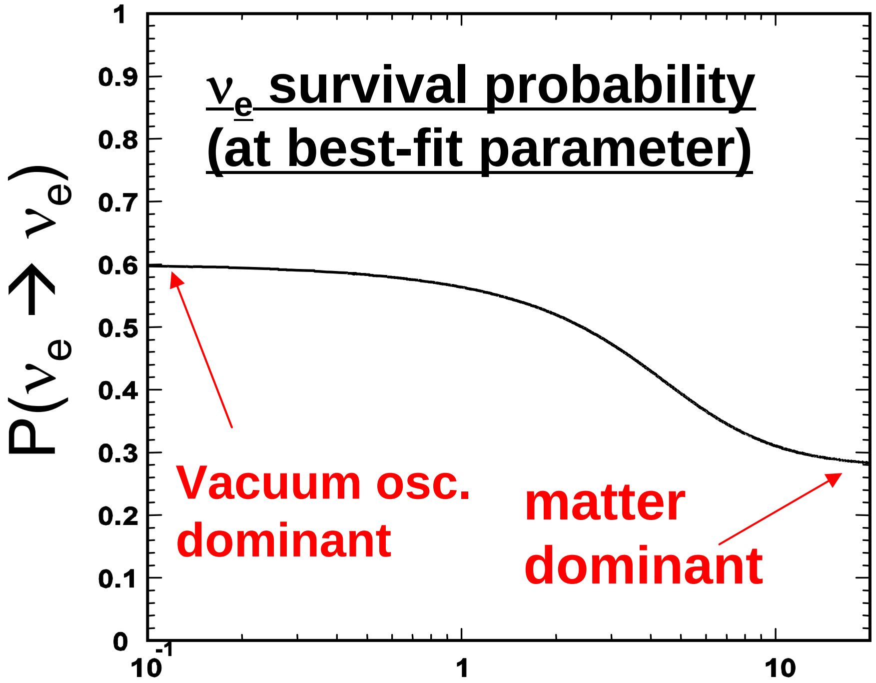
Expected Day/Night asymmetry

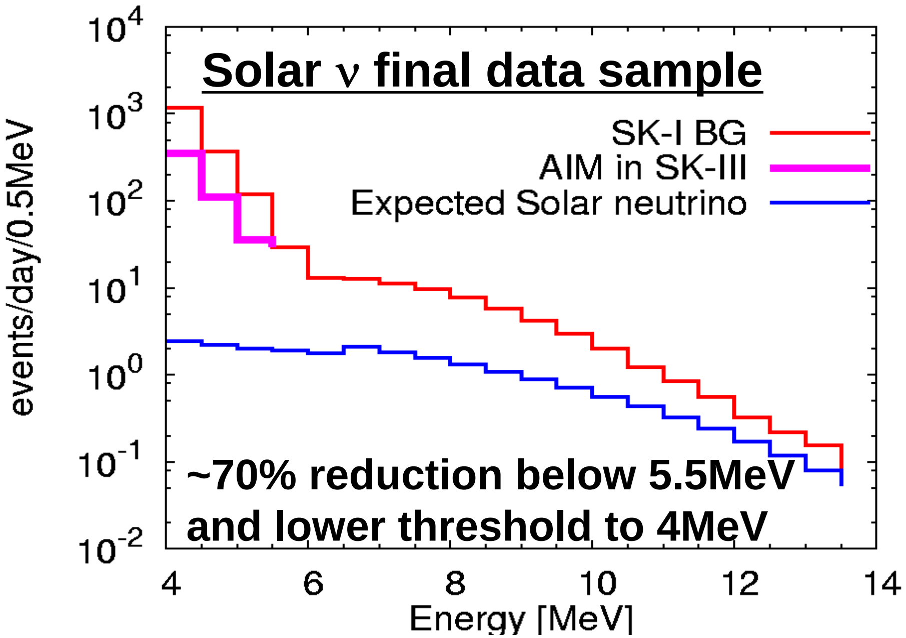


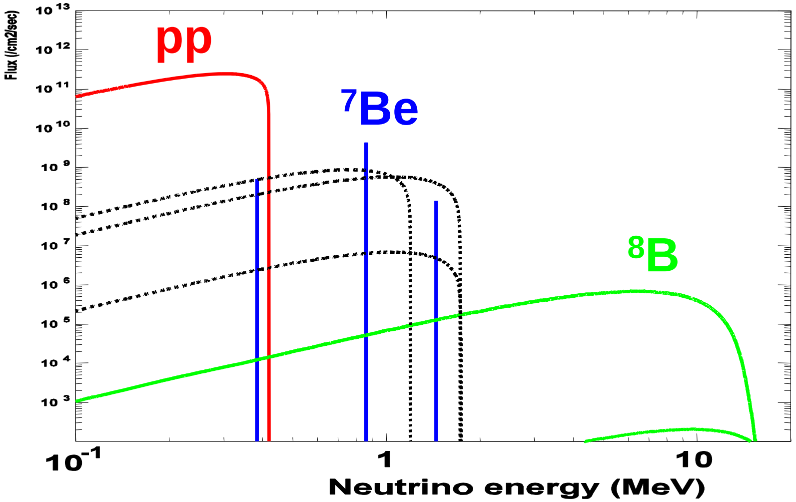
Expected spectrum distortion

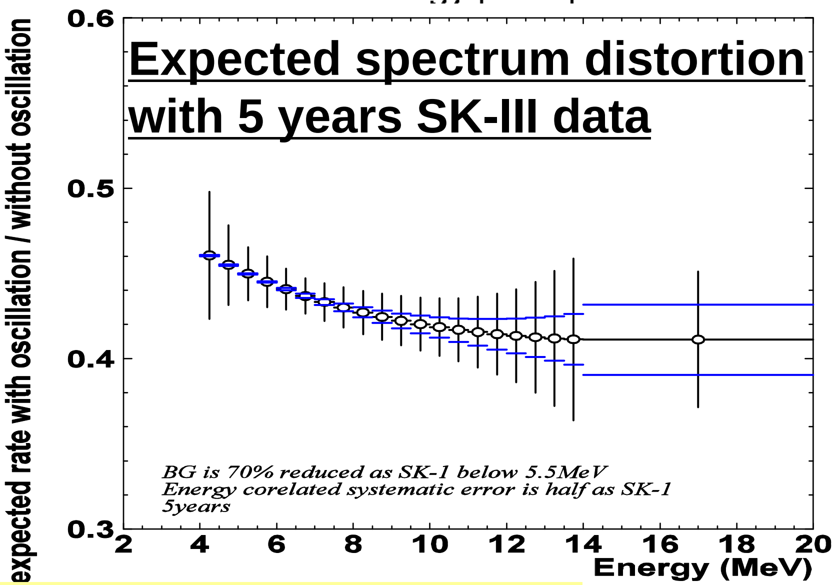


Future prospects in SK-III









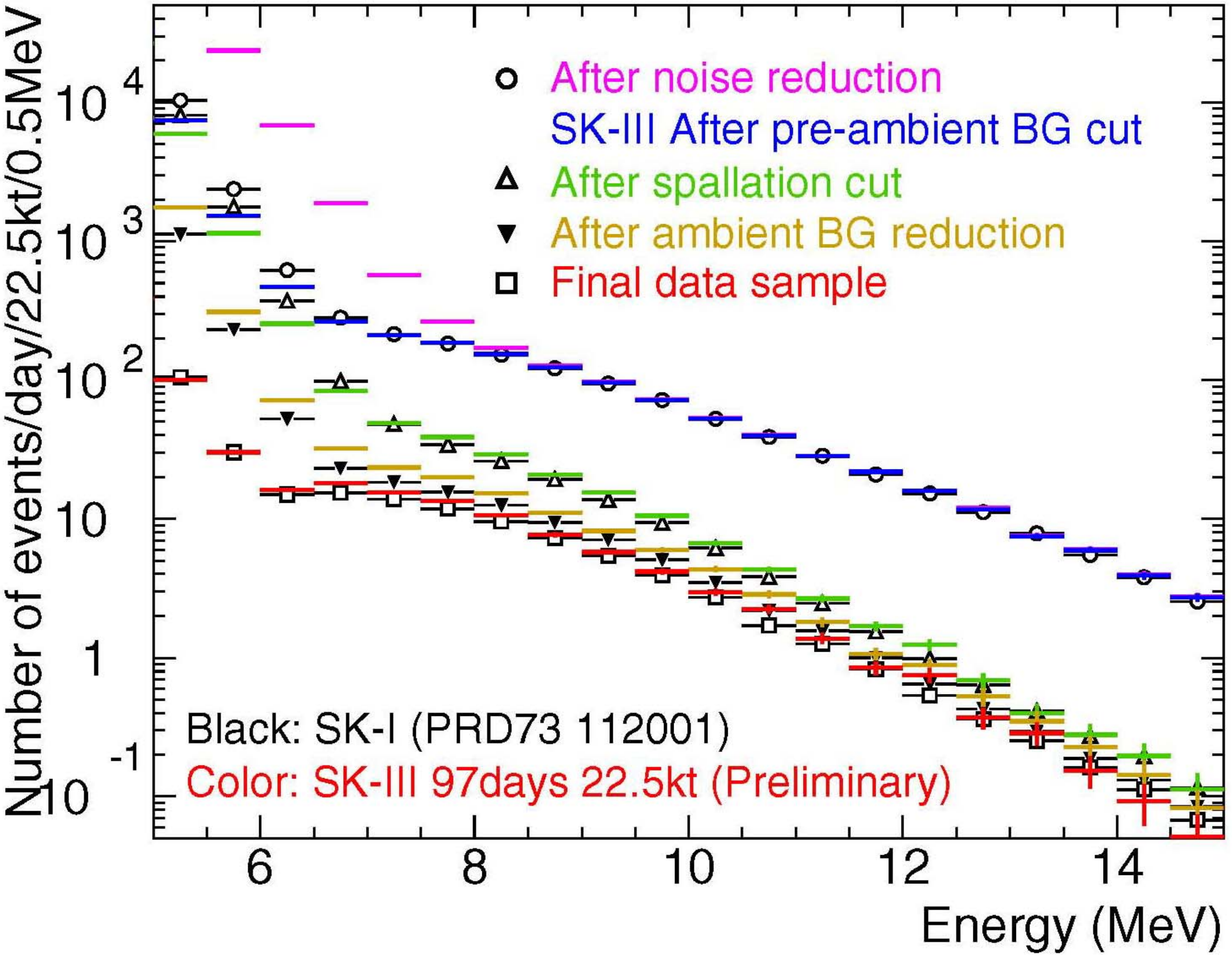
We would like to see a spectrum distortion

SK-III solar ν analysis

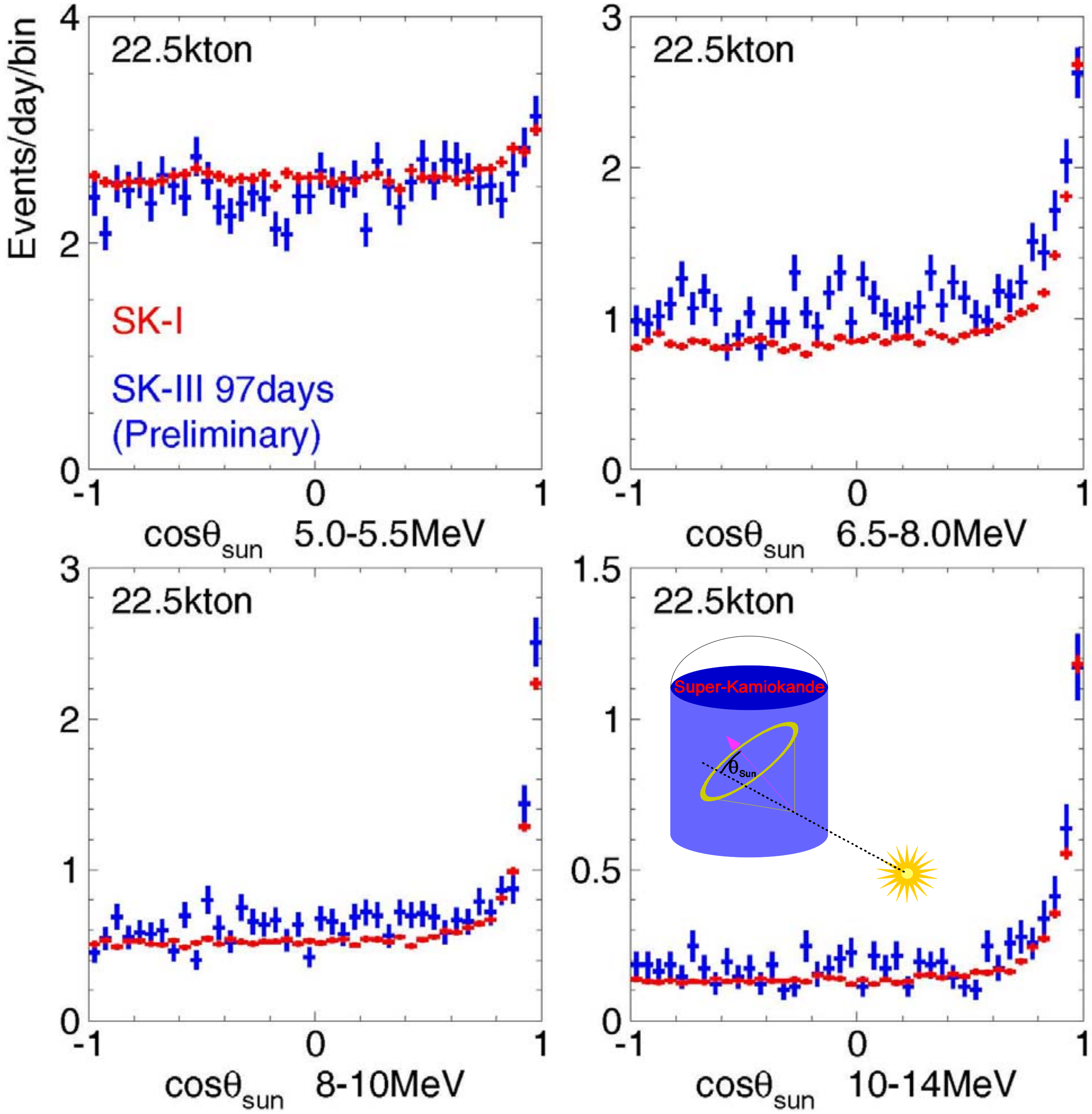
- Dataset: (the first SK-III SLE data)
  - Jan. 24, 2007 ~ May 21, 2007
  - Live time 97 days
  - Super Low Energy (SLE) trigger mode
  - Trigger efficiency: ~100%@5.0MeV
- Analysis:
  - Applied preliminary SK-III analysis tools, then compared the first SK-III SLE data with SK-I final results.
  - These tools are still under improvement.
  - The efficiency for the ^8B solar neutrino signal of the final data sample was adjusted to the SK-I analysis. (not optimized yet)

Reduction steps

- **Agreement of SK-III and SK-I looks quite good!**



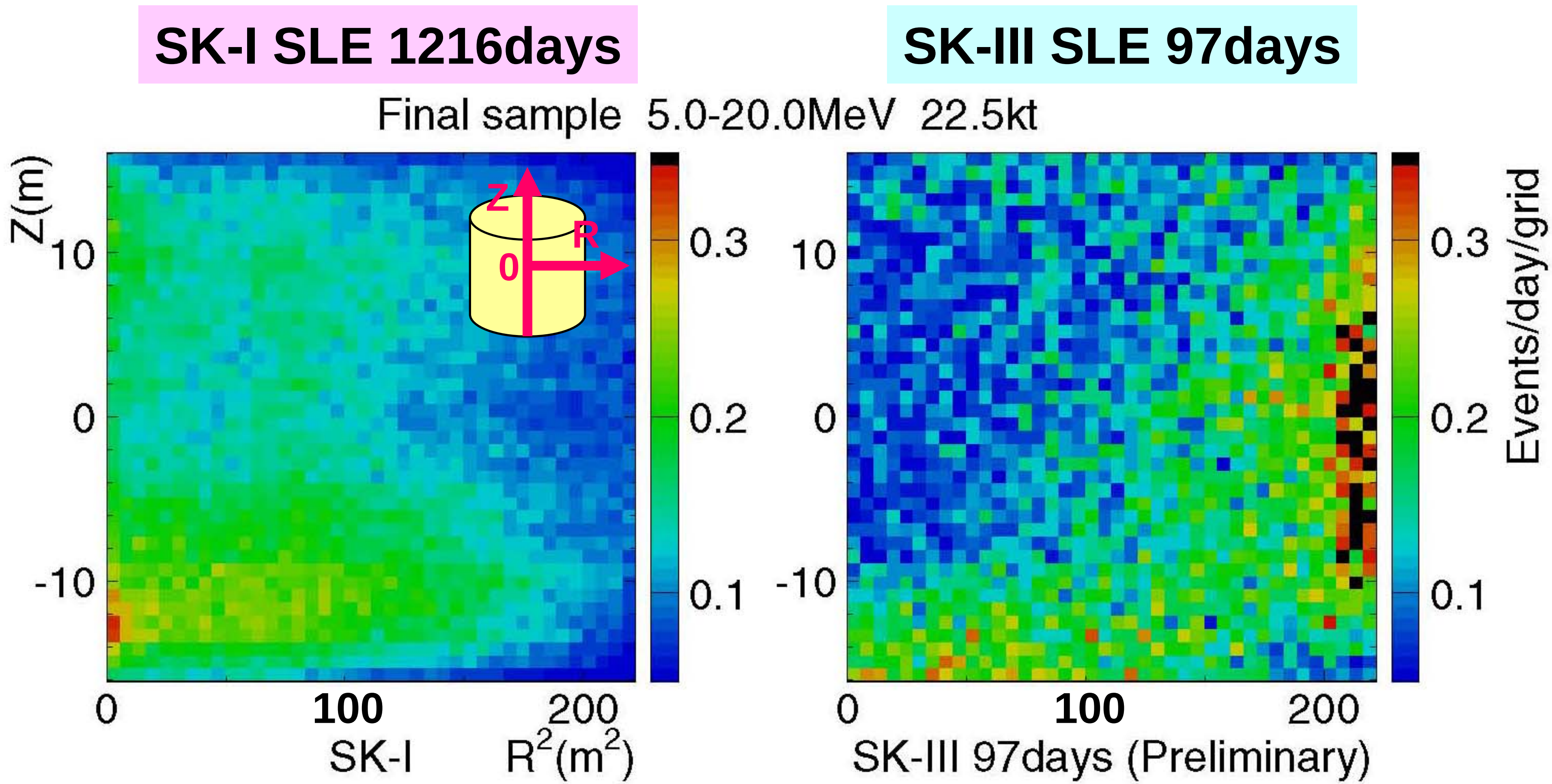
Angular distributions



2m Fid. Vol. (22.5kton)

- Signal event rates look consistent
- SK-III has already reached to the similar signal to noise ratio as SK-I in 5.0-20MeV in 22.5kt

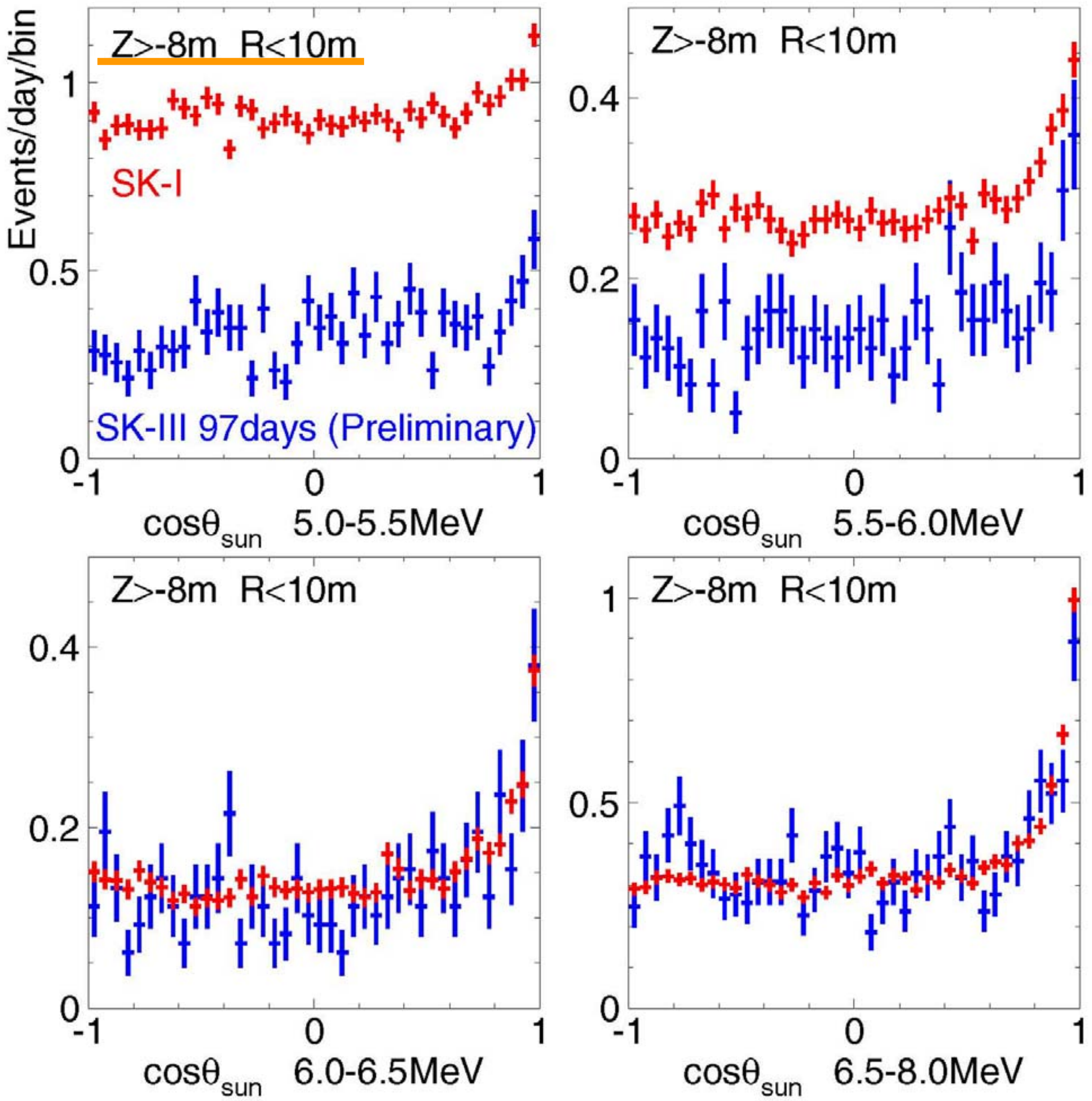
Vertex distribution



- **There are more events near SK-III barrel & bottom.**
- **SK-III has lower event rates in the central-top region.**

(Both SK-I & SK-III rates in R>~10m are reduced by the same external event cut)

Angular distributions

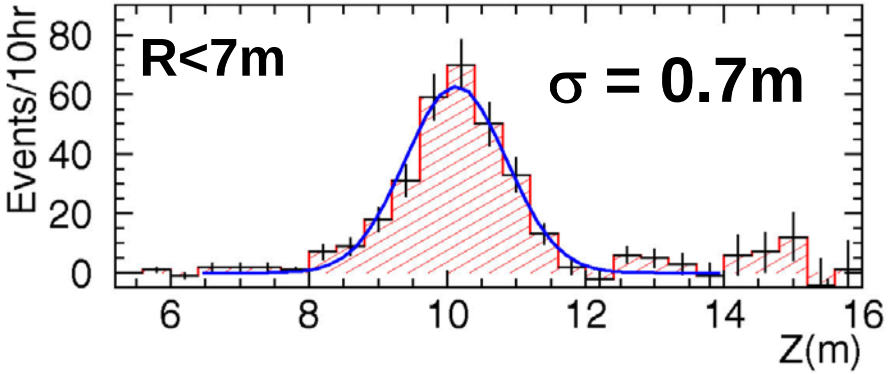


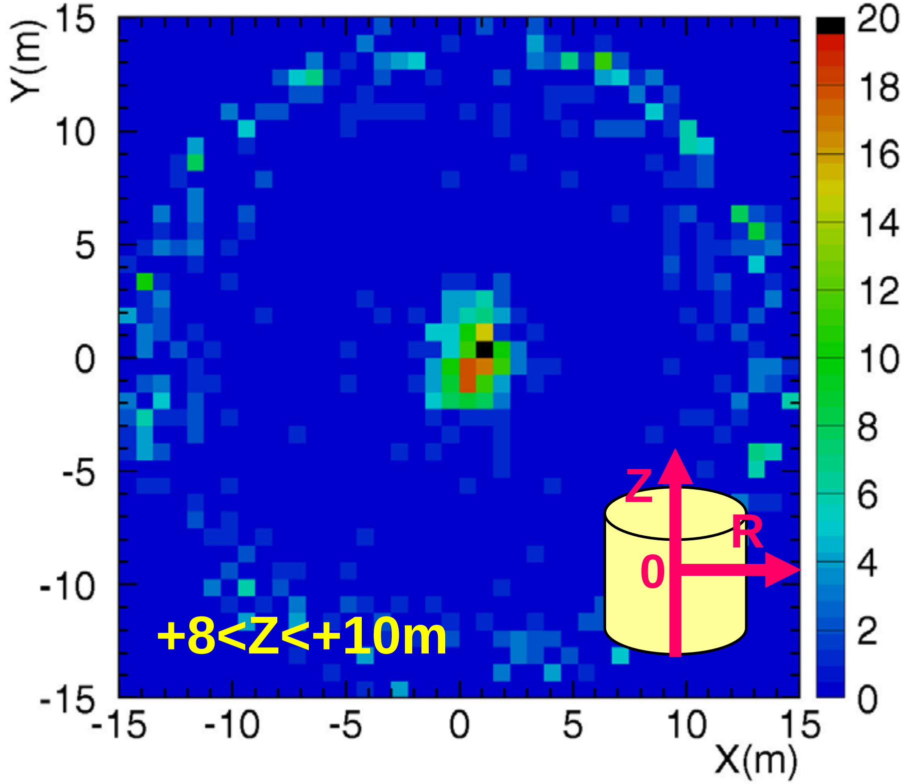
Central-top region

- **SK-III BG rate is smaller than SK-I in 5.0-5.5MeV in the central top region**
- **Signal rate looks consistent.**

Radon injection in SK-III

C.f. Rn injection in SK-I: PLB 452 (1999) 418





- Inject purified water with known amount of Rn into a position in the SK detector through a long ¼-inch tube
- Event reconstruction works well below 5MeV region
- Detection efficiency for Rn will be obtained.
- Water movement in the detector can be studied.

- ~20Bq Rn, in central-top region
- Rn run – BG run
- Energy ~ 4.0-5.0MeV
- After ambient BG cut

Summary

- The upper limits for the supernova neutrinos are updated. (90%C.L., SK-I + SK-II)
  - Burst limit: <0.32 SN/year in 100kpc
  - SRN flux limit: < 1.08 /cm^2/sec (preliminary)

- The first SK-III SLE data were obtained.
  - Live time=97days, 22.5kt, 5.0-20MeV
- The S/N in 22.5kt looked similar as SK-I.
- More events from barrel & bottom in SK-III.
- In the central region, SK-III BG rate is smaller than SK-I in 5.0-5.5MeV.