Mar. 6, 2001 @ 9th International Workshop on "Neutrino Telescopes"

Super-Kamiokande Solar Neutrinos, Results and Perspectives

Yasuo Takeuchi
(Kamioka Observatory, ICRR, Univ. of Tokyo)
For the Super-Kamiokande collaboration

Outline

- SK detector
- What is new
- Results
  - ^{8}B Flux
  - Time variation
  - Day/Night variation
  - Energy spectrum
  - Hep flux
  - Oscillation analysis
- KamLAND
- Summary

This presentation is available at
http://www-sk.icrr.u-tokyo.ac.jp/~takeuchi/radon/

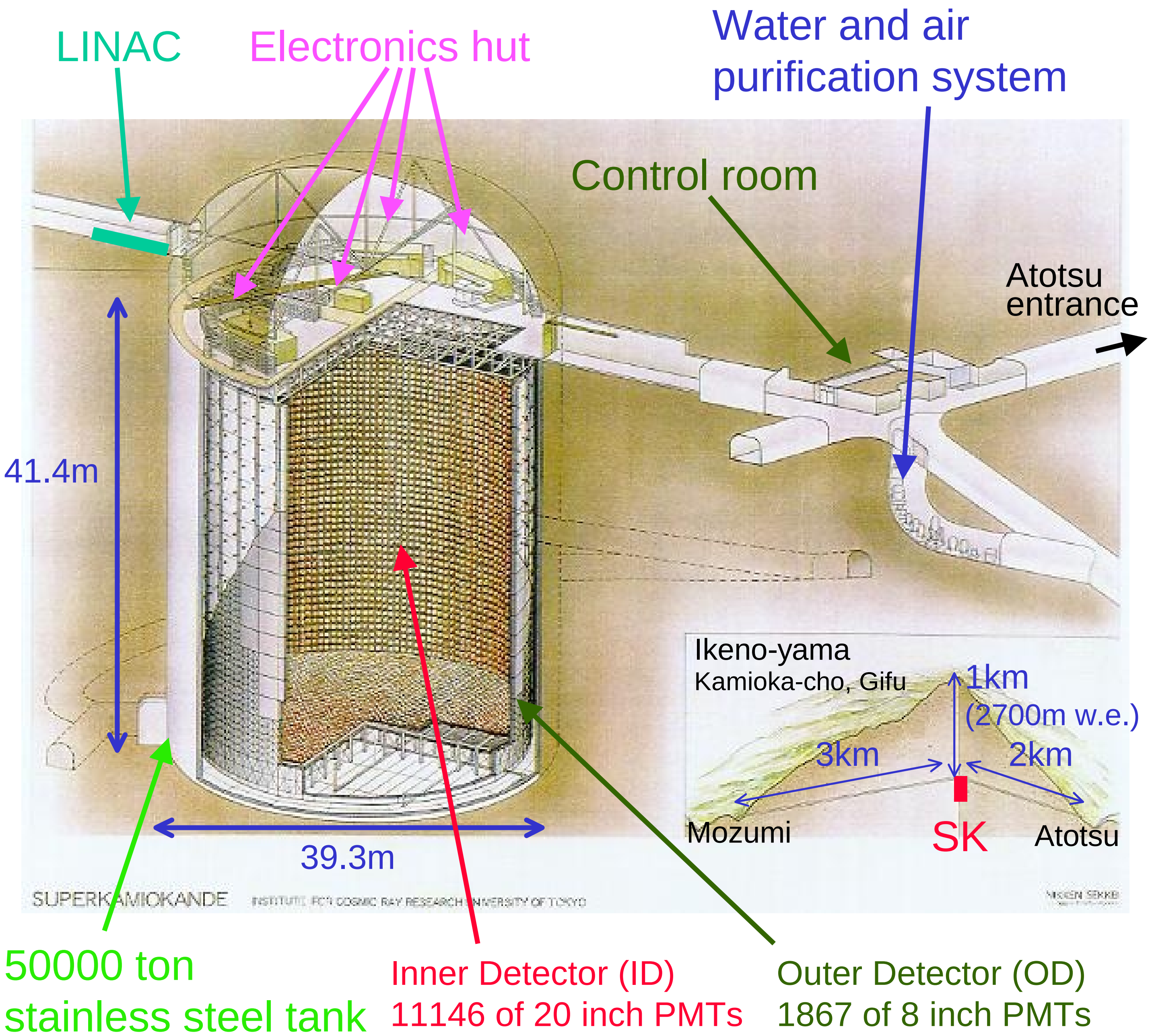
The Super-Kamiokande Collaboration

(as of Aug. 2000)

~ 25 institution, ~120 collaborator

Institute for Cosmic Ray Research (ICRR), The University of Tokyo
Kamioka Observatory
S. Fukuda, Y. Fukuda, M. Ishitsuka, Y. Itow, J. Kameda, K. Kobayashi, Y. Koshio, M. Miura, S. Moriyama, M. Nakahata, S. Nakayama, Y. Obayashi, K. Okumura, N. Sakurai, M. Shiozawa, Y. Suzuki, H. Takeuchi, Y. Takeuchi, T. Toshito, Y. Totsuka (spokesman), S. Yamada
Research Center for Cosmic Neutrinos (RCCN)
T. Kajita, K. Kaneyuki, A. Okada
Boston University
M. Earl, A. Habig, E. Kearns, M. D. Messier, K. Scholberg, J. L. Stone, L. R. Sulak, C. W. Walter
Brookhaven National Laboratory
M. Goldhaber
University of California, Irvine
T. Barszczak, D. Casper, W. Gajewski, W. R. Kropp, S. Mine, L. R. Price, M. Smy, H. W.Sobel, M. R. Vagins
California State University, Dominguez Hills
K. S. Ganezer, W. E. Keig
George Mason University
R. W. Ellsworth
Gifu University
S. Tasaka
University of Hawaii
A. Kibayashi, J. G. Learned, S. Matsuno, D. Takemori
High Energy Accelerator Research Organization (KEK)
Y. Hayato, T. Ishii, T. Kobayashi, K. Nakamura, Y. Oyama, A. Sakai, M. Sakuda, O. Sasaki
Kobe University
M. Kohama, A. T. Suzuki
University of Kyoto
T. Inagaki, K. Nishikawa
Los Alamos National Laboratory
T. J. Haines
Louisiana State University
E. Blaufuss, B. K. Kim, R. Sanford, R. Svoboda
University of Maryland at Collage Park
M. L. Chen, J. A. Goodman, G. Guillian, G. W. Sullivan
State University of New York at Stony Brook
J. Hill, C. K. Jung, K. Martens, M. Malek, C. Mauger, C. McGrew, E. Sharkey, B. Viren, C. Yanagisawa
Niigata University
M. Kirisawa, S. Inaba, c. Mitsuda, K. Miyano, H. Okawzawa, C. Saji, M. Takahasi, M. Takahata
Osaka University
Y. Nagashima, K. Nitta, M. Takita, M. Yoshida
Seoul National University
S. B. Kim
Shizuoka University
T. Ishizuka
Tohoku University
M. Etoh, Y. Gando, T. Hasegawa, K. Inoue, K. Ishihara, T. Maruyama, J. Shirai, A. Suzuki
University of Tokyo
M. Koshiba
Tokai University
Y. Hatakeyama, Y. Ichikawa, M. Koike, K. Nishijima
Tokyo Institute of Technology
H. Fujiyasu, H. Ishino, M. Morii, Y. Watanabe
University of Warsaw
U. Golebiewska, D. Kielczewska
University of Washington
S.C. Boyd, A. L. Stachyra, R. J. Wilkes, K. K. Young

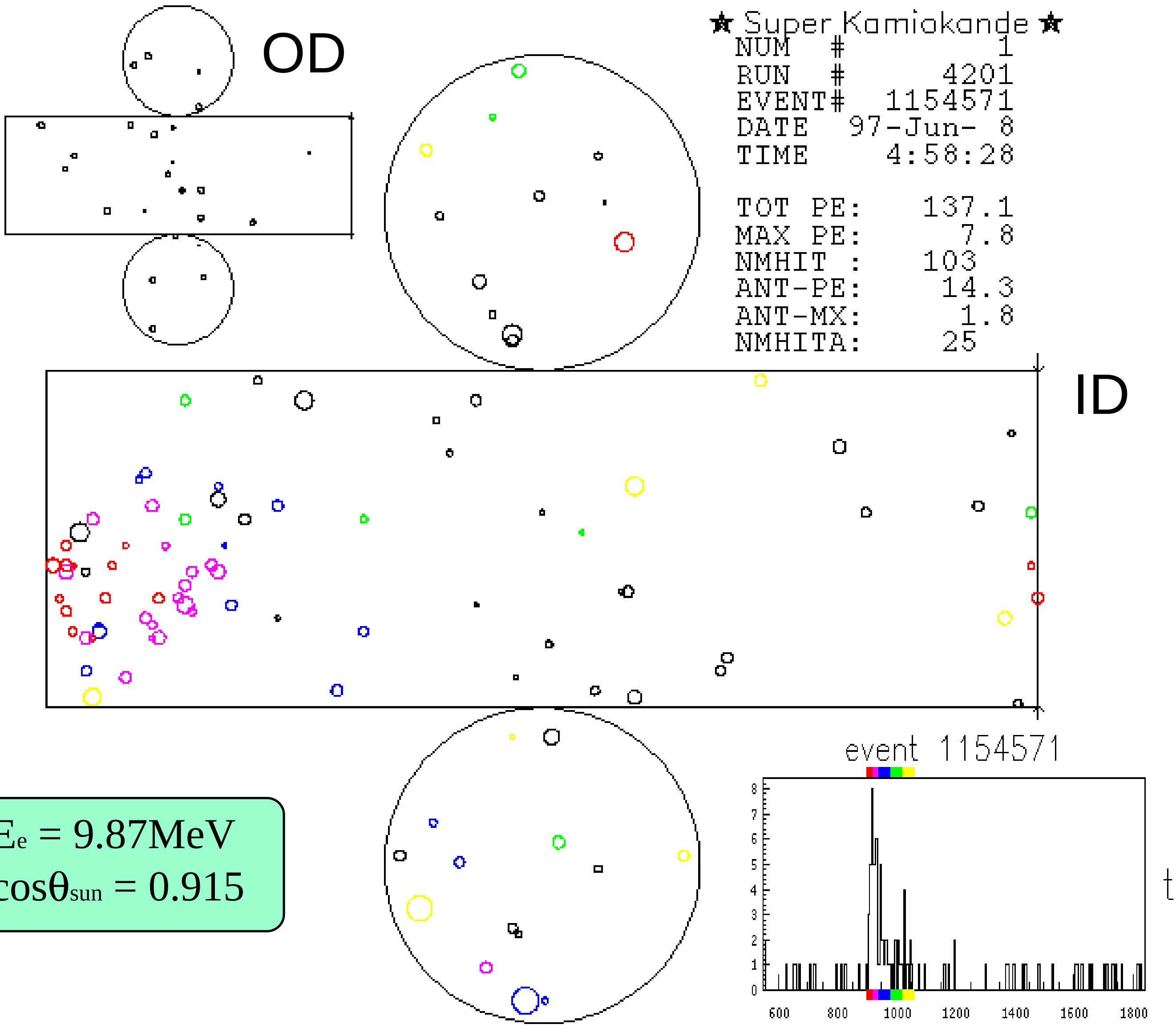
Super-Kamiokande



• photo coverage	40%
• outer detector	2.5m for all surfaces
• fid. vol. for ν_{solar}	22.5kt (2m from ID wall)
• for 10 MeV electron	
vertex resolution	87cm
energy resolution	14%
angular resolution	26^o

A Typical low-energy event

- Timing information — vertex position
- Ring pattern — direction
- number of hit PMTs — energy



E_e = 9.87MeV
$\cos\theta_{sun}$ = 0.915

Detect solar neutrinos by

$$\nu + e \rightarrow \nu + e \quad \text{scattering}$$

What's new (1)

- Data update

Run1742-8656 (1117day)

1996/05/31-2000/04/24

Run1742-9299 (1258day)

1996/05/31-2000/10/06 **(new)**

- Lower energy threshold

5.5-20MeV → 5.0-20MeV

  - Improve analysis tools

    6.5-20MeV: Background –63% Signal –20%

  - re-tune M.C. simulation

    energy scale was shifted by 0.27 %
    (within estimated systematic error of 0.64%)

  - re-estimate systematic errors

  - Improving water purification system

    Install new reverse osmosis system (Mar. 2000)
    Install new membrane degasifier system (Jan. 2001)

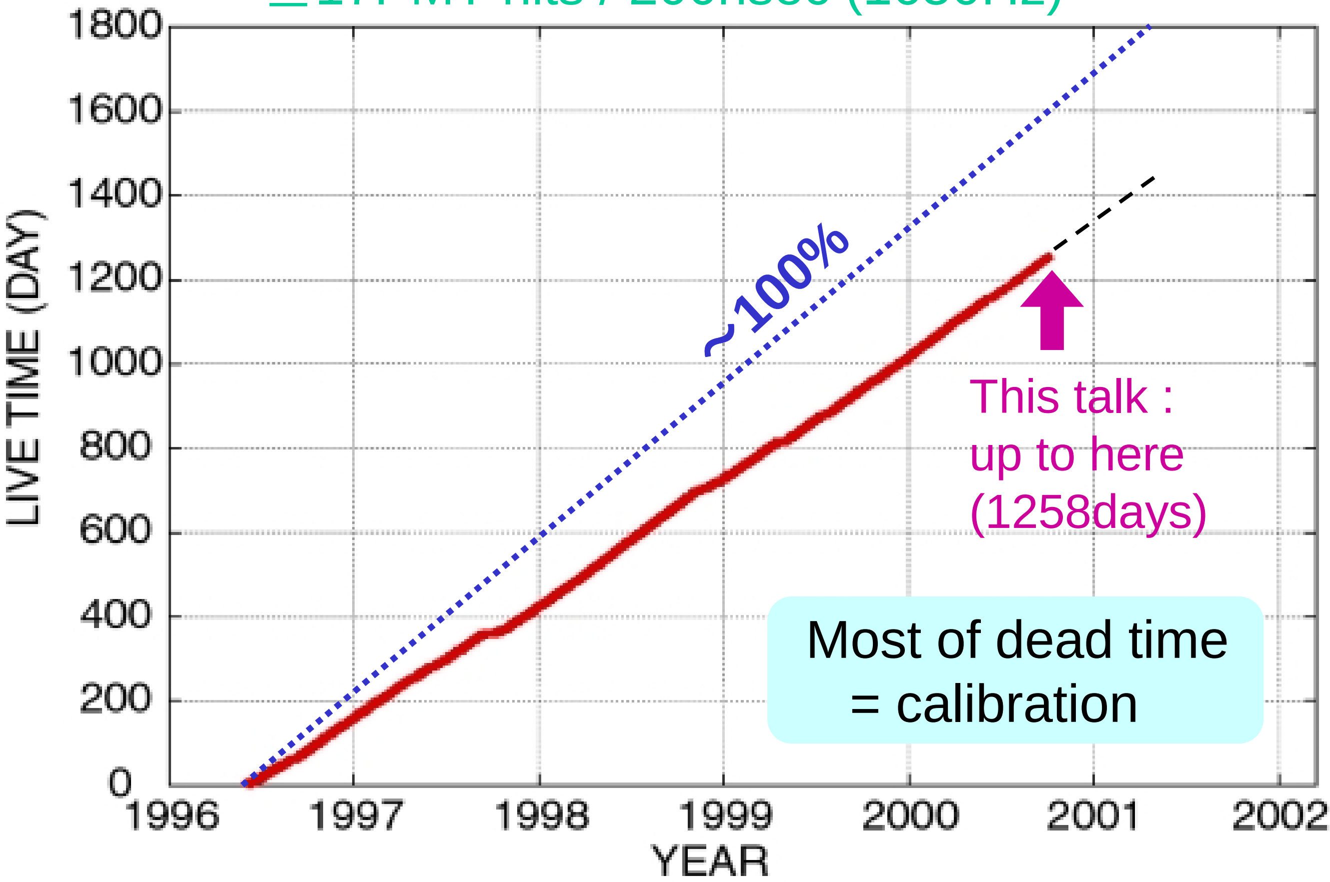
  - lower trigger threshold

Trigger threshold

- Low-Energy(LE) trigger (April 1996~)
  ≧29PMT hits / 200nsec (10Hz)
- Super-Low-Energy(SLE) trigger (May 1997~)
  ≧24PMT hits / 200nsec (120Hz)

raw rate ～120Hz (most of them are close to the ID wall)
→ on-line fid. vol. cut → 20Hz

- SLE-version 2 trigger (September 1999~)
  ≧20PMT hits / 200nsec (550Hz)
- SLE-version 3 trigger (July 2000~)
  ≧17PMT hits / 200nsec (1650Hz)



5.7 / 6.5MeV →
4.7 / 5.5MeV ········→→
4.2 / 5.0MeV ··············→
3.7 / 4.5MeV ···················→····→

@50%/100% trigger ef.

6.5MeV ← 5.0MeV →
current analysis energy threshold

What's new (2)

- Improve signal extraction method

Use extended maximum likelihood method (EMLM)

$$L_E \equiv \frac{e^{-T} \cdot T^N}{N!} \cdot L$$

T: true number of events
N: observed number of events

Statistical error of higher energy bins (= small N) became reasonable.

- New solar model

BP98 SSM → BP2000 SSM

BP2000 (astro-ph/0010346)

^{8}B	$5.15(1.00^{+0.20}_{-0.16})\times10^6$/cm^2/s
hep	9.3×10^3/cm^2/s (BP98: 2.10)

- New ^{8}B ν spectrum

Bahcall et al. 1996 → Ortiz et al. 2000

PRL 85 (2000) 2909

- New oscillation analysis

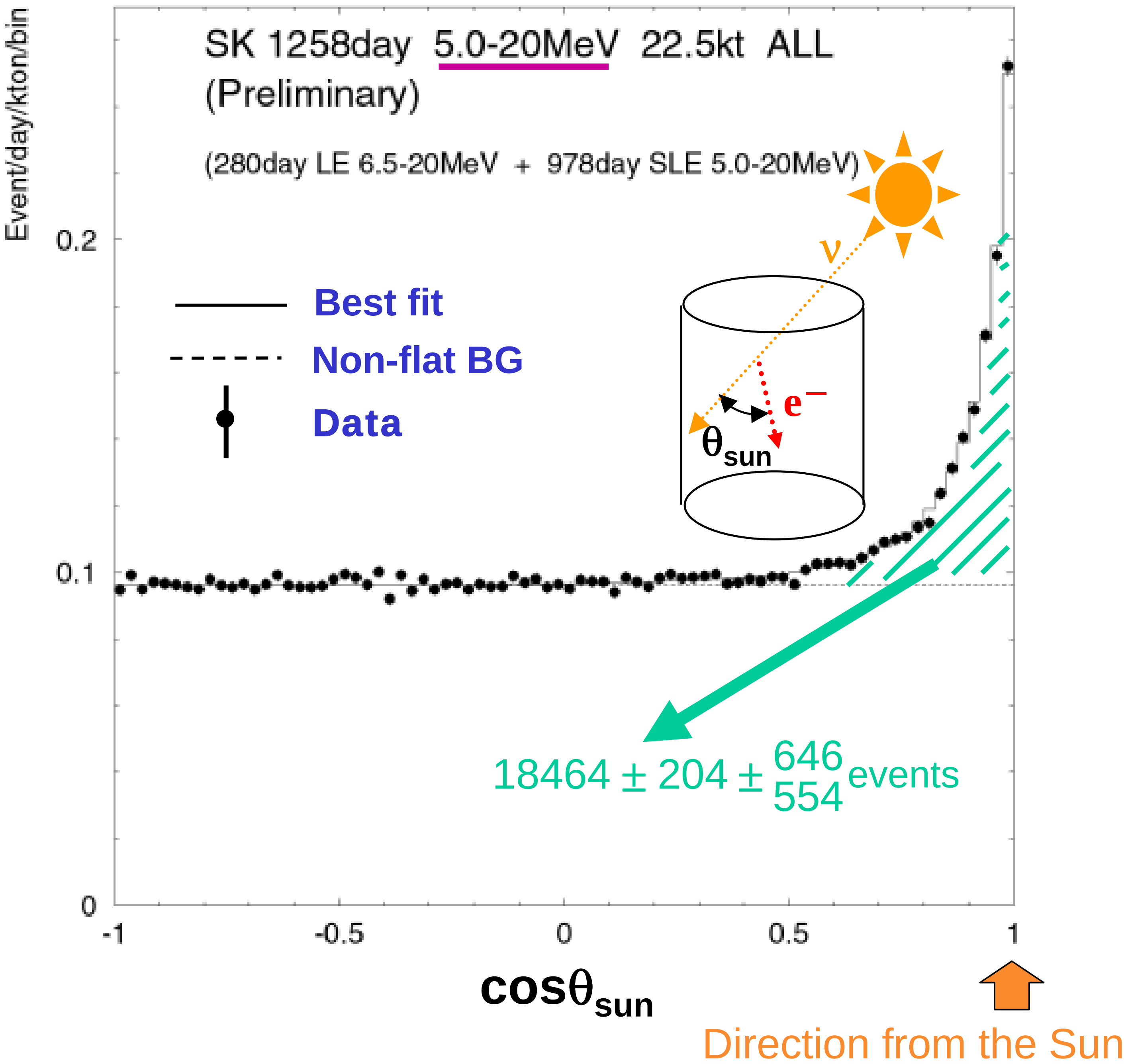
Day/Night 2bin x Energy 19bin & D/N 7bin x E 8bin

(preliminary)

^{8}B flux

May 31, 1996 – Oct. 6, 2000

1258 days



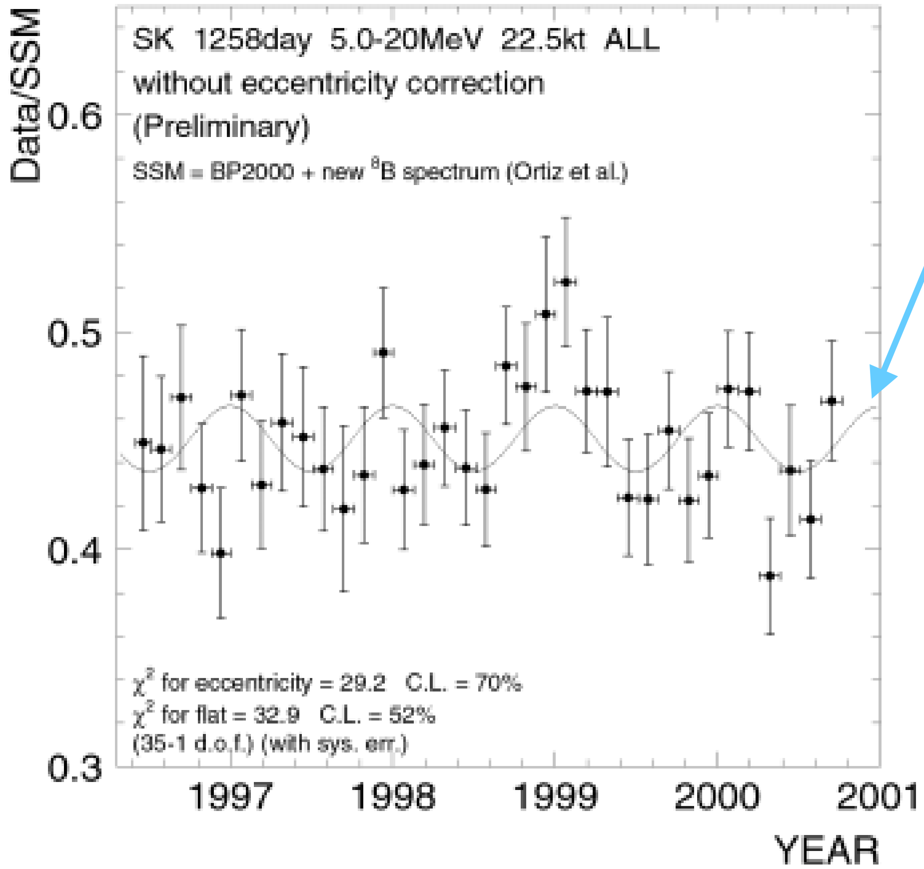
^{8}B FLUX= $2.32 \pm ^{0.03}_{0.03}$ (stat.) $\pm ^{0.08}_{0.07}$ (syst.) [$\times 10^6$/cm^2/s]

$\frac{\text{Data}}{\text{SSM}} = 0.451 \pm ^{0.005}_{0.005}$ (stat.) $\pm ^{0.016}_{0.014}$ (syst.)

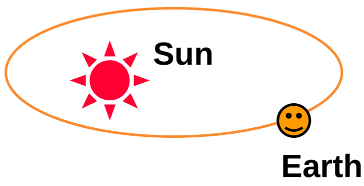
SSM = BP2000 + new ^{8}B ν spectrum (Ortiz et al.)

(preliminary)

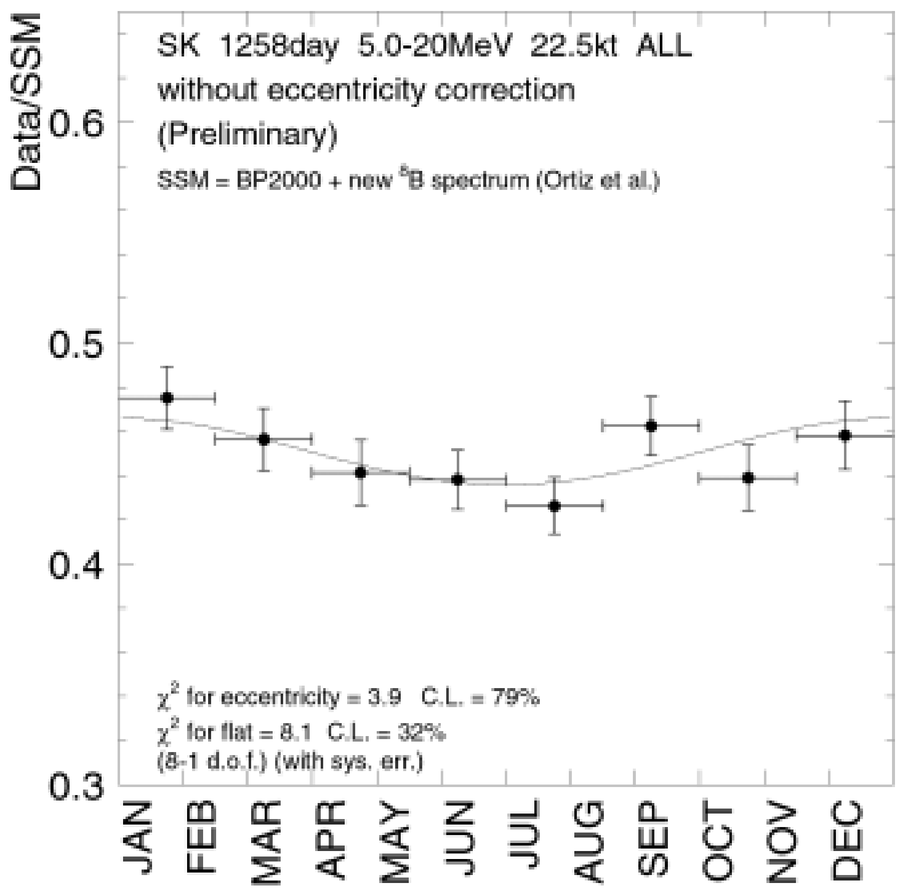
Time variation of the flux



Expected flux variation caused by the eccentricity of the earth



Seasonal variation of the flux



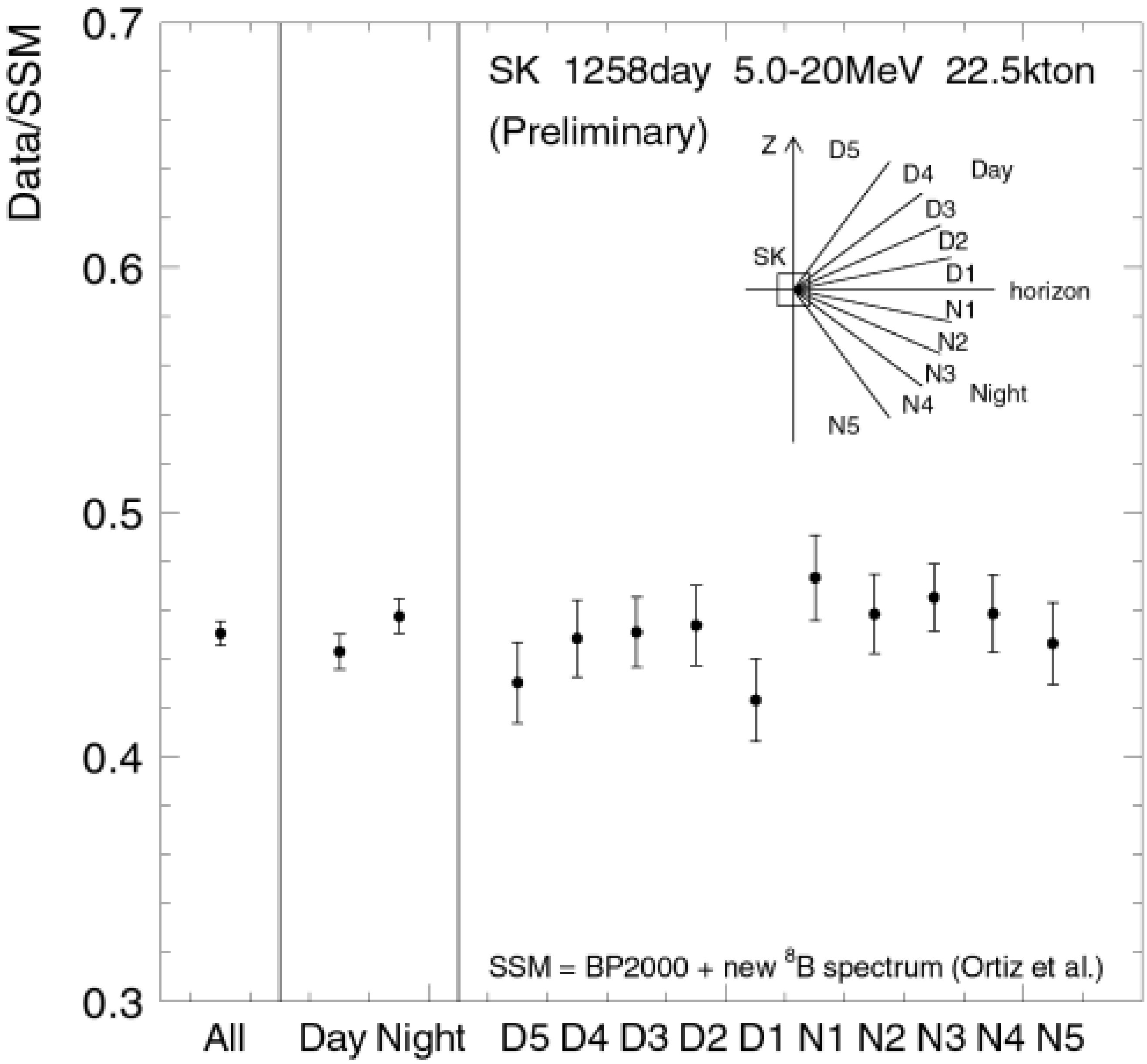
χ^2 for eccentricity
3.9 (79%)

χ^2 for flat
8.1 (32%)
(7d.o.f.)
(with sys. err.)

Need more statistics

(preliminary)

Day / Night



Day: 622 effective days

$$\phi(^8B) = 2.28 \pm 0.04 \pm^{0.08}_{0.07} \ [\times 10^6/cm^2/s]$$

Night: 636 effective days

$$\phi(^8B) = 2.36 \pm 0.04 \pm^{0.08}_{0.07} \ [\times 10^6/cm^2/s]$$

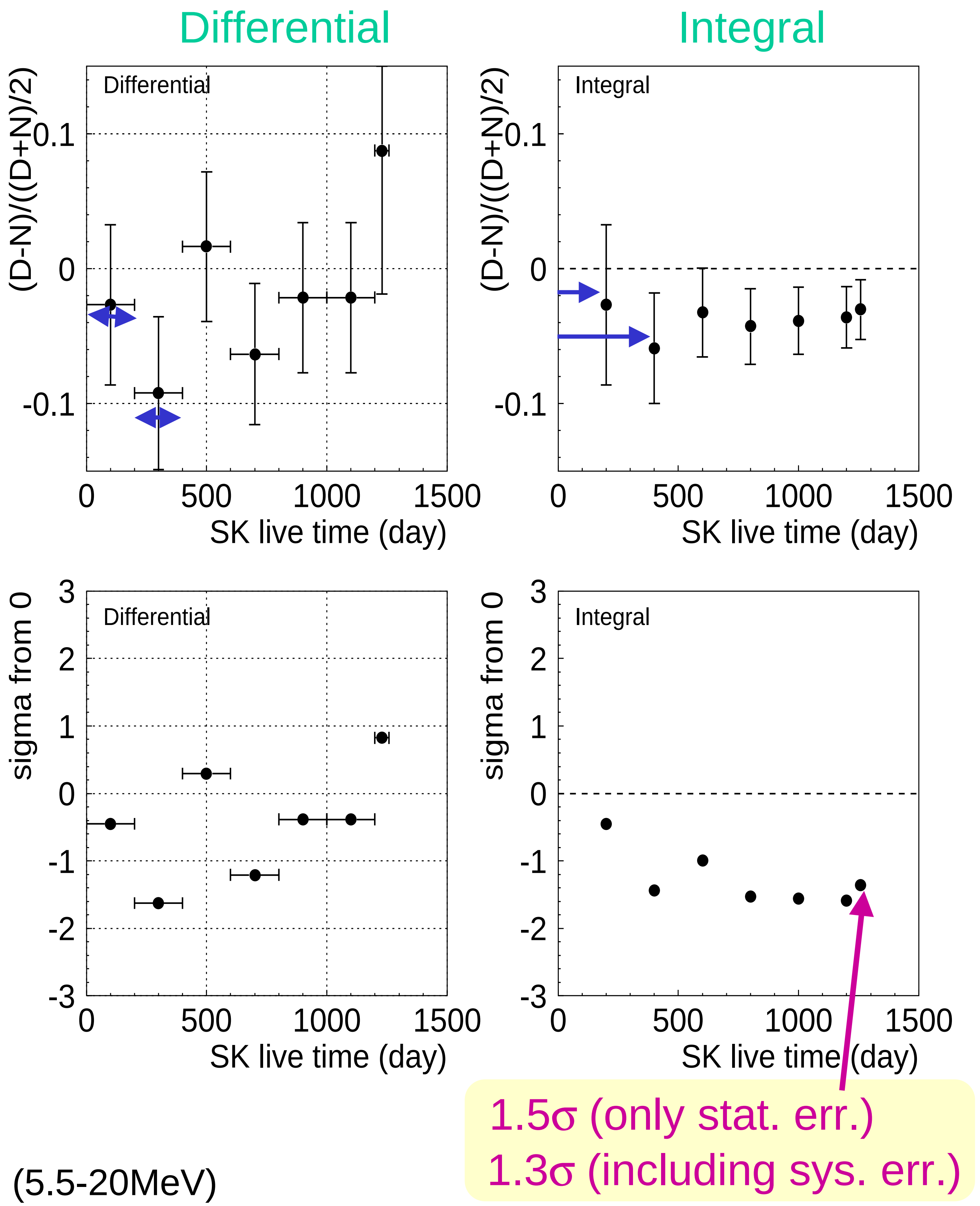
$$\frac{N-D}{(N+D)/2} = 0.033 \pm 0.022(stat.) \pm {}^{0.013}_{0.012} (sys.)$$

(eccentricity is corrected)

(preliminary)

Significance vs. time (day/night)

Errors: only statistical

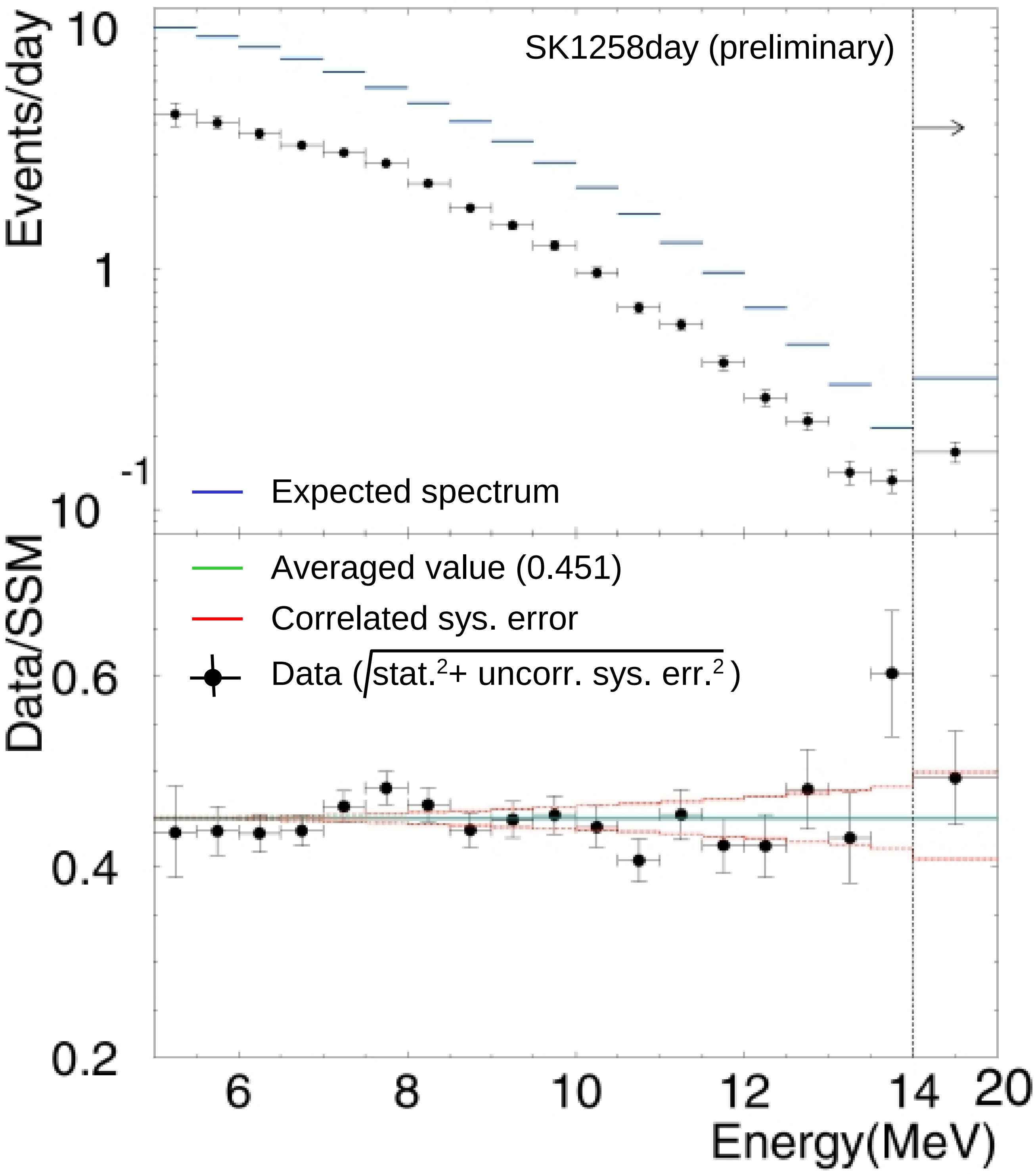


(5.5-20MeV)

(preliminary)

Energy spectrum

Spectrum distortion highly depends on oscillation parameters



χ^2 for flat = 19.0 / 18 (d.o.f) 39% C.L.

(preliminary)

Hep flux

Select best aperture using M.C. ⇨18-21MeV

1.3±2.0 event observed in the the 18-21MeV window

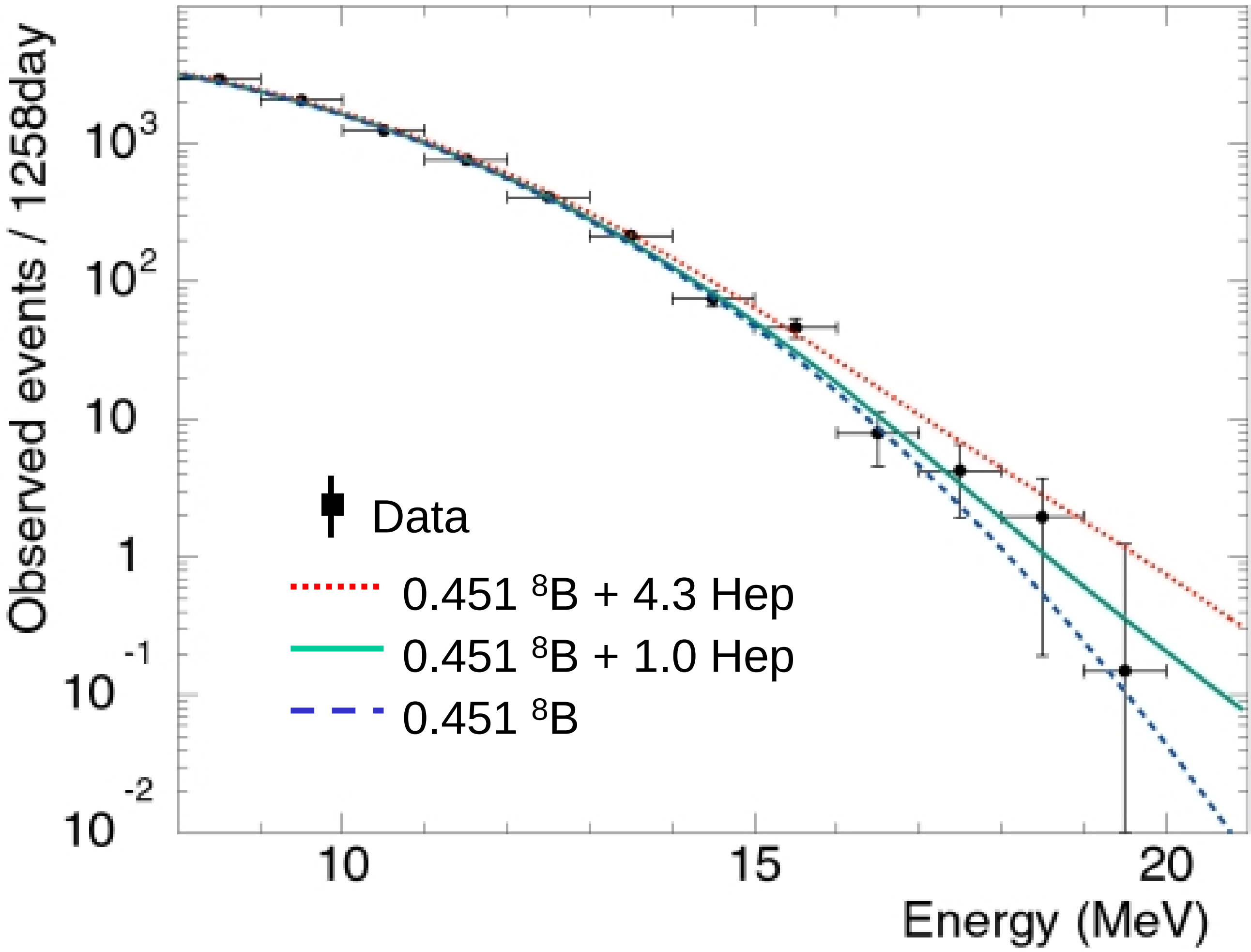
Assume all signals coming from Hep

⇩

Hep flux < 40 x10^3 /cm^2/s (90%C.L.)

(4.3 x BP2000 SSM flux)

Solar neutrino energy spectrum in 1MeV bin



Oscillation analysis

Input data

- BP2000 neutrino flux
- Ortiz et al. 2000 ^{8}B spectrum shape
- Ortiz et al. 2000 ^{8}B spectrum (experimental) error
- Bahcall et al. 1996 ^{8}B spectrum theoretical error
- Bahcall et al. 1996 radiative correction
- PREM electron density in the Earth
- Hep flux is treated as a free parameter (hep free)
- BP2000 electron density in Sun
- BP2000 generate position

Analysis 1 (day spectrum + night spectrum)

19 energy bin
2 zenith angle bin

Total 38 data points

Analysis 2 (zenith spectra) new

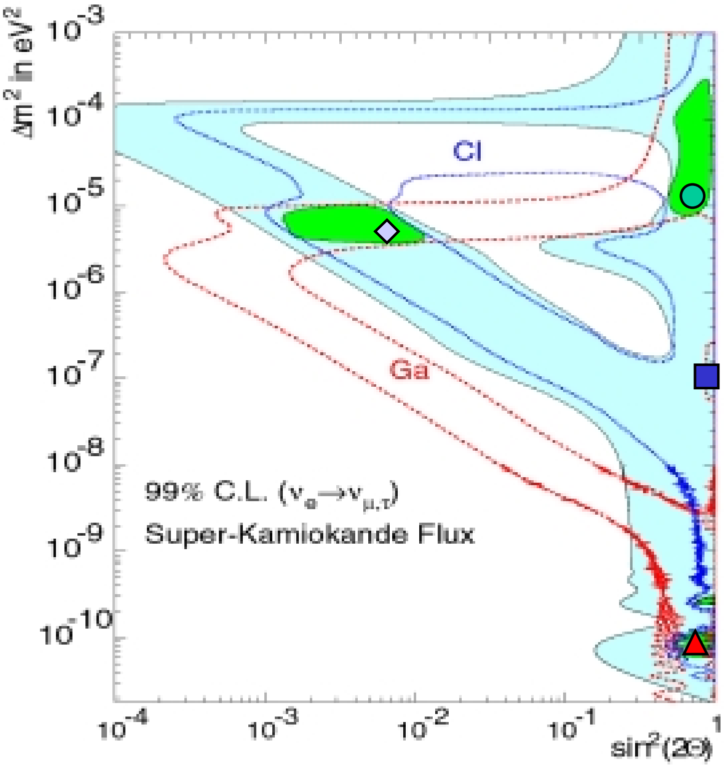
6 (+2) energy bin
7 zenith angle bin

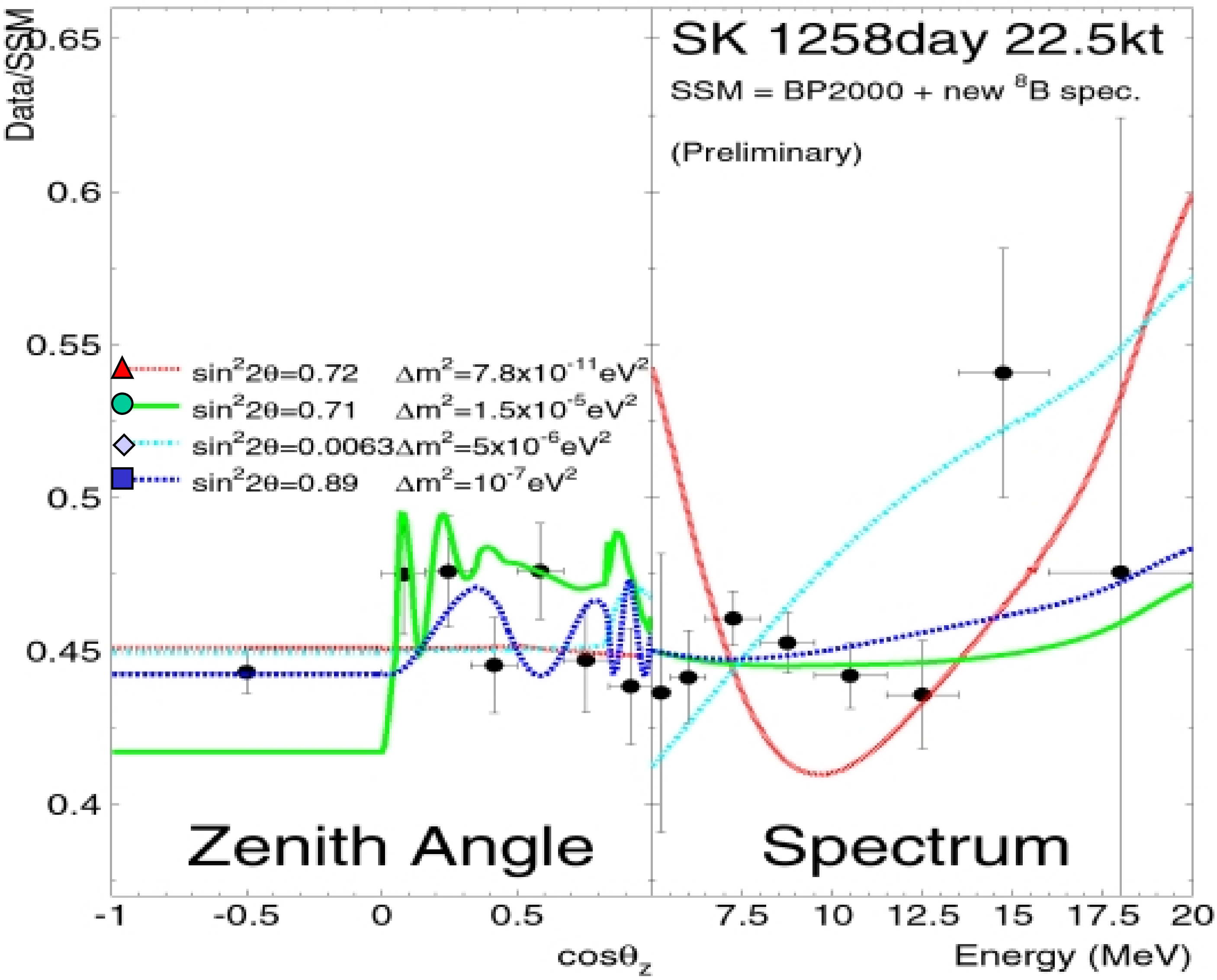
Total 44 data points

(Zenith bin of 5.0-5.5MeV and 16.0-20.0MeV
is not divided because of poor statistics.)

Typical expectations

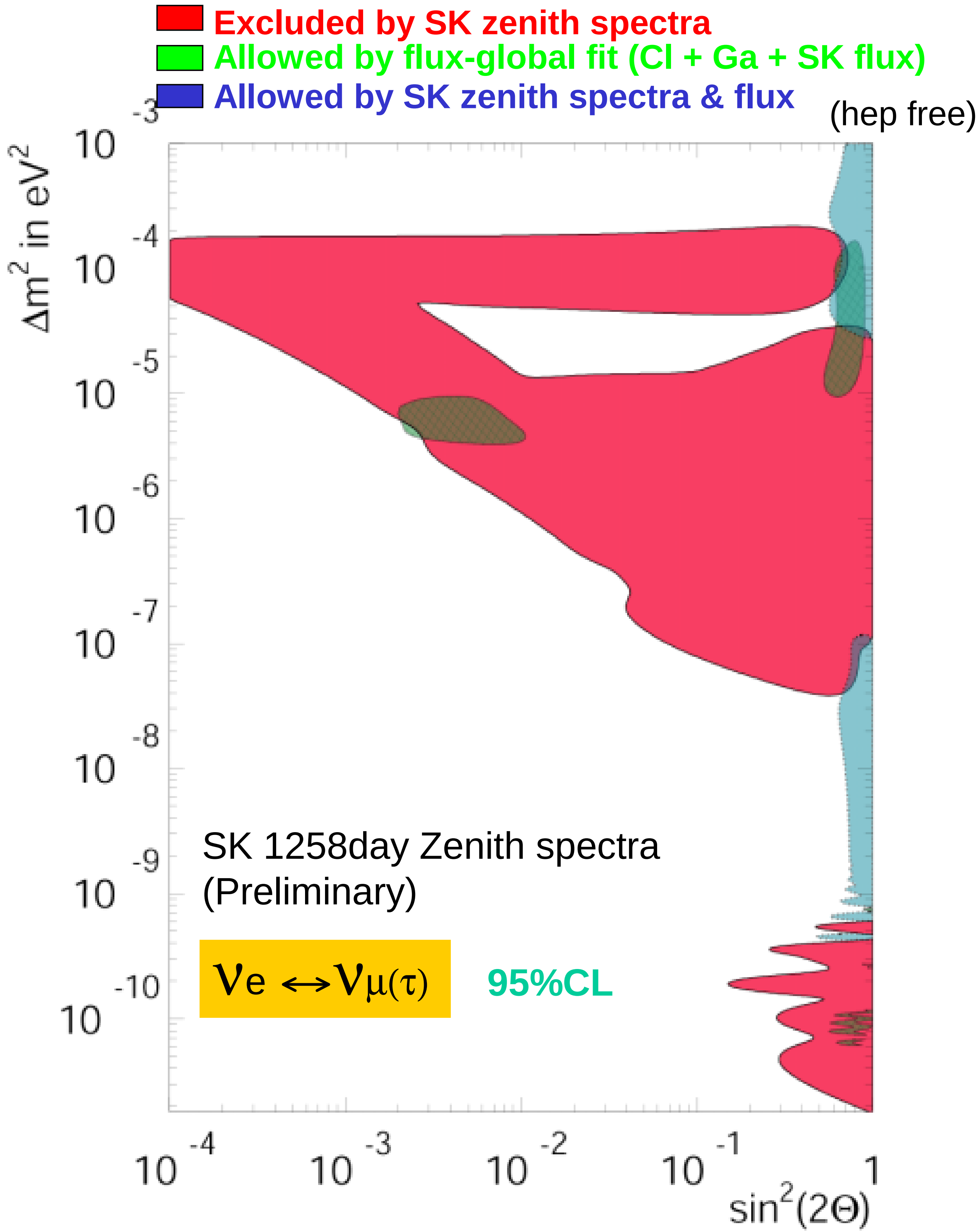
- ▲ VAC (Just-So)
- ● MSW LMA
- ◇ MSW SMA
- ■ MSW LOW





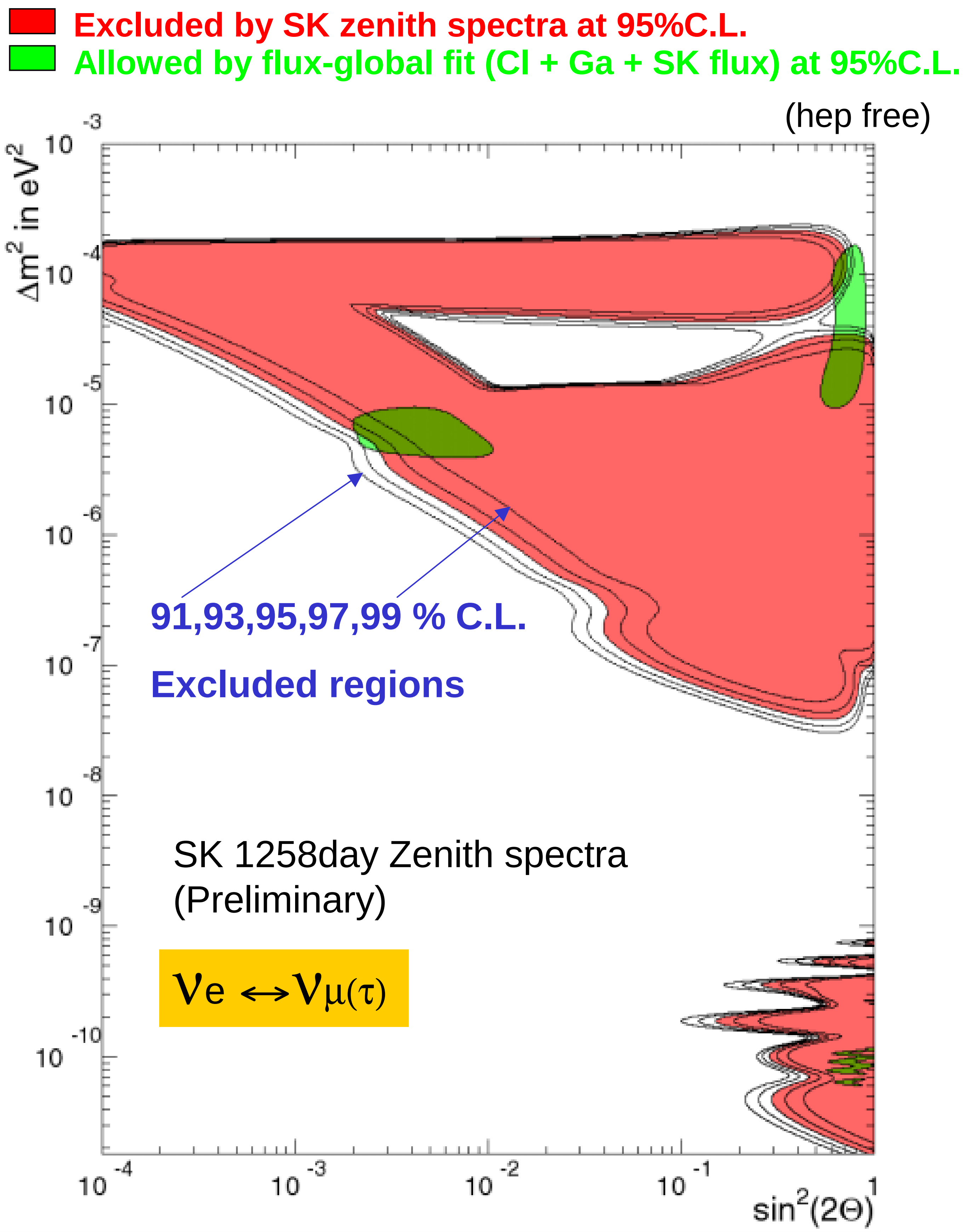
(preliminary)

Oscillation analysis (SK vs. global, active)



SK favors large mixing angle regions.

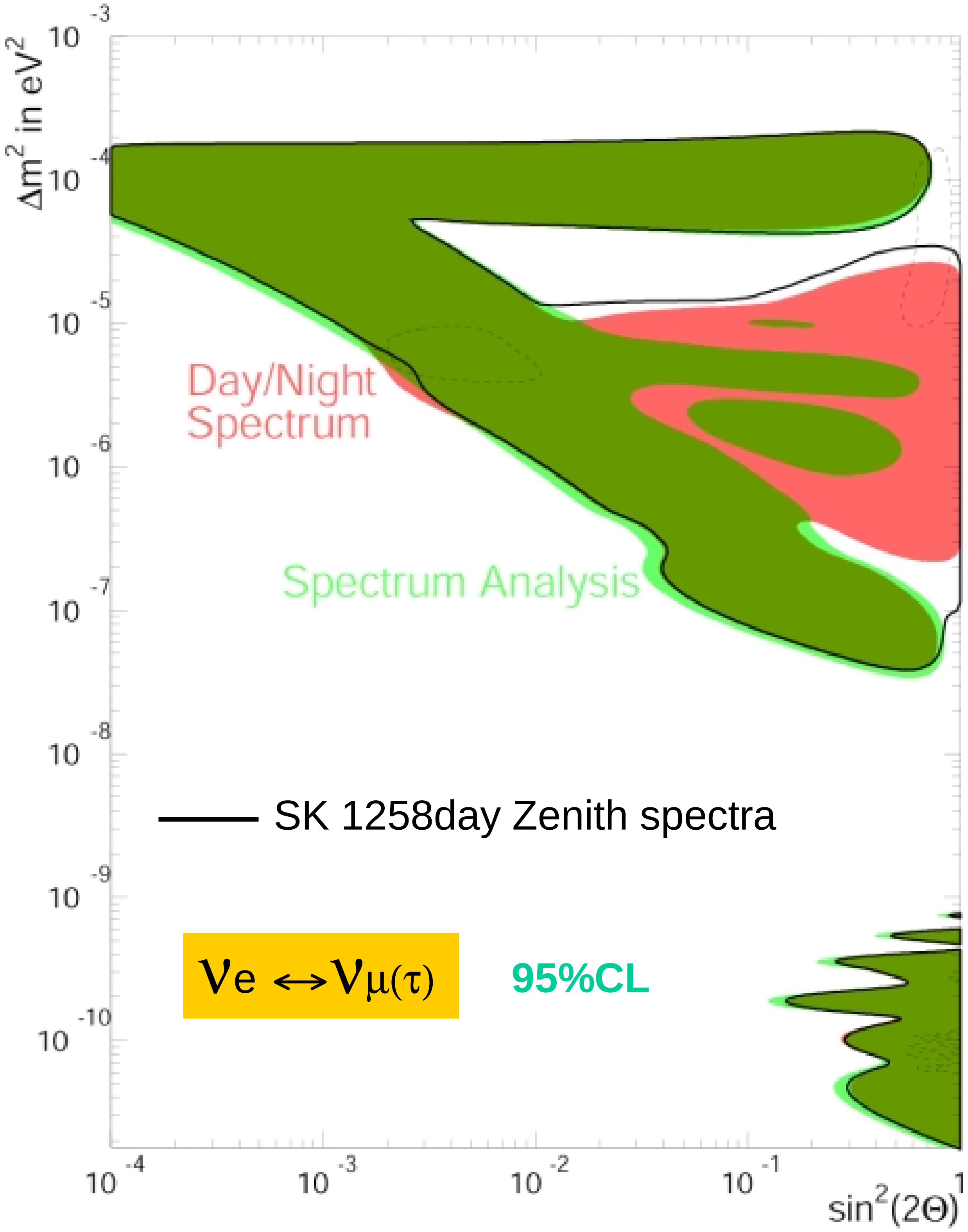
How SMA region is sensitive (preliminary)



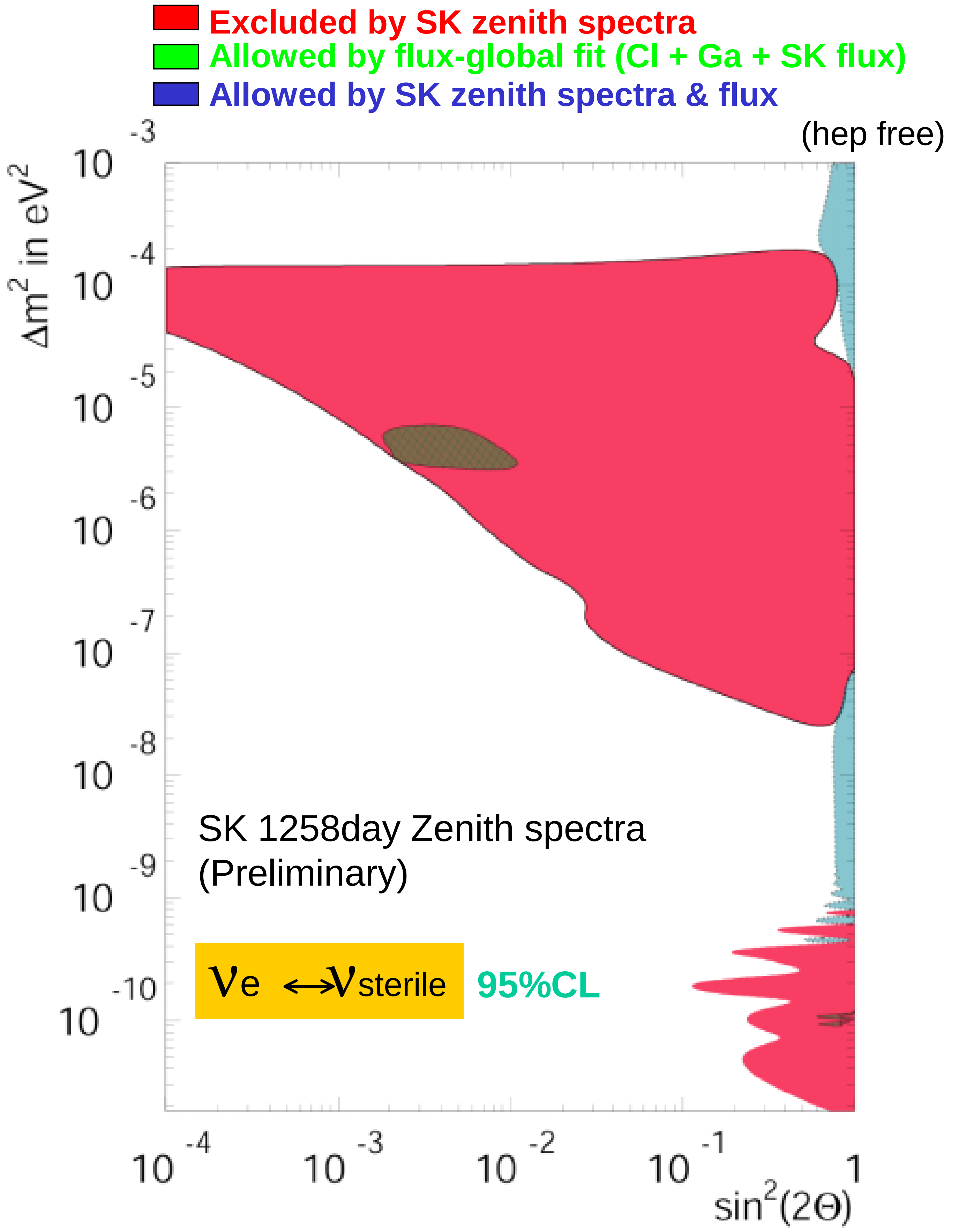
Confidence level at SMA region changes rather rapidly.

(preliminary)

Comparison among different analyses



Oscillation analysis (SK vs. global, sterile)

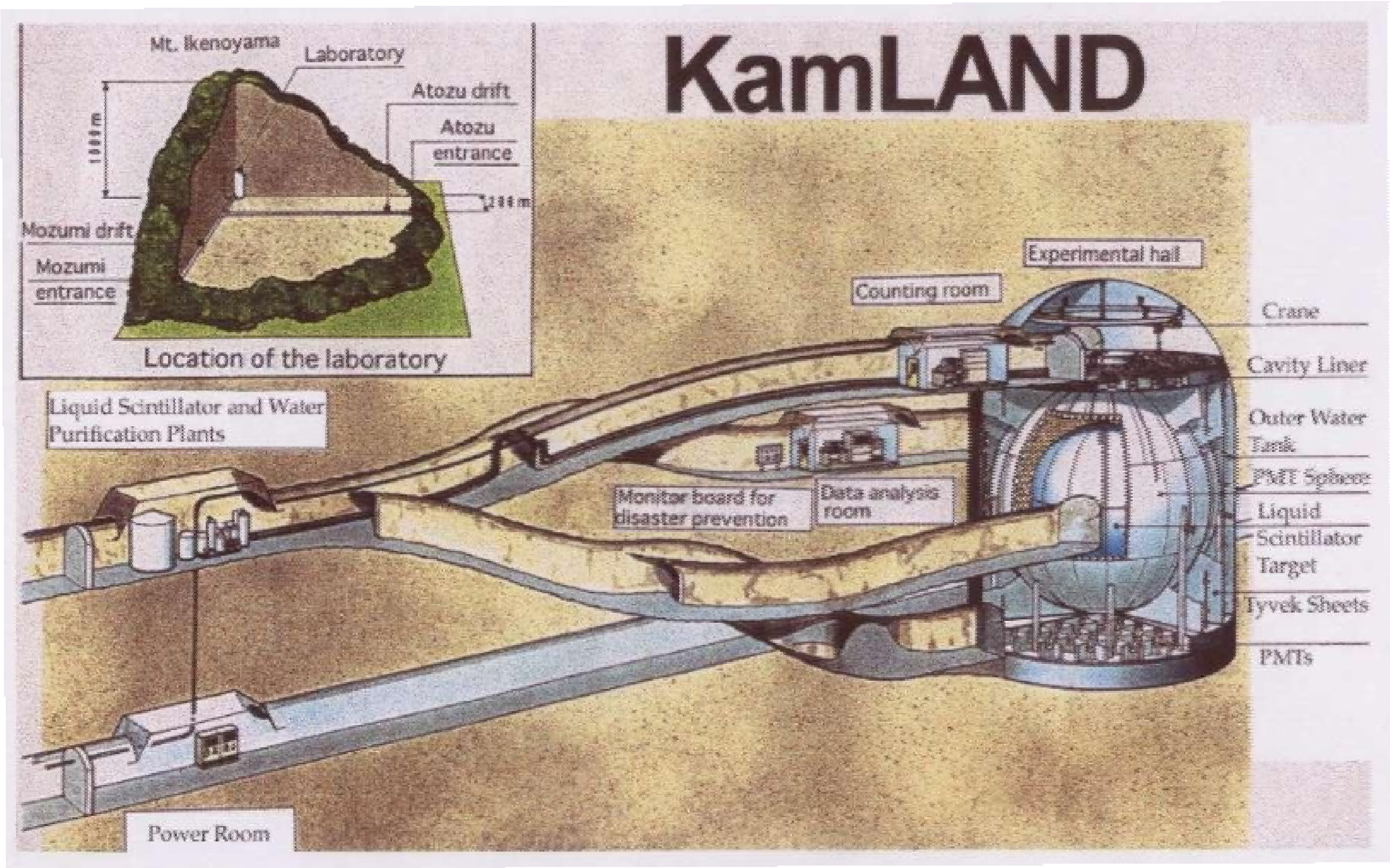


2-flavor sterile solutions are disfavored at 95% C.L. by comparing flux-global fit and SK zenith spectra

KamLAND

http://www.awa.tohoku.ac.jp/KamLAND

Kamioka Liquid scintillator Anti-Neutrino Detector



long baseline
reactor experiment

converted from
KAMIOKANDE

hosted by
Tohoku University

Filling: Apr. 2001~
Observation: Oct. 2001~

1,000 m^3 liq. scint.

1,300 17-inch PMTs
+600 20-inch PMTs

22+14% coverage

anti: 3,000m^3 water

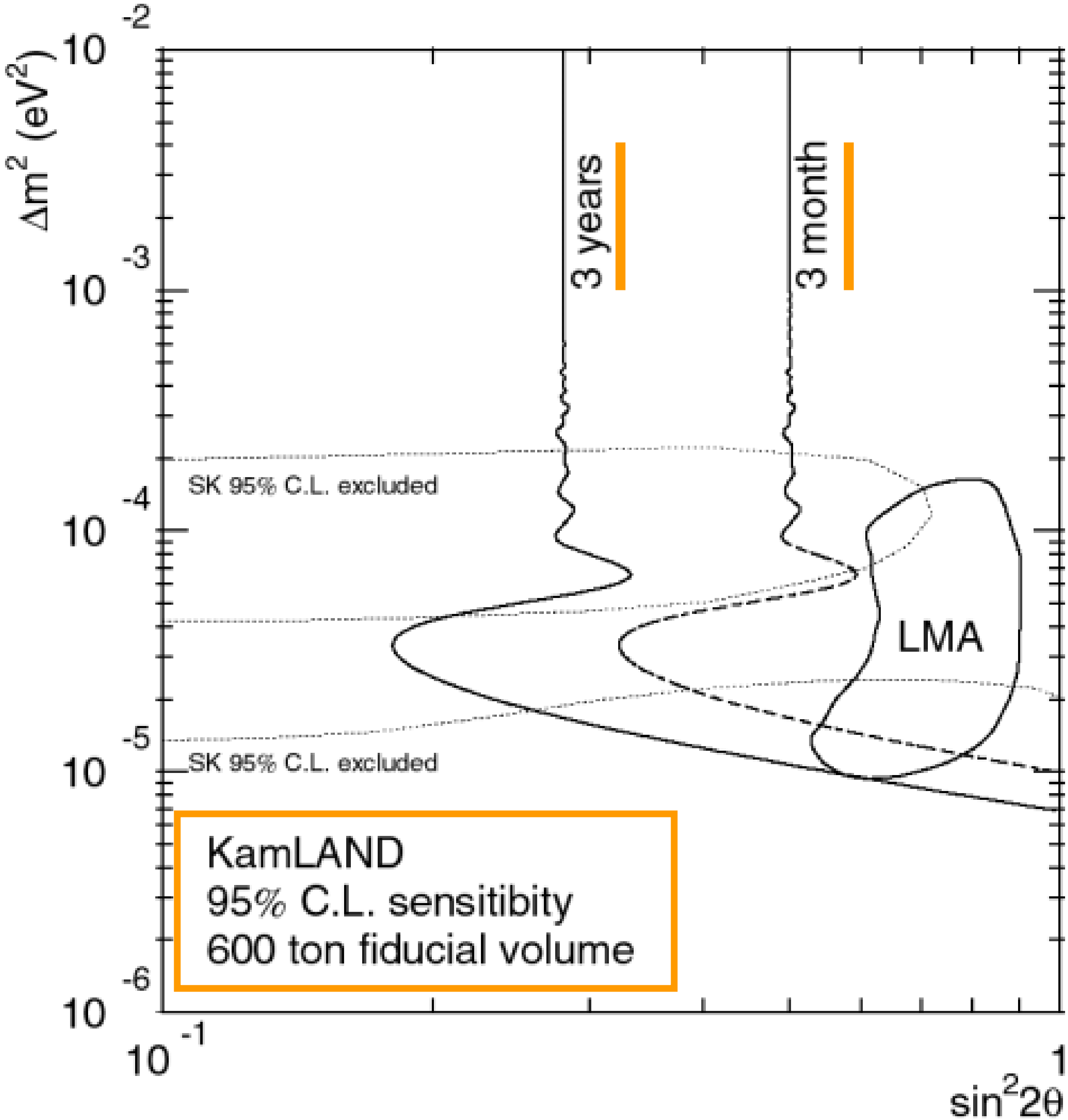
reactor L~170km

700 events/kt/year

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

(E_{th} = 1.8MeV)

KamLAND: sensitivity



From K.Inoue (Tohoku Univ.)

Summary

•1258day results (Preliminary)

Improved signal extraction method is used

Energy region: 5.0-20MeV

^{8}B Flux= 2.32 $\pm$0.03(stat.) $\pm^{0.08}_{0.07}$(syst.) [x10^6/cm^2/s]

$$\frac{N-D}{(N+D)/2} = 0.033 \pm 0.022(stat.) \pm^{0.013}_{0.012} (sys.)$$

1.3σ (including sys. err.)

Spectrum: χ^2 for flat = 19.0 / 18d.o.f. 39%C.L.

Hep flux < 40 x 10^3 /cm^2/s (90%C.L.)
(4.3 x BP2000 SSM)

Seasonal: χ^2 for eccentricity = 3.9 / 7d.o.f. 79%C.L.
(including sys. err.)

Oscillation analysis:

- New data binning is used
- SK favors large mixing
- 2-flavor sterile solutions are disfavored
- C.L. in SMA region changes rather rapidly