

# **News on Solar Neutrinos from Super-Kamiokande**

**VIII International Workshop on "Neutrino Telescopes"**

**23 February 1999**

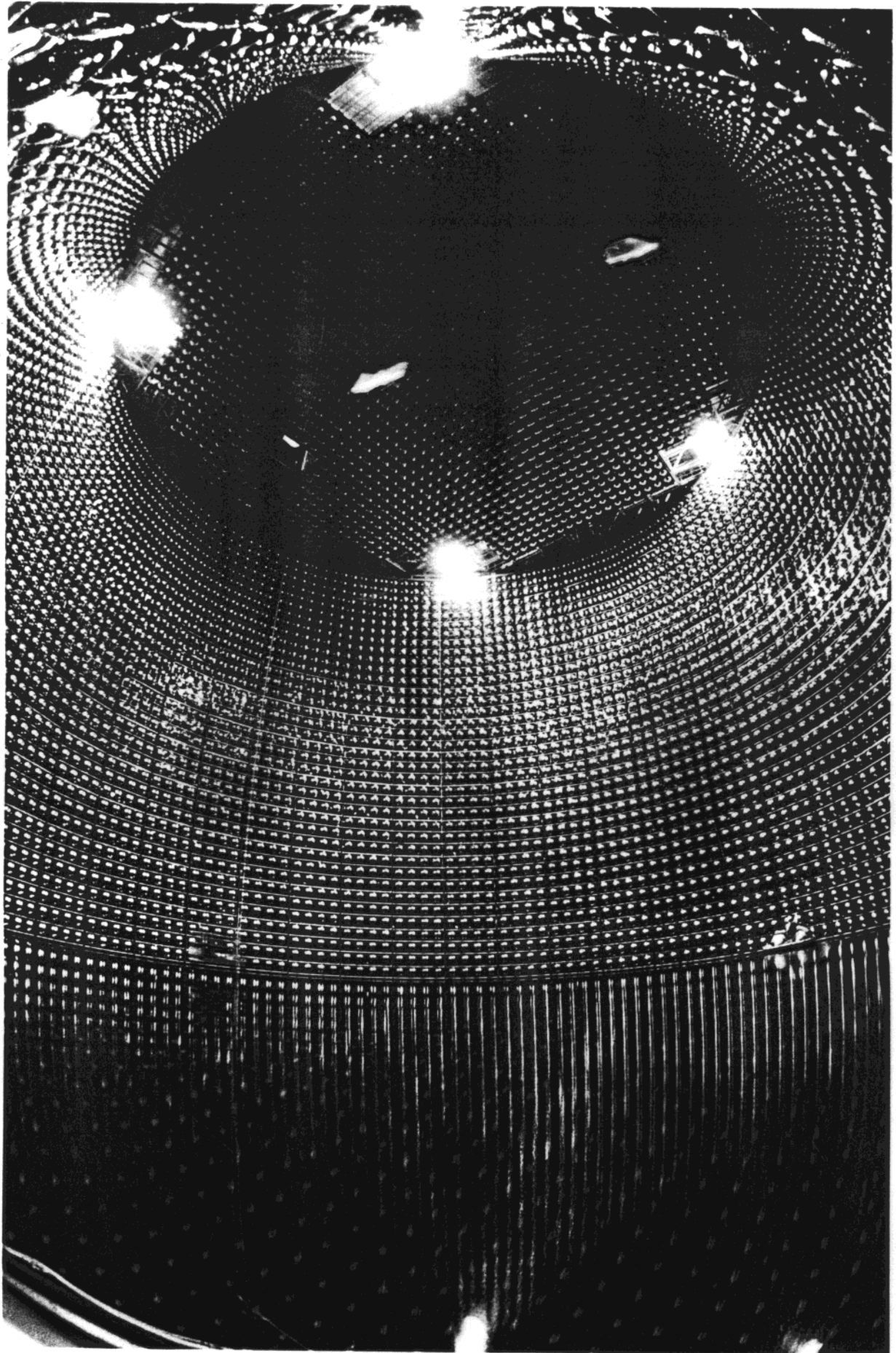
**Kunio Inoue**

**Research Center for Neutrino Science, Tohoku University**

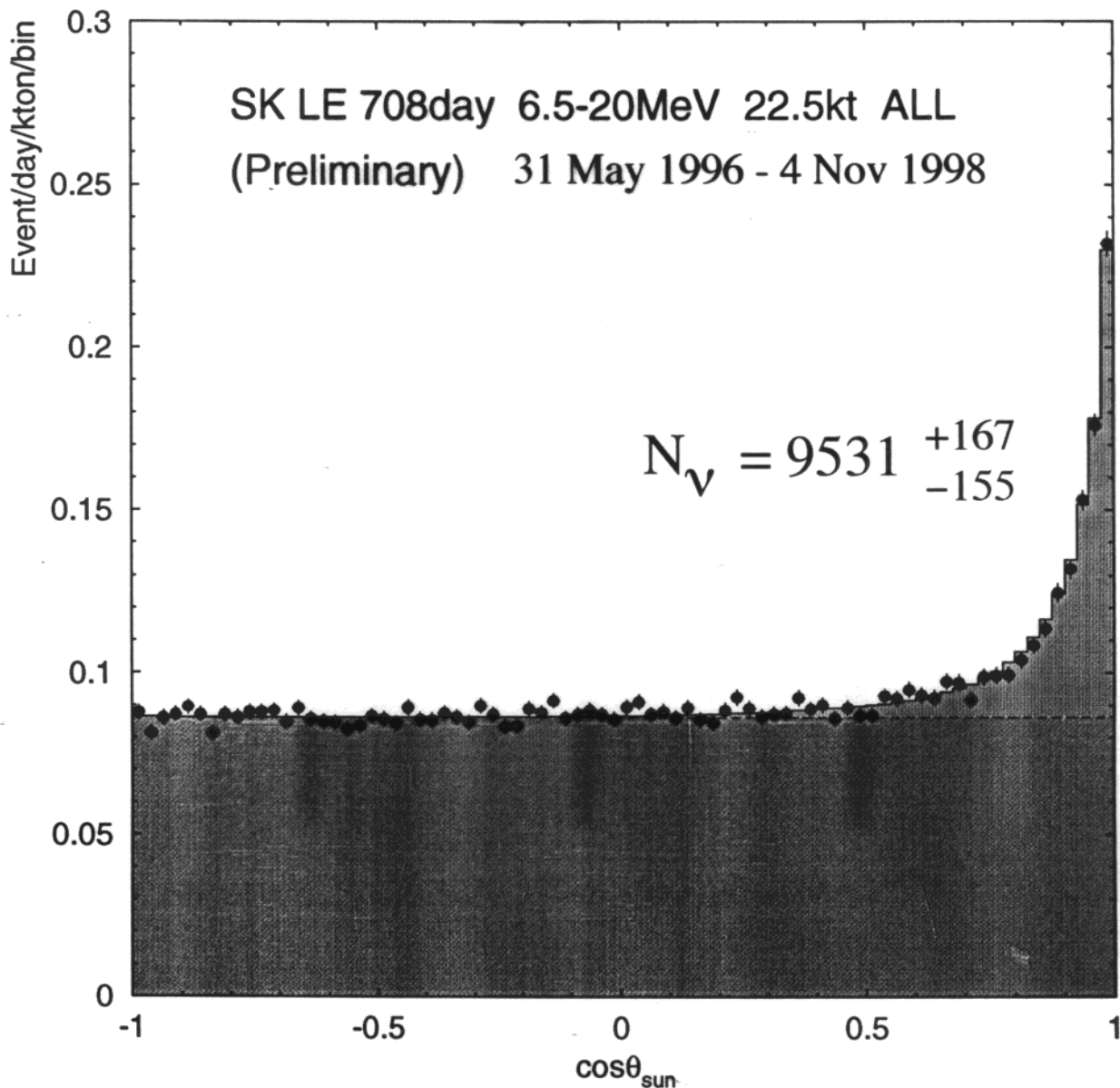
# Contents

- ◇ updated flux result with 708 days of data
- ◇ Day-Night variation
- ◇ Super Low Energy (SLE) data
- ◇ Spectrum with SLE data
- ◇ Hep-flux-free spectrum analysis
- ◇ Seasonal variation
- ◇ Conclusions

Jan 1996



# Updated flux result with 708 days of data



$$\phi(^8\text{B}) = 2.419 \begin{matrix} +0.042 \\ -0.039 \end{matrix} \text{ (stat)} \begin{matrix} +0.068 \\ -0.065 \end{matrix} \text{ (sys)} \times 10^6 \text{ /cm}^2\text{/sec}$$

$$\text{Data/SSM}_{\text{BP98}} = 0.470 \pm 0.008 \pm 0.013$$

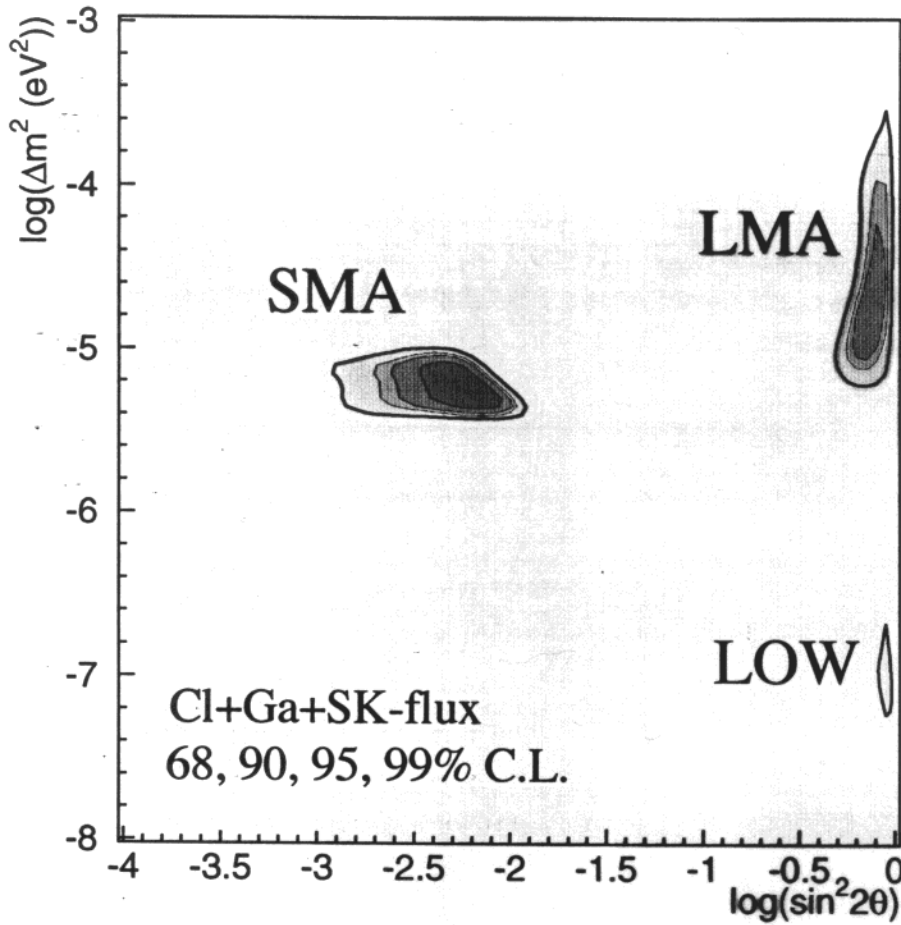
$$\text{Data/SSM}_{\text{BTCM98}} = 0.502 \pm 0.008 \pm 0.014$$

# Systematic Errors

for 22.5 kton,  
6.5-20MeV

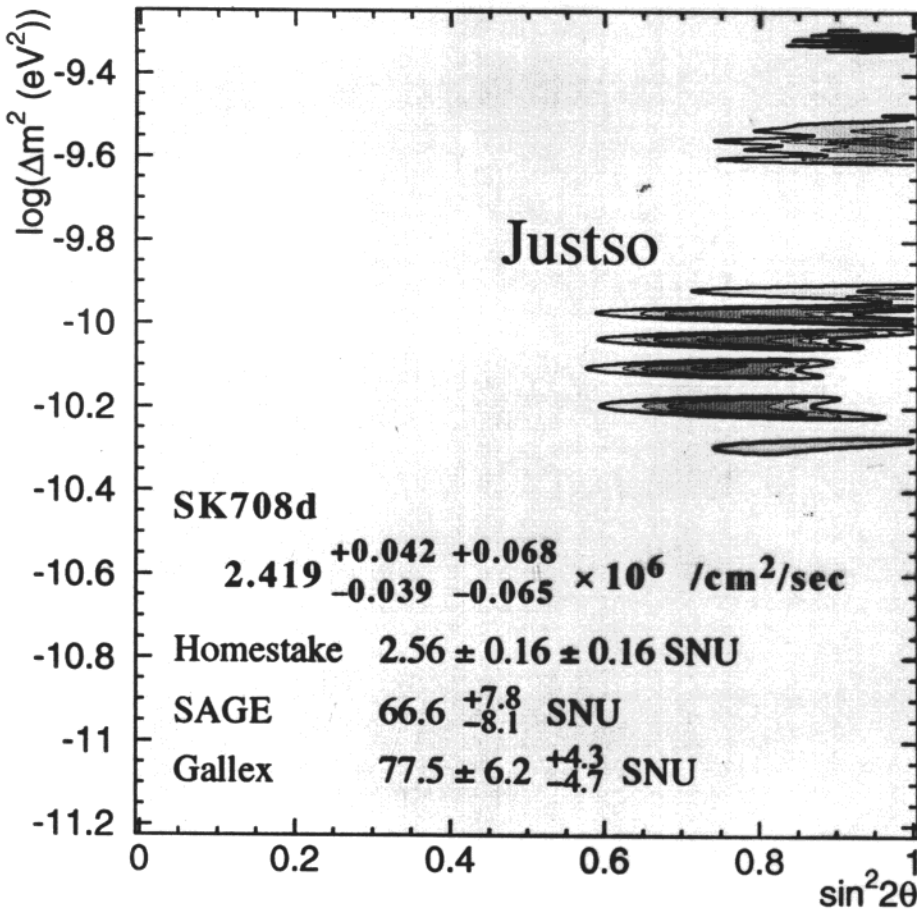
	Flux	Seasonal	Day-Night binned data
E-Scale, Resolution, $^8\text{B}$ spectrum	+1.9 -1.8	+1.2 -1.1	+1.2 -1.1
Trigger Efficiency	$\pm 0.2$	$\pm 0.2$	-
Noise event Cut	$\pm 0.7$	-	-
Reduction	$\pm 0.2$	-	$\pm 0.1$
Vertex Shift	$\pm 1.5$	-	-
non-flat B.G.	$\pm 0.1$	$\pm 0.1$	$\pm 0.4$
Direction	$\pm 1.0$	-	-
Cross Section	$\pm 0.5$	-	-
Spallation Dead Time	$\pm 0.1$	$\pm 0.1$	$\pm 0.1$
Live Time	$\pm 0.1$	$\pm 0.1$	$\pm 0.1$
<b>Total</b>	+2.8 -2.7	+1.2 -1.1	+1.3 -1.2

# Global fit with SK 708 days flux

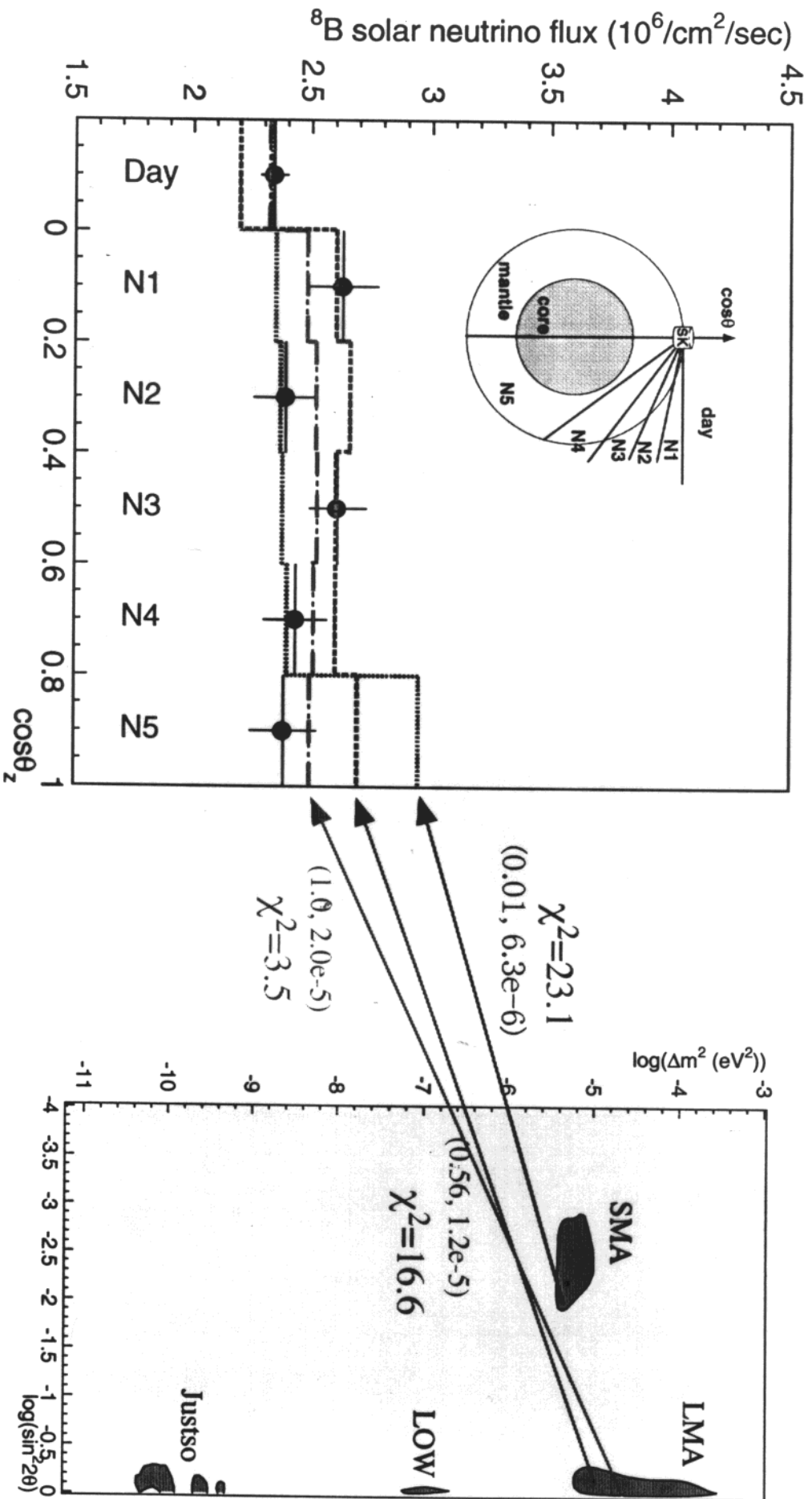


$\chi^2_{\min} = 0.9$   
@ (6.3e-3, 5.0e-6)

no oscillation  
 $\chi^2 = 62.0$



# Day-Night variation



$$\frac{N}{D} - 1 = 0.060 \pm 0.036 \text{ (stat)} \pm 0.008 \text{ (sys)}$$

$$\frac{N5}{\langle D, N1-N4 \rangle} - 1 = -0.013 \quad \begin{matrix} +0.060 \\ -0.058 \end{matrix} \text{ (stat)} \pm 0.013 \text{ (sys)}$$

# $\chi^2$ definitions

Day-Night variation

$$\chi_{DN}^2 = \sum_{i=D, N, \dots, N5} \left\{ \frac{\phi_i - \alpha \times \phi_i^{osci} (\sin^2 2\theta, \Delta m^2)}{\sqrt{\sigma_i^2 + \sigma_{sys,i}^2}} \right\}^2$$

$\alpha$ : free

DN spectra

$$\chi_{DN-spectra}^2 = \sum_{i=D, N} \sum_{j=1, 18} \left\{ \frac{\phi_{ij} - \phi_{ij}^{osci} \times \alpha \times f_j(\epsilon_{exp}, \epsilon_{theo})}{\sigma_{ij}} \right\}^2 + \left( \frac{\epsilon_{exp}}{\sigma_{exp}} \right)^2 + \left( \frac{\epsilon_{theo}}{\sigma_{theo}} \right)^2$$

$\alpha$ : free     $\sigma_{ij} = \sqrt{\sigma_{stat,ij}^2 + \sigma_{uncorr.sys,ij}^2}$      $f$ : response function     $\epsilon$ : correlated errors

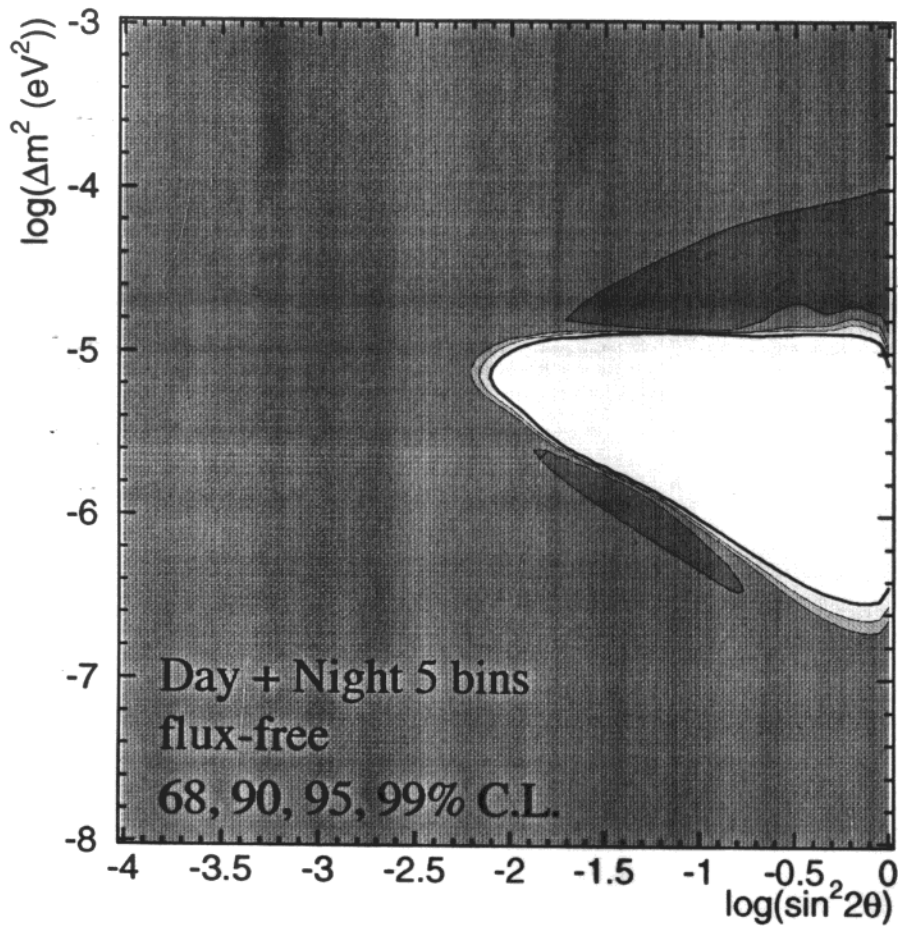
DN spectra, hep-free

$$\chi_{DN-spectra, hep-free}^2 = \sum_{i=D, N} \sum_{j=1, 18} \left\{ \frac{\phi_{ij} - (\phi_{8B,ij}^{osci} \times \alpha_{8B} + \phi_{hep,ij}^{osci} \times \alpha_{hep}) \times f_j(\epsilon_{exp}, \epsilon_{theo})}{\sigma_{ij}} \right\}^2 + \left( \frac{\epsilon_{exp}}{\sigma_{exp}} \right)^2 + \left( \frac{\epsilon_{theo}}{\sigma_{theo}} \right)^2$$

$\alpha_{8B}, \alpha_{hep}$ : free



# Day-Night variation

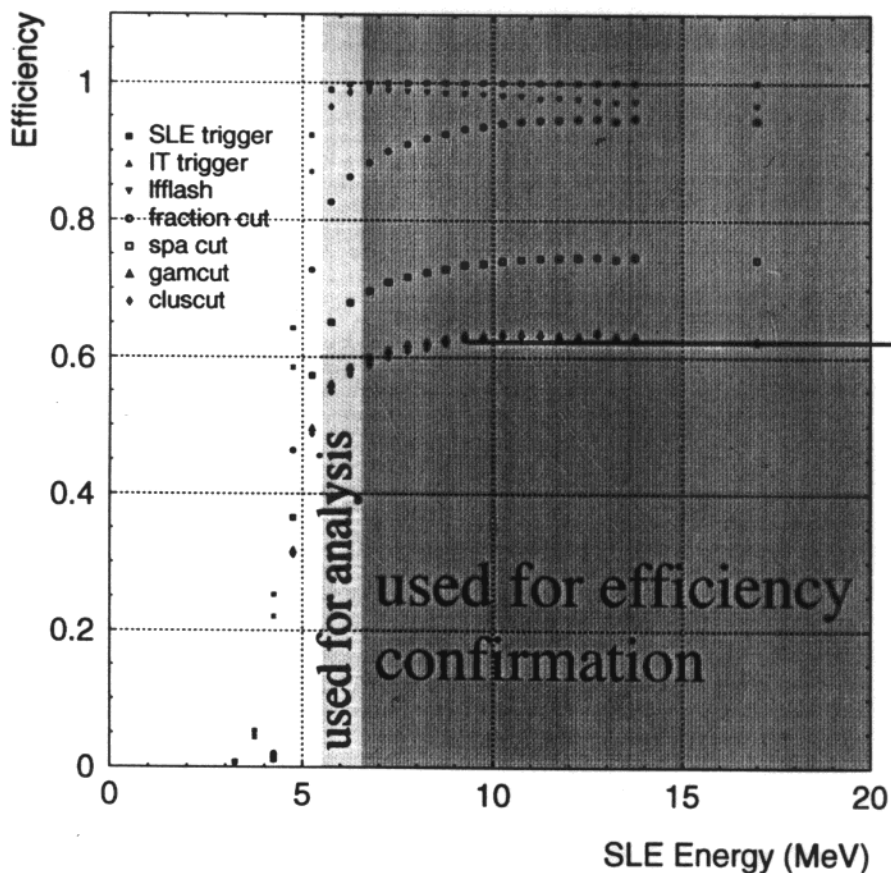
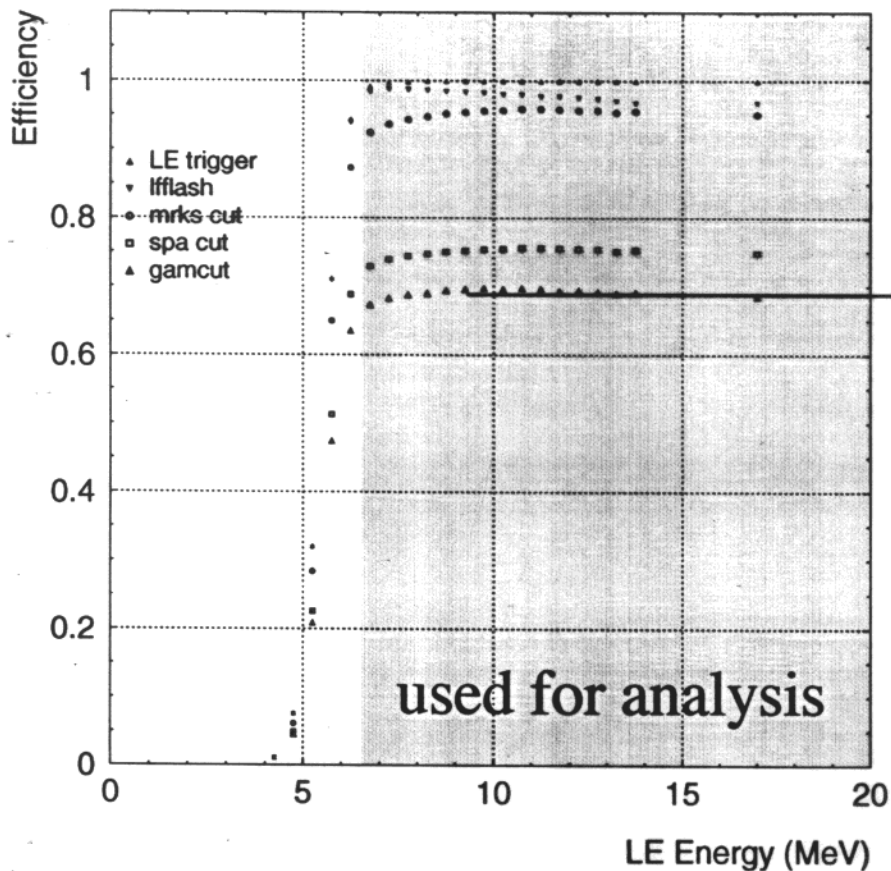


$$\chi^2_{\min} = 3.5$$

$$@ (1.0, 2.0e-5)$$

$$\chi^2_{\text{flat}} = 6.7$$

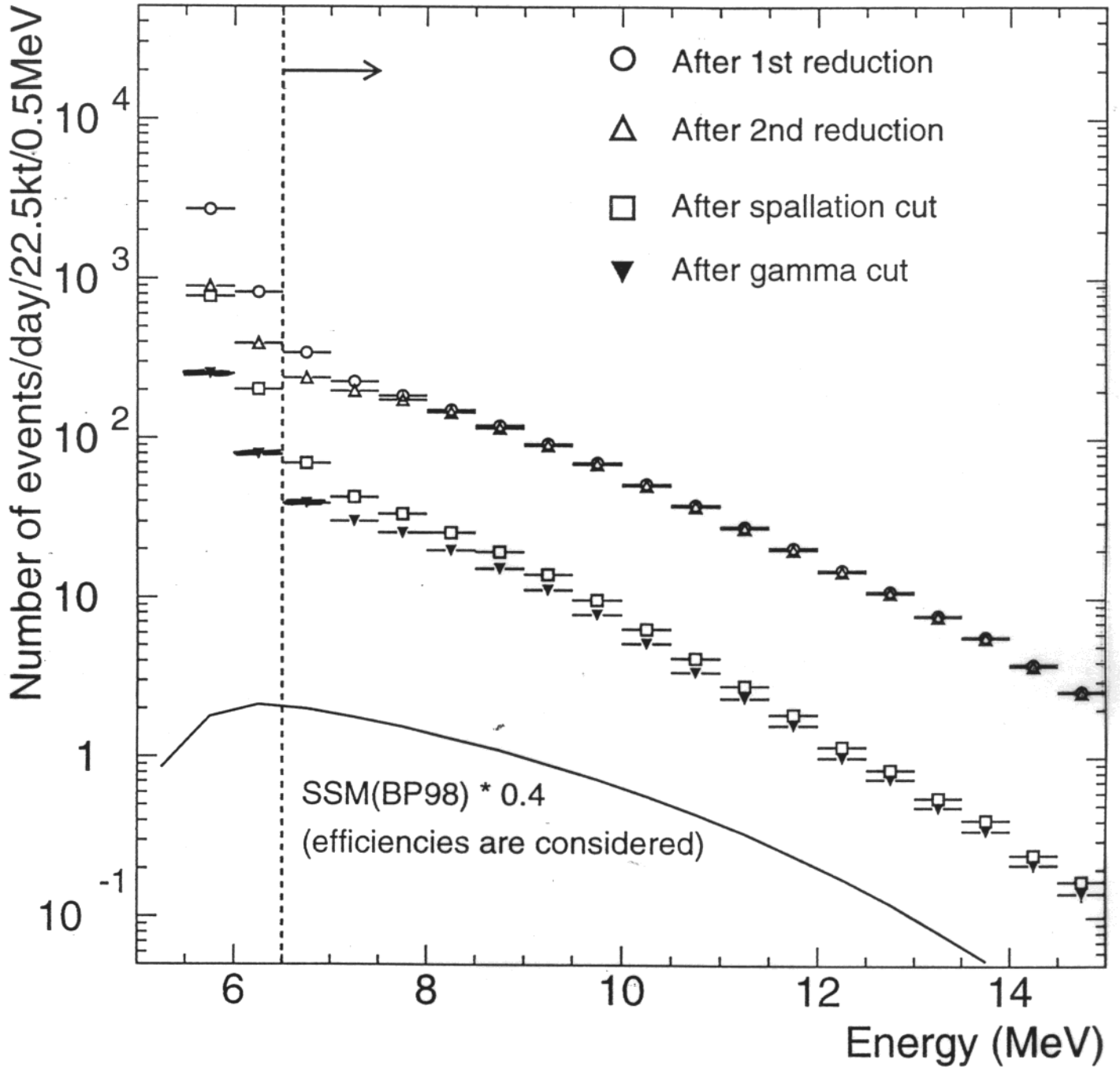
# Super Low Energy (SLE) Data



(Preliminary)

# Super-Kamiokande LE 708day

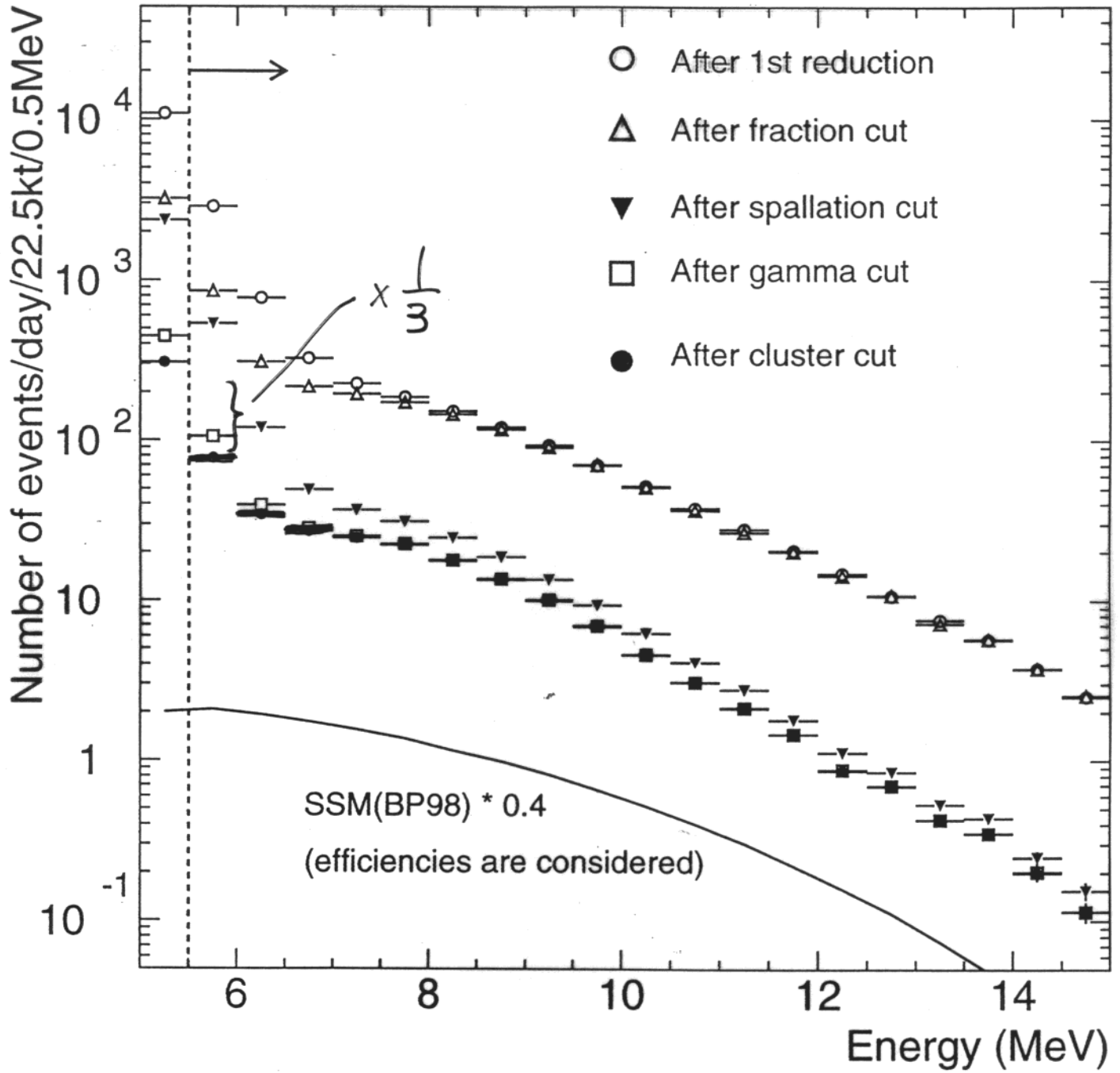
Fid. vol. 22.5kton, ALL



(Preliminary)

# Super-Kamiokande SLE 419day

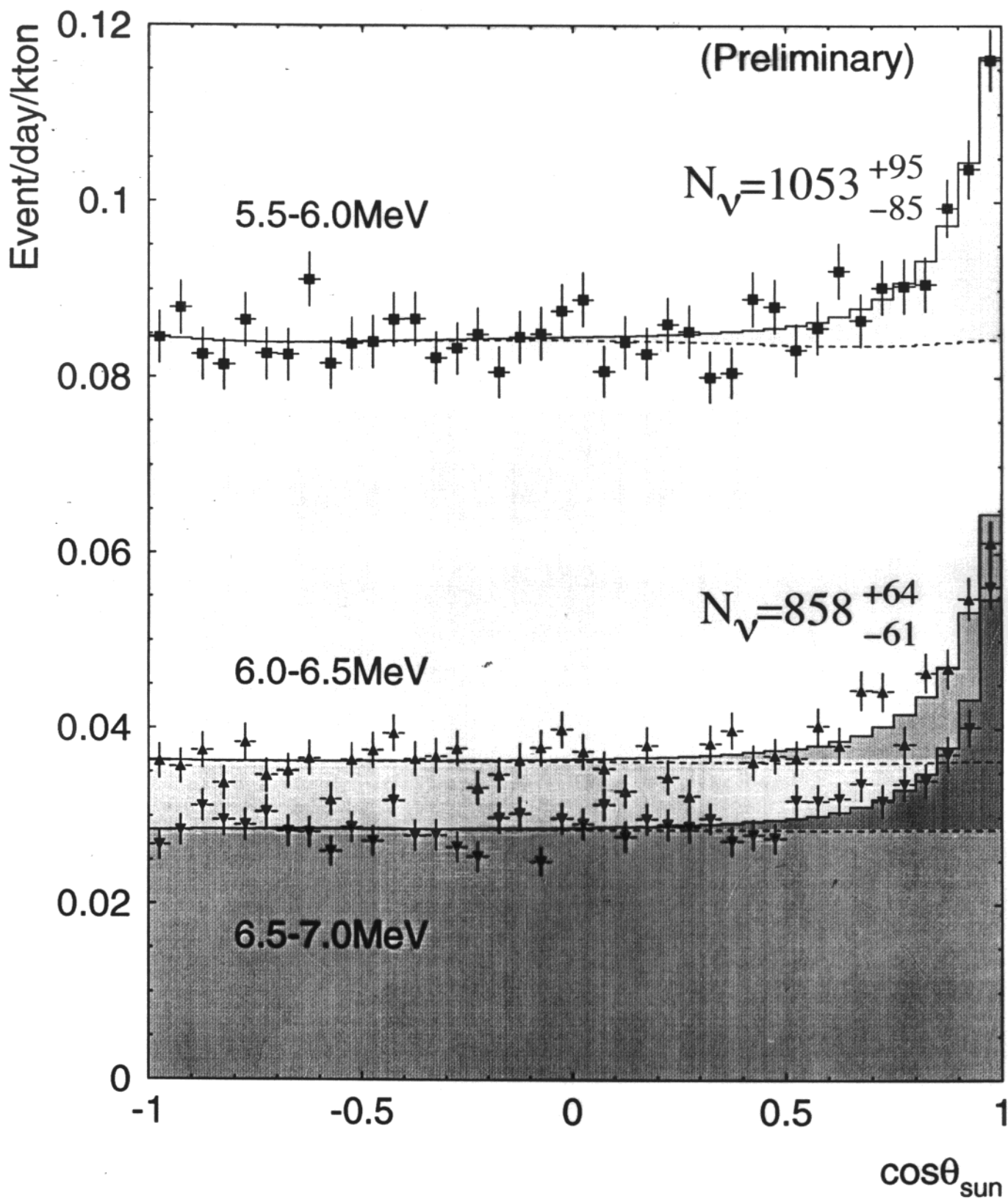
Fig. vol. 22.5kton, ALL



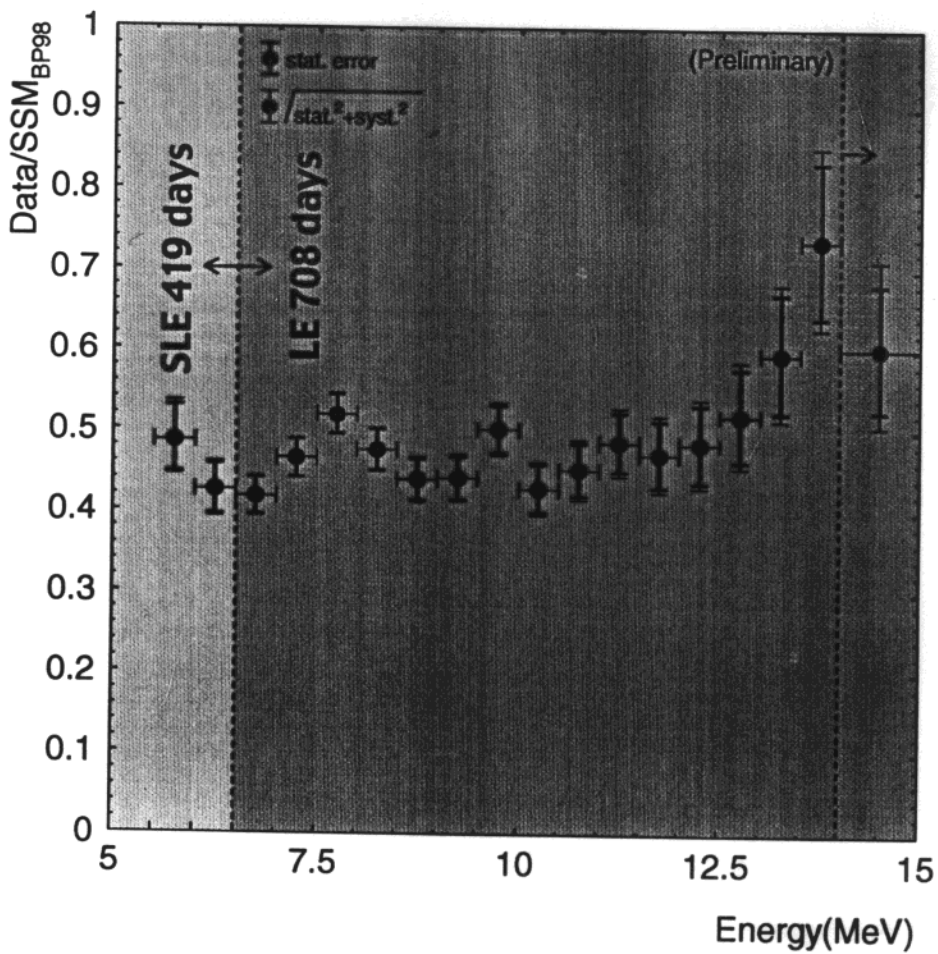
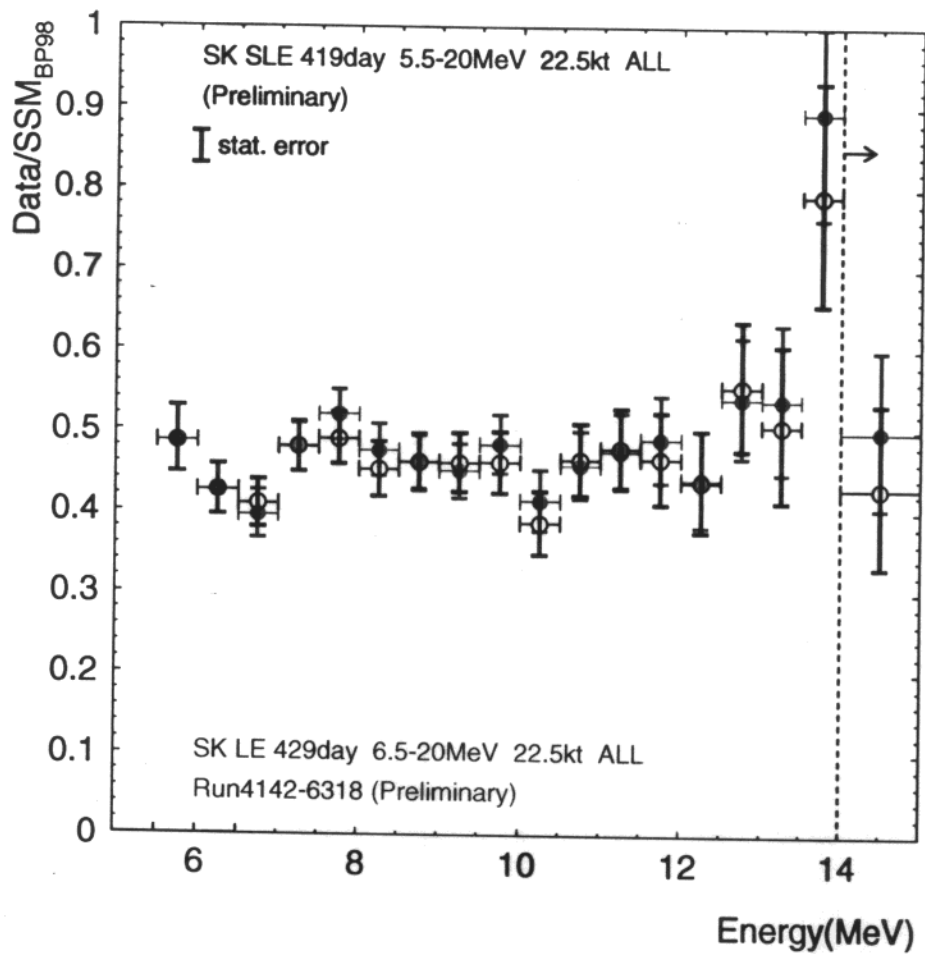
# Solar neutrino signal in the SLE data

SK SLE 419day 22.5kton

29 May 1997 - 4 Nov 1998

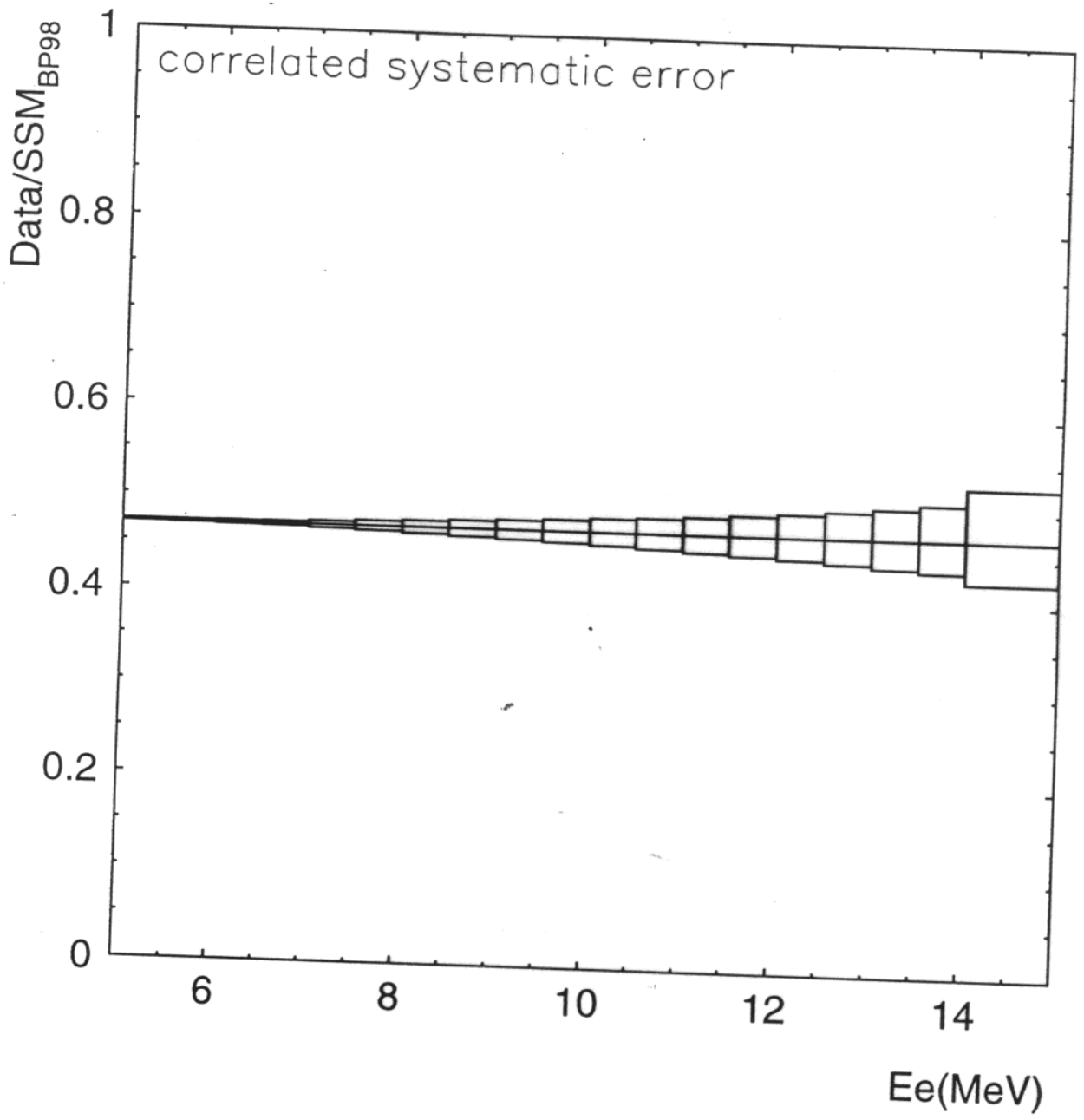


# Spectrum with SLE data



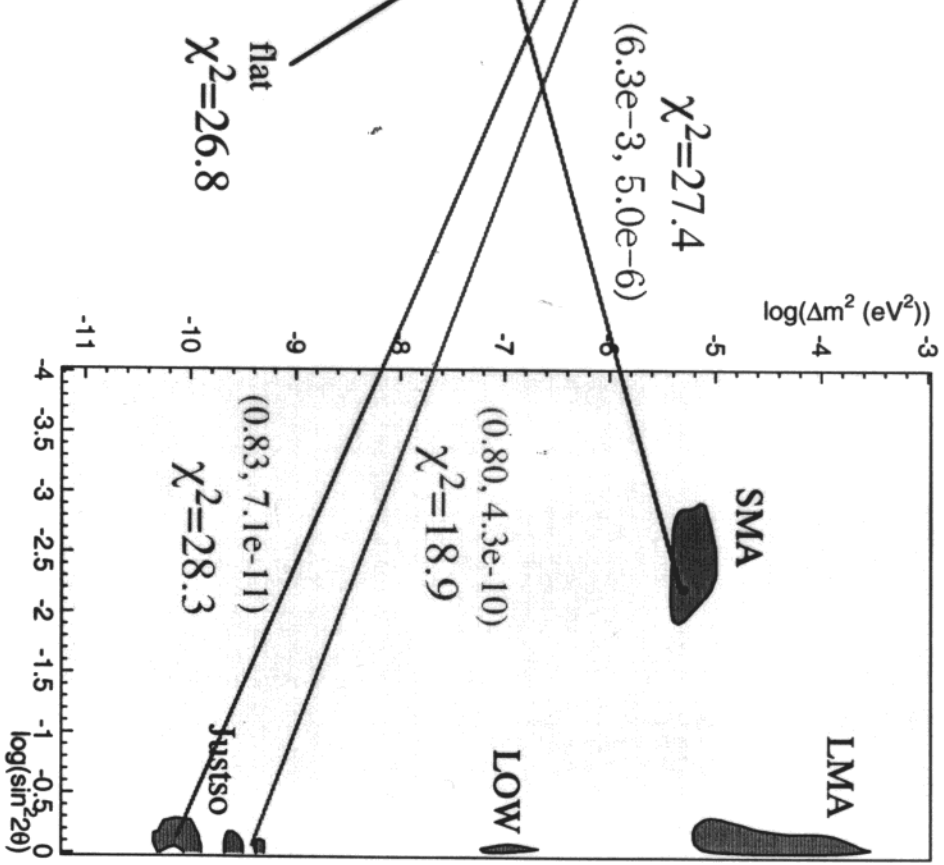
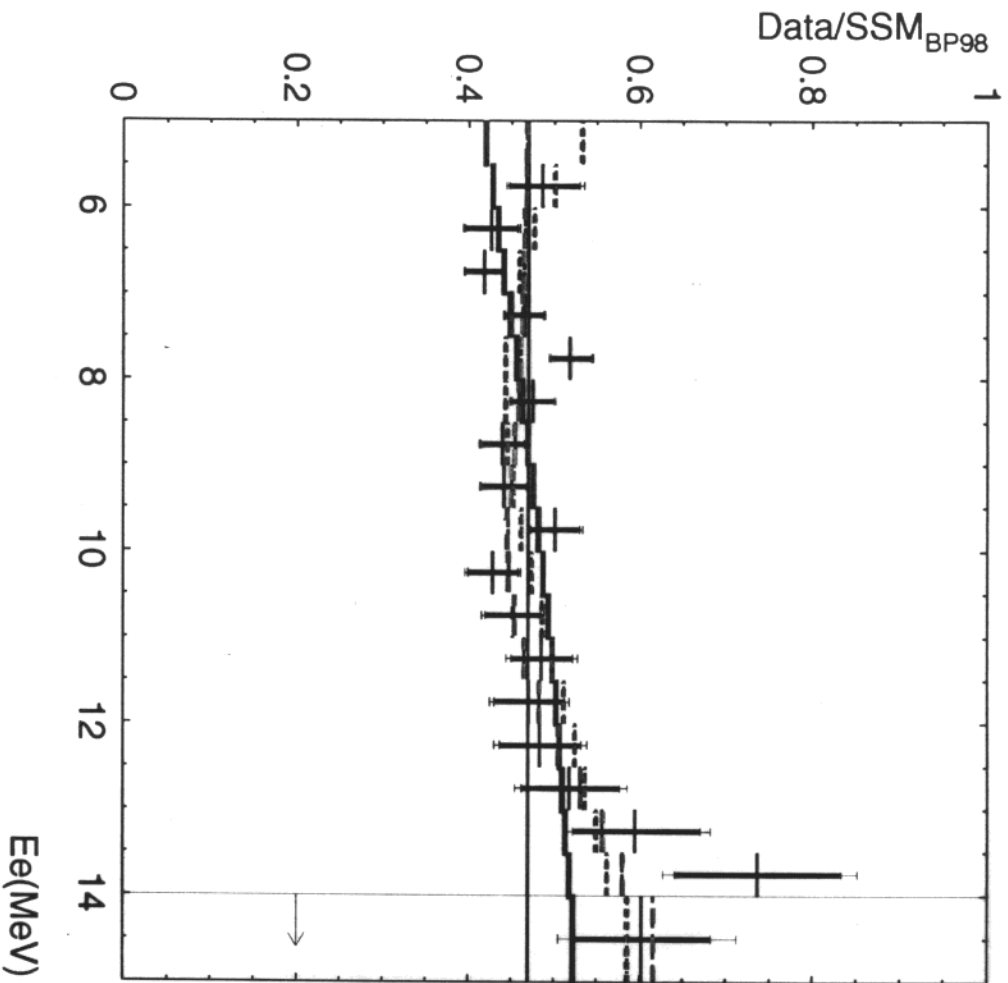
# Systematic Errors for energy spectrum

	SLE analysis		LE analysis	
	5.5-6.0	6.0-6.5	6.5-7.0	7.0-
<b>Correlated Error</b> E-Scale, Resolution, <sup>8</sup> B spectrum	see figure			
<b>Trigger Efficiency</b>	+2.6	+0.4	+1.1 -0.9	-
<b>Noise event Cut</b>	+2.7 -1.8	+2.4 -1.3	±0.7	←
<b>Reduction</b>	±0.2	←	←	←
<b>Vertex Shift</b>	±0.5	←	←	←
<b>non-flat B.G.</b>	±0.1	←	←	←
<b>Direction</b>	±1.0	←	←	←
<b>Cross Section</b>	±0.5	←	←	←
<b>Spallation Dead Time</b>	-	←	←	←
<b>Live Time</b>	-	←	←	←
<b>Relative between SLE &amp; LE</b>	±2.0	±2.0	-	←
<b>Total</b>	see figure			

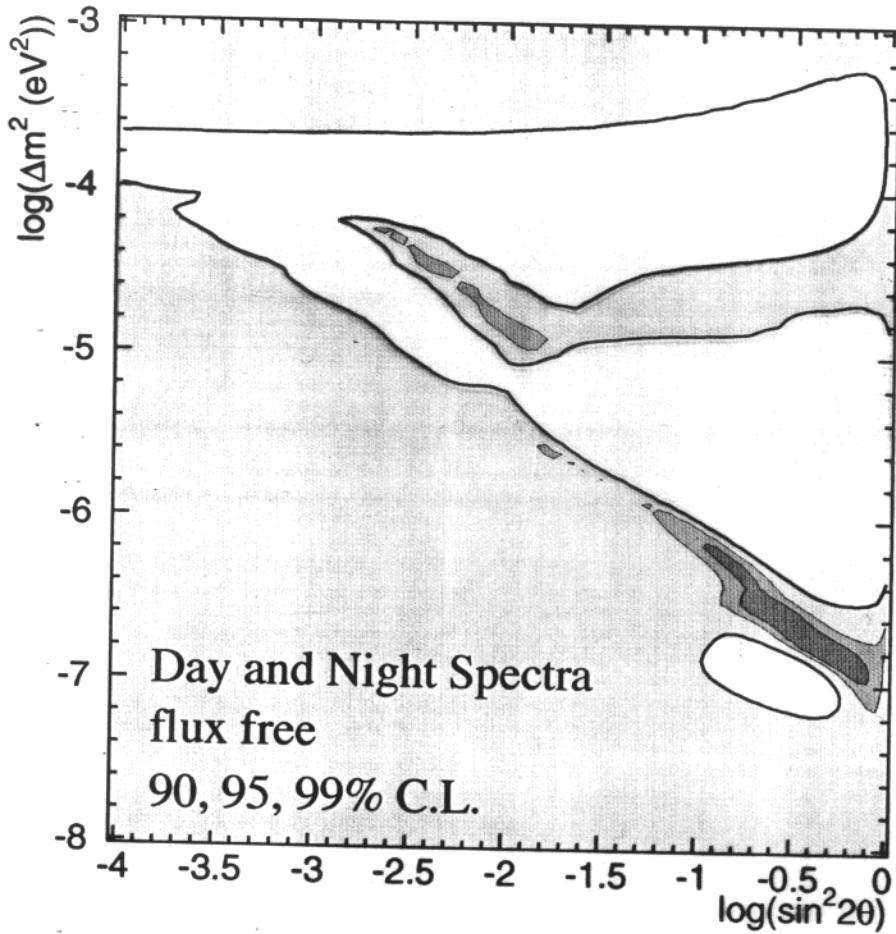




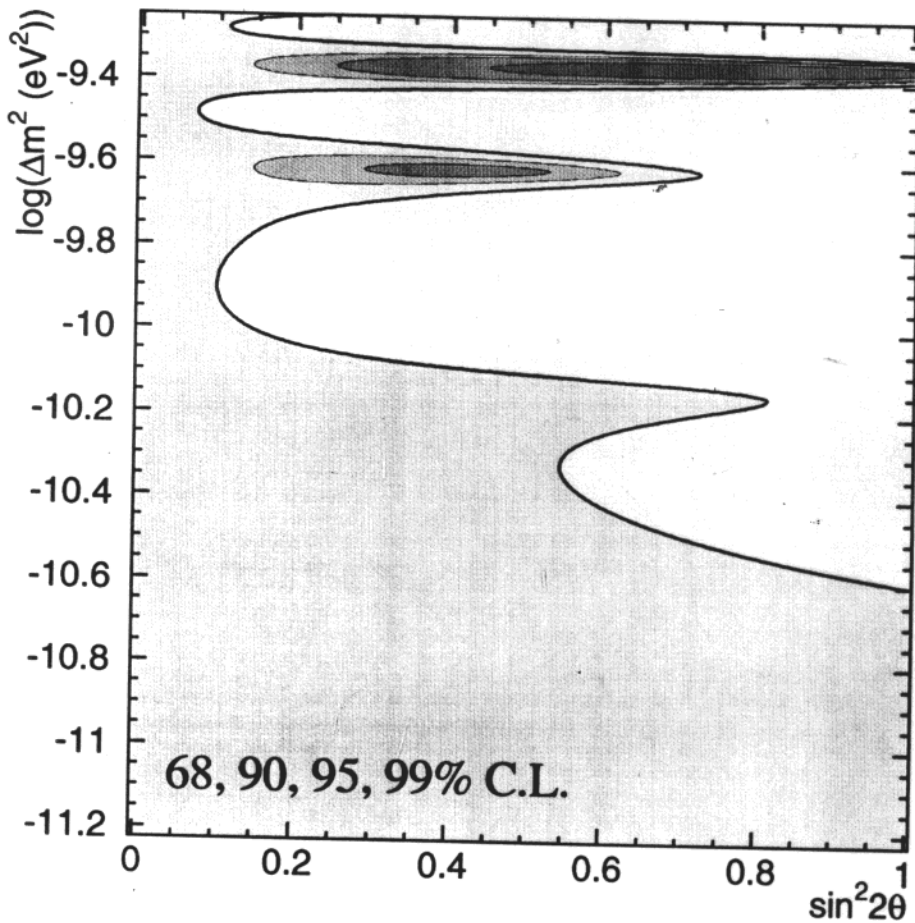
# Spectrum (18 bins, $^8\text{B}$ flux free)



# SK Day and Night Spectra (36 bins, $^8\text{B}$ flux free)

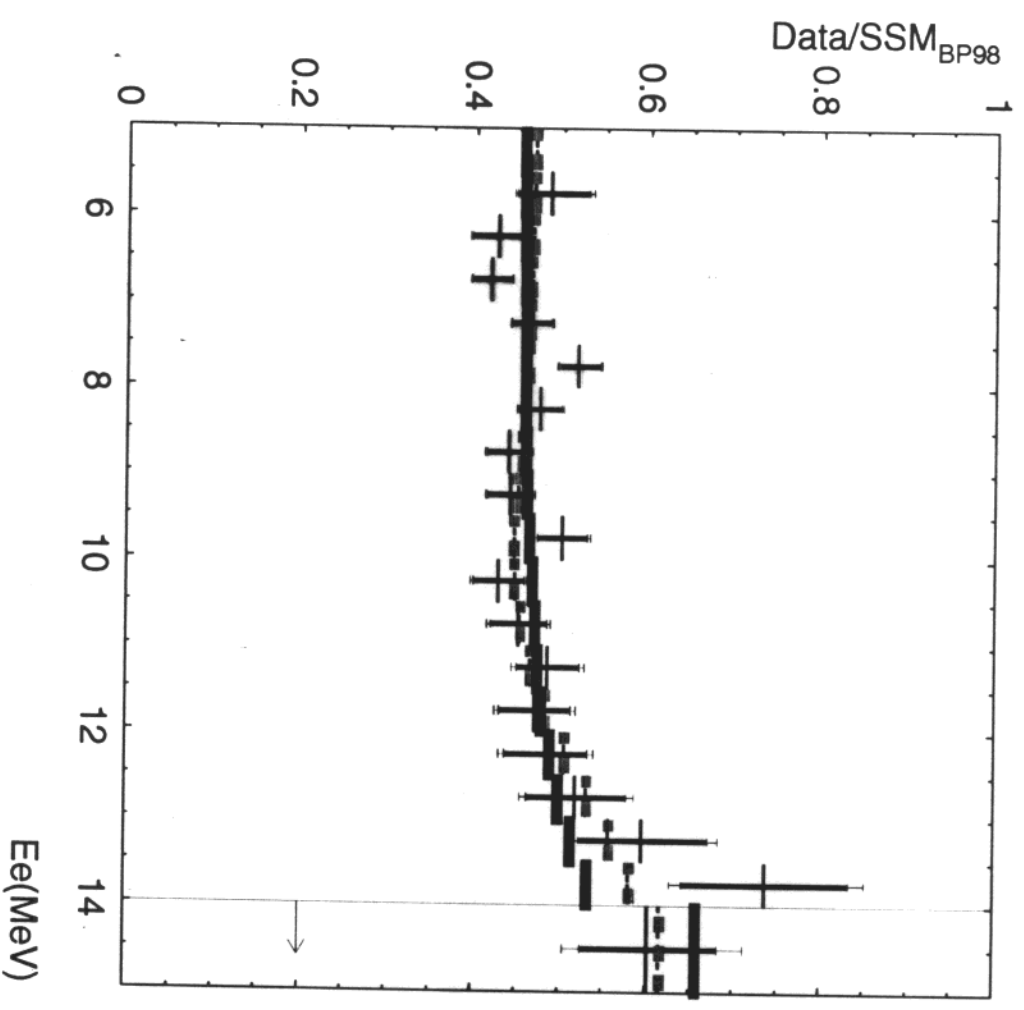


no oscillation  
 $\chi^2 = 55.0$



$\chi^2_{\min} = 47.0$   
@ (0.80,  $4.3\text{e-}10$ )

# Spectrum (18 bins, $^8\text{B}$ flux free, hep flux free)

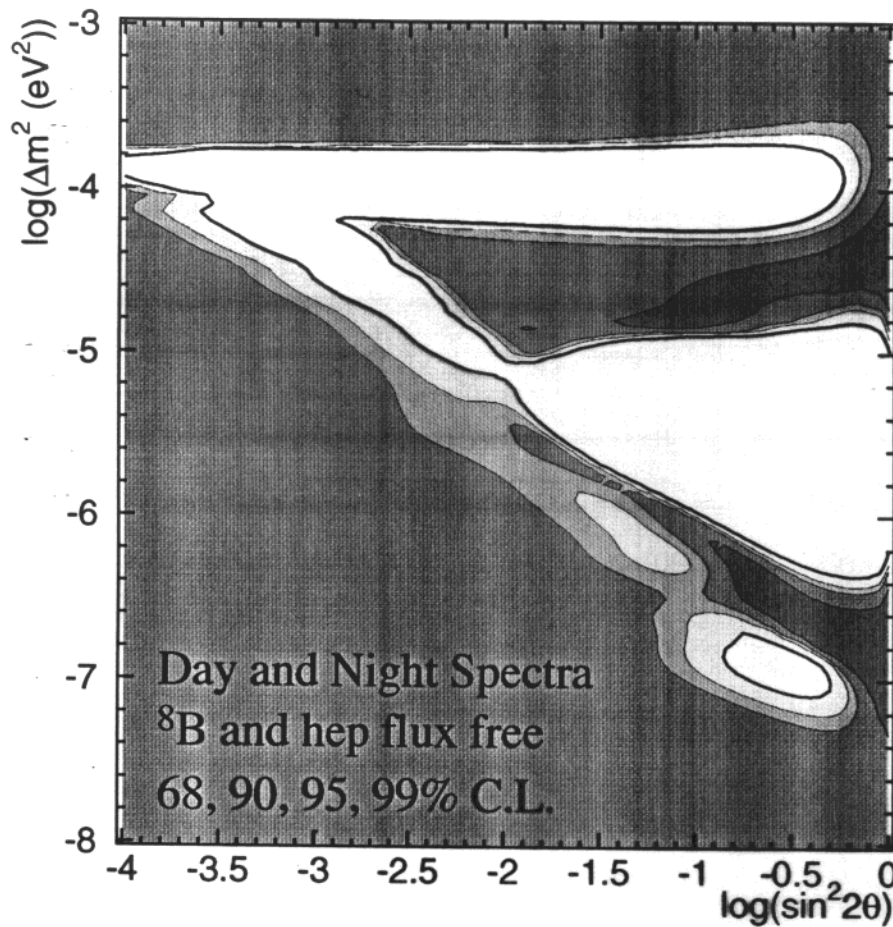


$\chi^2=21.9$  14 x hep

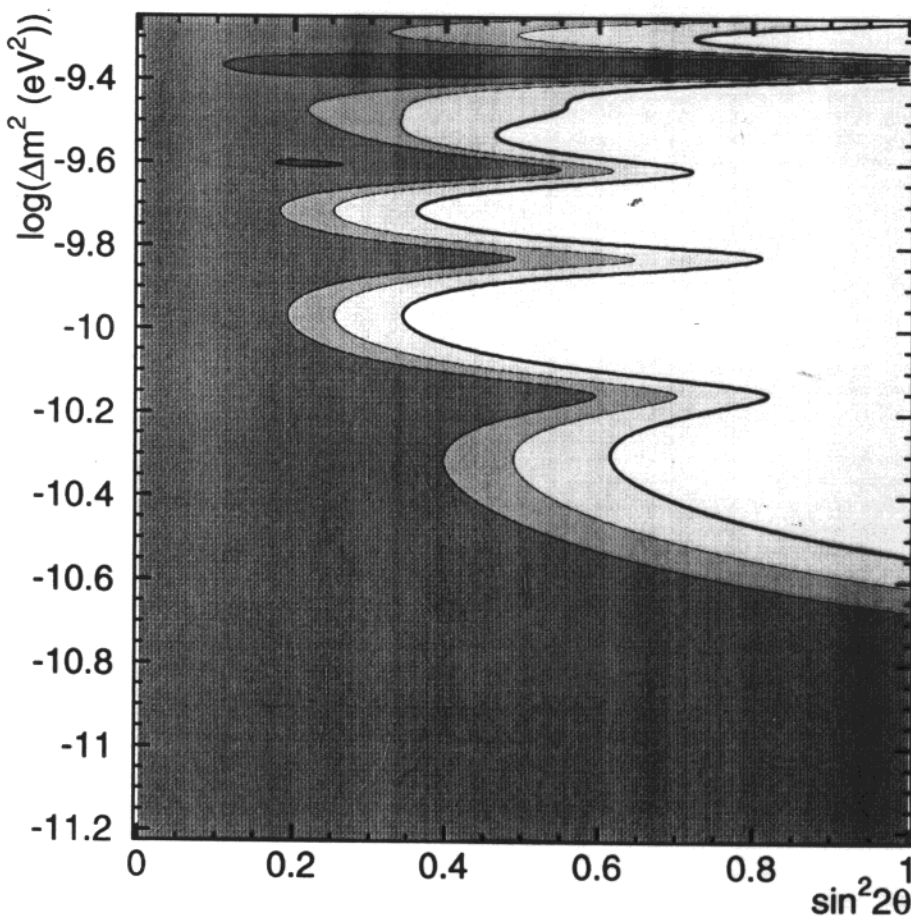
$\chi^2=18.9$   
(0.80, 4.3e-10)

**Best fit**  
in SSM hep analysis

# SK DN spectra (36 bins, $^8\text{B}$ and hep flux free)

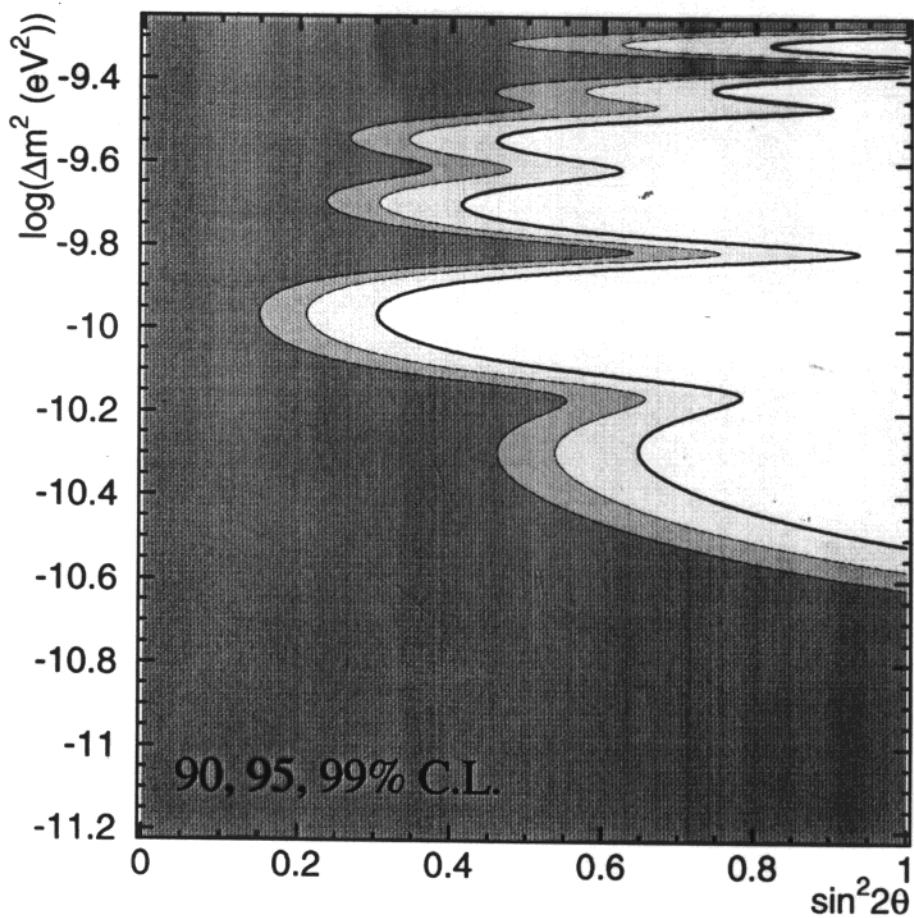
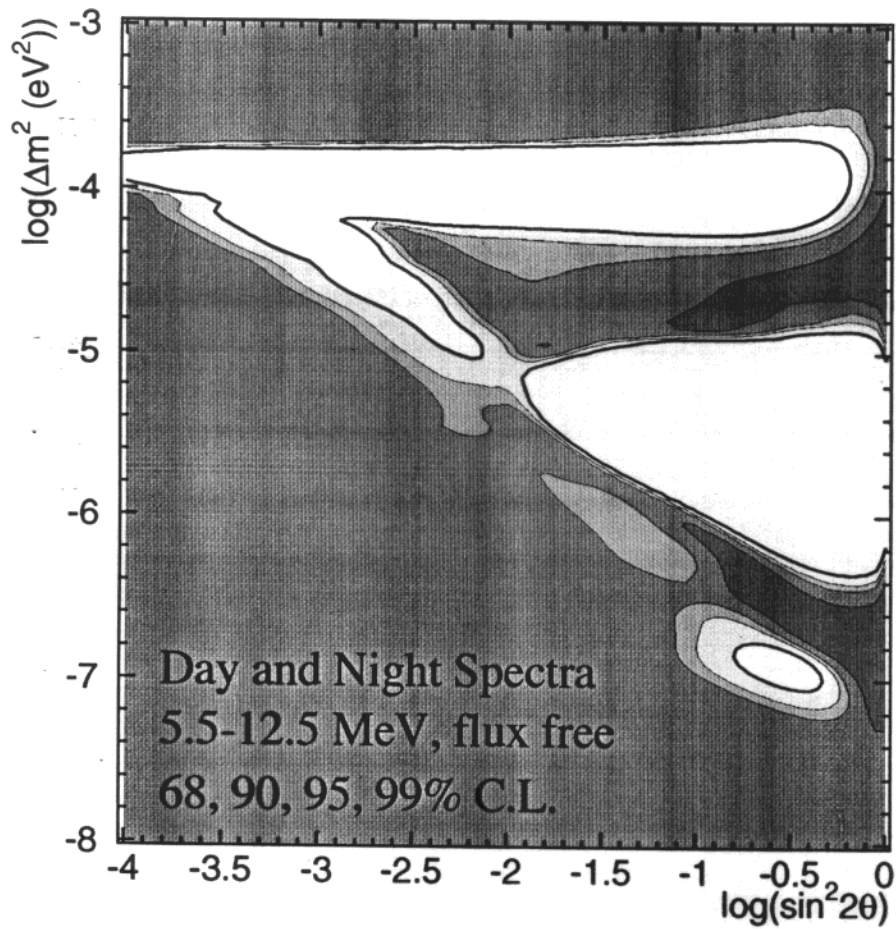


no oscillation  
 $\chi^2 = 49.9$  hep=14

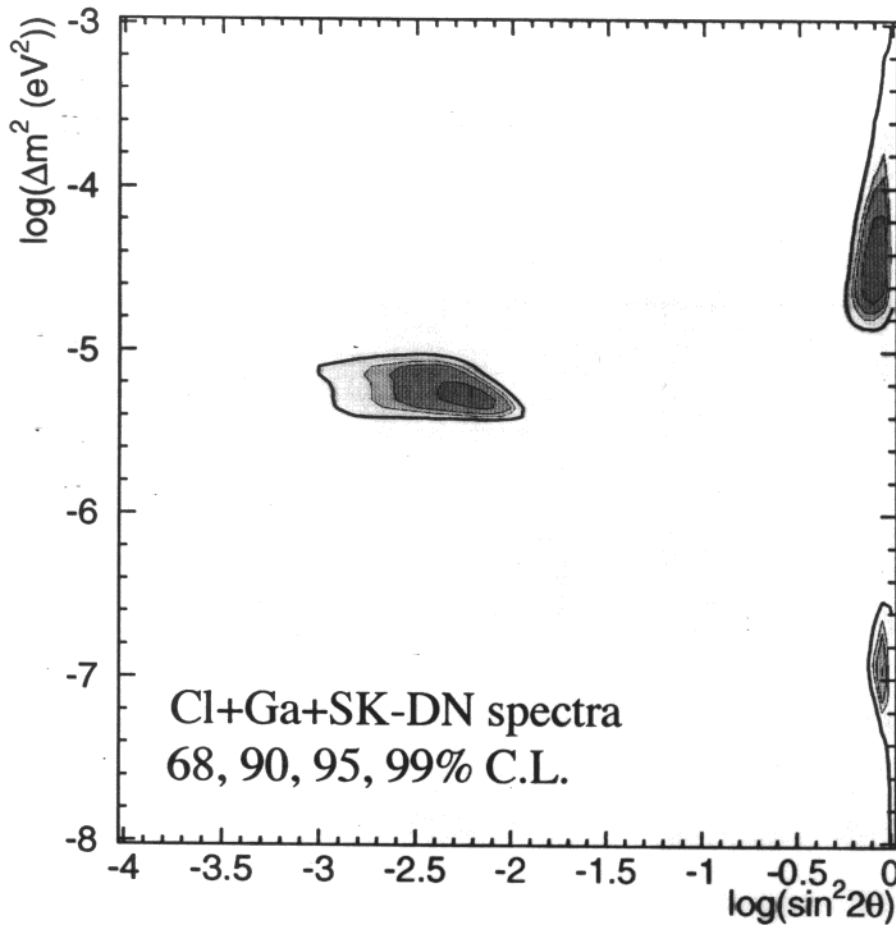


$\chi^2_{\min} = 47.0$   
@ (0.80,  $4.3e-10$ )

DN spectra, 5.5–12.5 MeV (28 bins,  $^8\text{B}$  flux free)



# Global Fit with SK DN spectra, hep-free



LMA

$$\chi^2_{\min} = 52.7 \text{ (hep=34)}$$

$$\text{@ } (0.79, 3.5e-5)$$

SMA

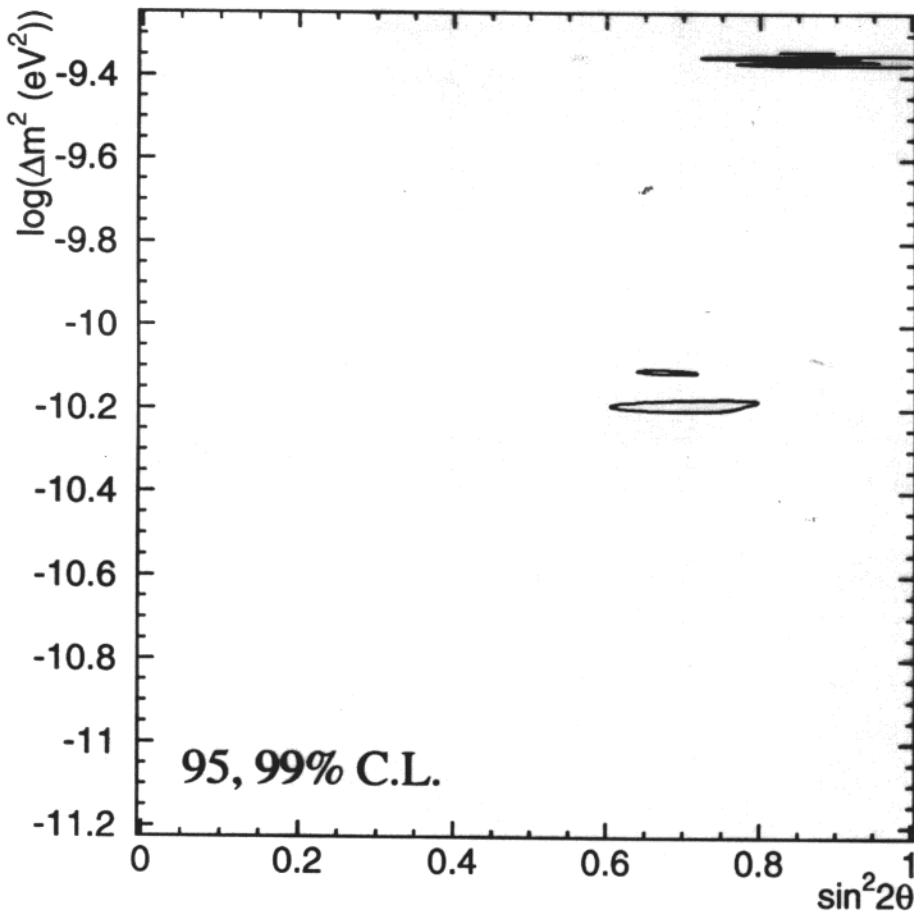
$$\chi^2 = 53.8$$

$$\text{@ } (6.3e-3, 5.0e-6)$$

LOW

$$\chi^2 = 54.9$$

$$\text{@ } (0.89, 1.1e-7)$$



Justso1

$$\chi^2 = 58.6$$

$$\text{@ } (0.89, 4.4e-10)$$

Justso2

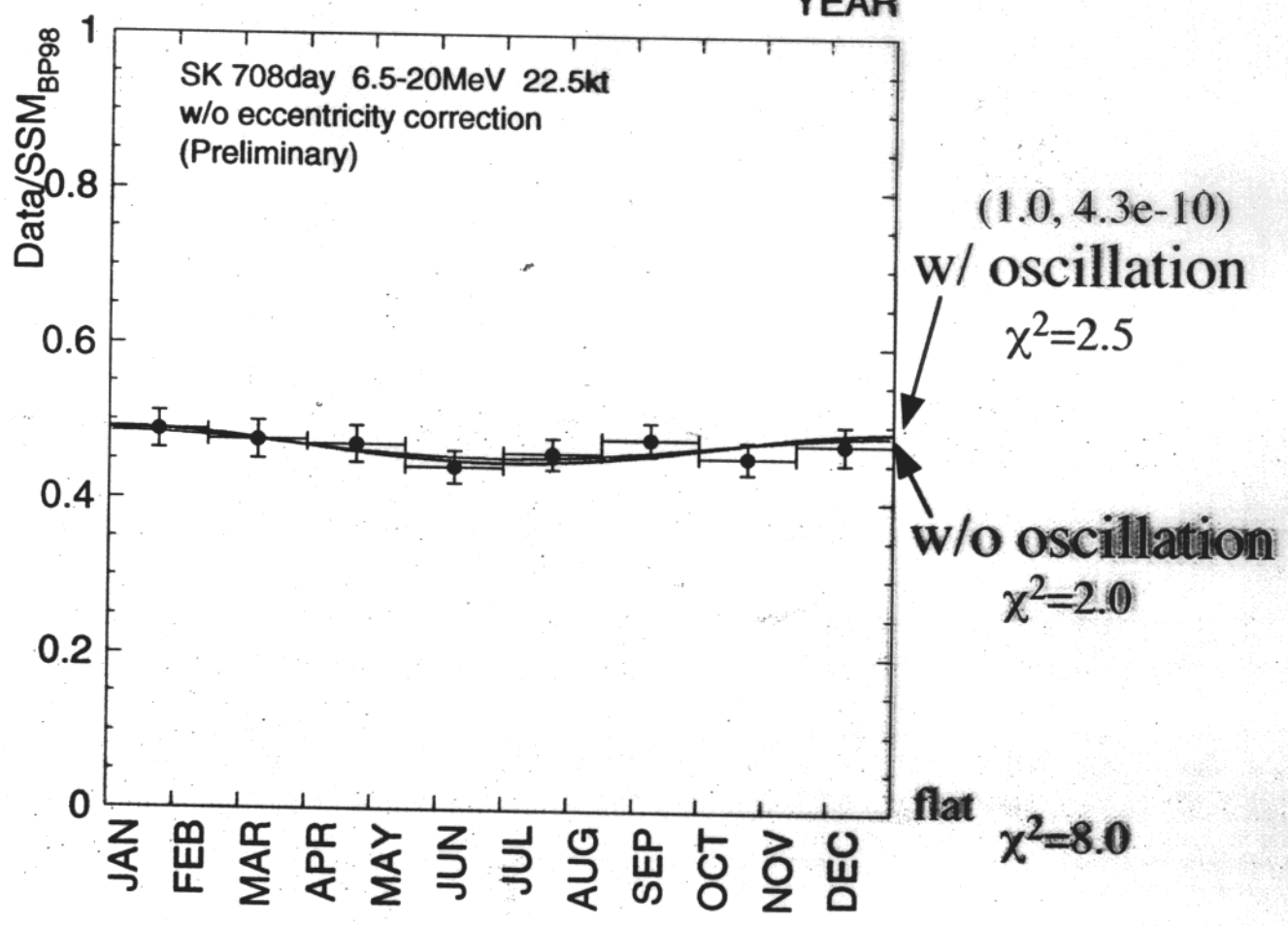
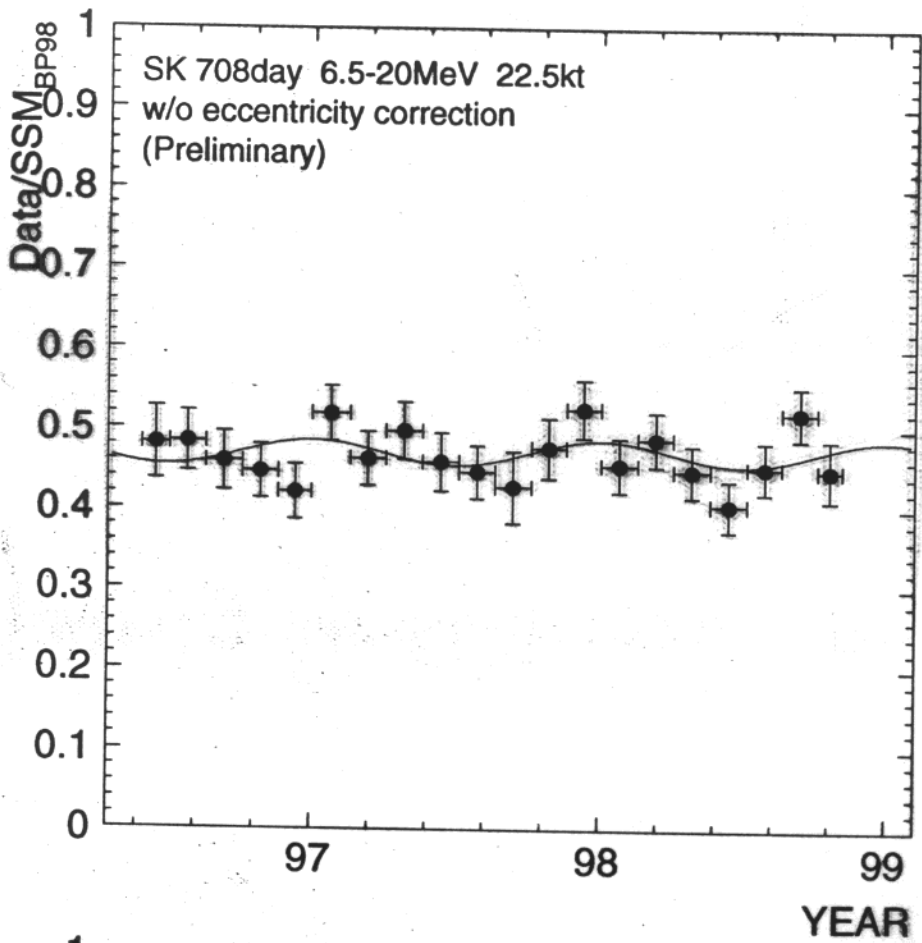
$$\chi^2 = 59.6$$

$$\text{@ } (0.70, 6.5e-11)$$

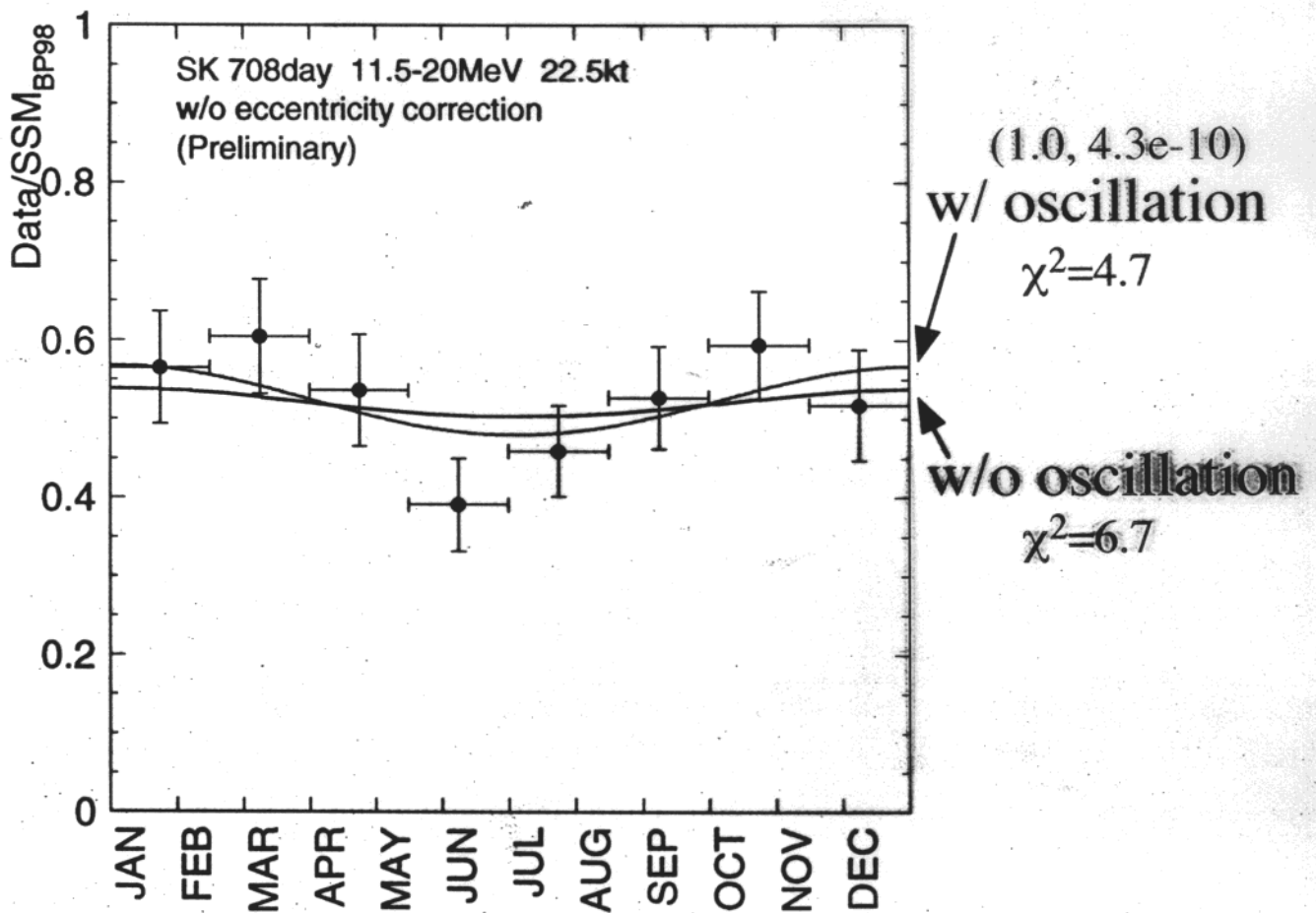
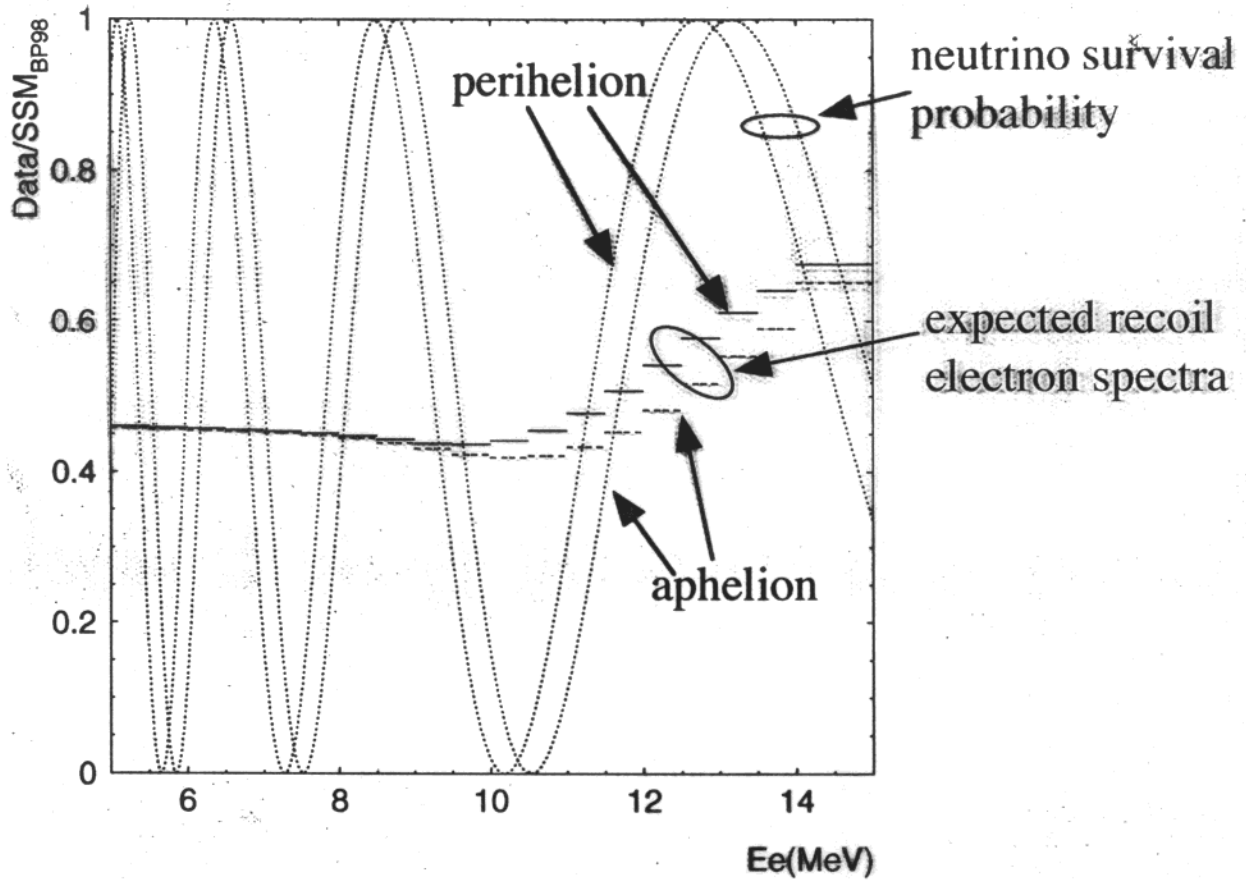
no oscillation

$$\chi^2 = 111.9$$

# Seasonal variation



# Seasonal variation in high energy





# Summary

- ◇  $^8\text{B}$  solar neutrino flux was obtained with 708 days of data.

$$\phi(^8\text{B}) \equiv 2.419^{+0.042}_{-0.039} \text{ (stat)} \quad ^{+0.068}_{-0.065} \text{ (sys)} \times 10^6 \text{ /cm}^2\text{/sec}$$

- ◇ No significant but small DN asymmetry was seen.

$$N/D-1 \equiv 0.060 \pm 0.036 \text{ (stat)} \pm 0.008 \text{ (sys)}$$

$$N5/\langle D, N1-N4 \rangle - 1 = -0.013^{+0.060}_{-0.058} \text{ (stat)} \pm 0.013 \text{ (sys)}$$

- ◇ The analysis threshold has been lowered to 5.5 MeV with SLE data.

Flat in low energy side and slope in high energy side  
Justso or large hep-flux seem to be necessary.

- ◇ No significant seasonal variation is seen, yet.

If the slope is due to the justso oscillation,  
seasonal variation will be seen in high energy bins.

IMA

Justso

Hep

SXA