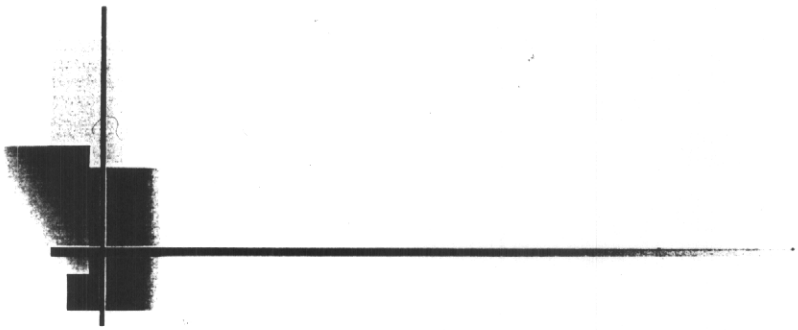

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The latest solar neutrino results in Super-Kamiokande

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Super-Kamiokande collaboration

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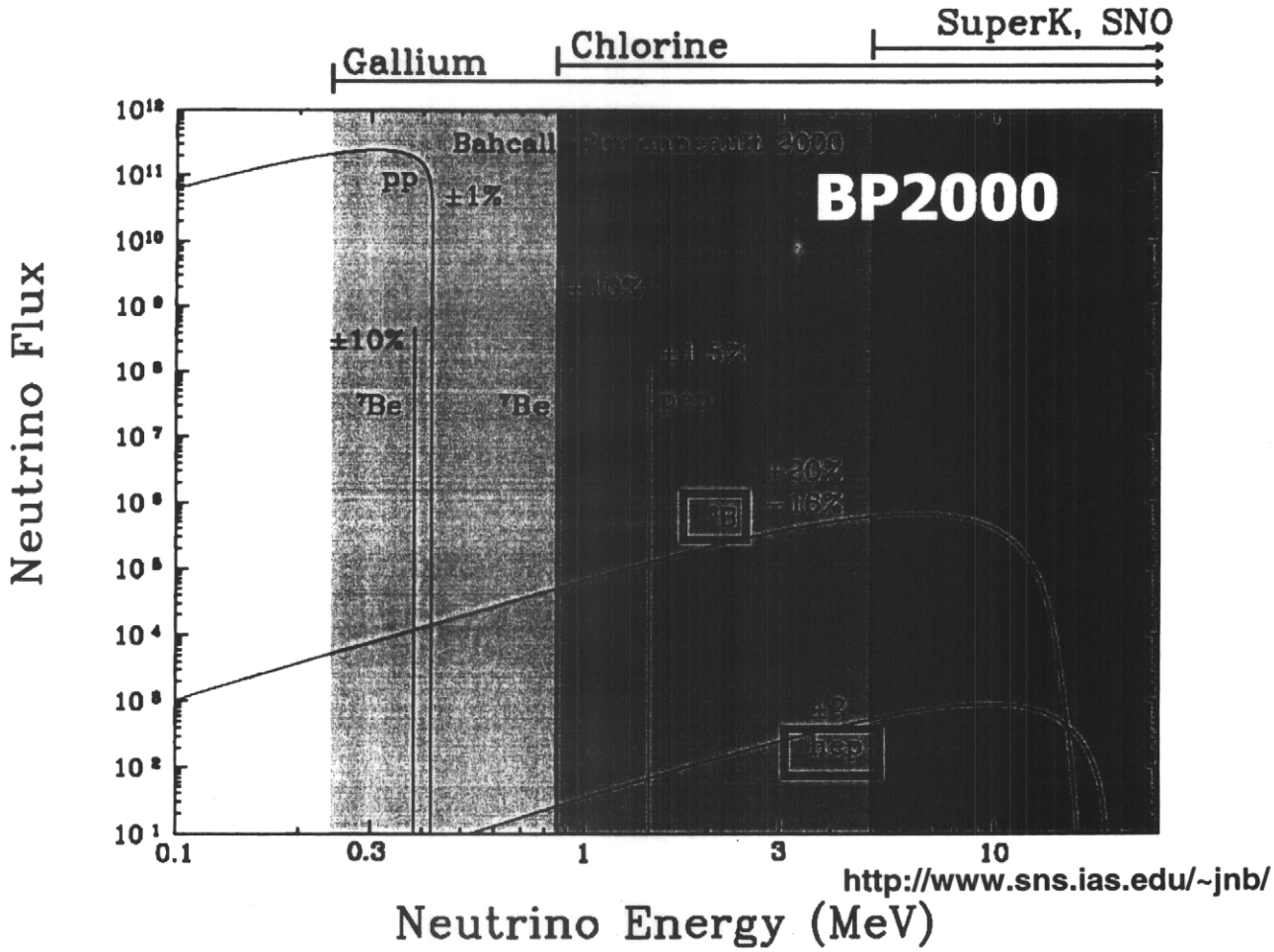
Introduction

- Solar neutrinos

$$4p \rightarrow {}^4He + 2\,e^+ + 2\,\nu_e + 26.7MeV$$

through the Sun immediately (--2sec)

Flux, spectrum… are calculated by Standard Solar Model (SSM)



Current experiments

$\left(R = \frac{\text{measured}}{\text{expected}}\right)$

- Chlorine (1970 -)

  $\nu_e + {}^{37}Cl \rightarrow e + {}^{37}Ar \quad (E_{th}=814keV)$

  $R=0.33 \pm 0.03$ (Homestake)

- Gallium (1990 -)

  $\nu_e + {}^{71}Ga \rightarrow e + {}^{71}Ge \quad (E_{th}=233keV)$

  $R=0.57 \pm 0.05$ (GNO+GALLEX)

  $R=0.58 \pm 0.06$ (SAGE)

- Water Cherenkov (1987 -)

  $\nu + e \rightarrow \nu + e \quad (E_{th}=5.0\text{-}7.0MeV)$

  $R= 0.54 \pm 0.07$ (Kamiokande)

  $R= 0.47 \pm 0.02$ (Super-K)

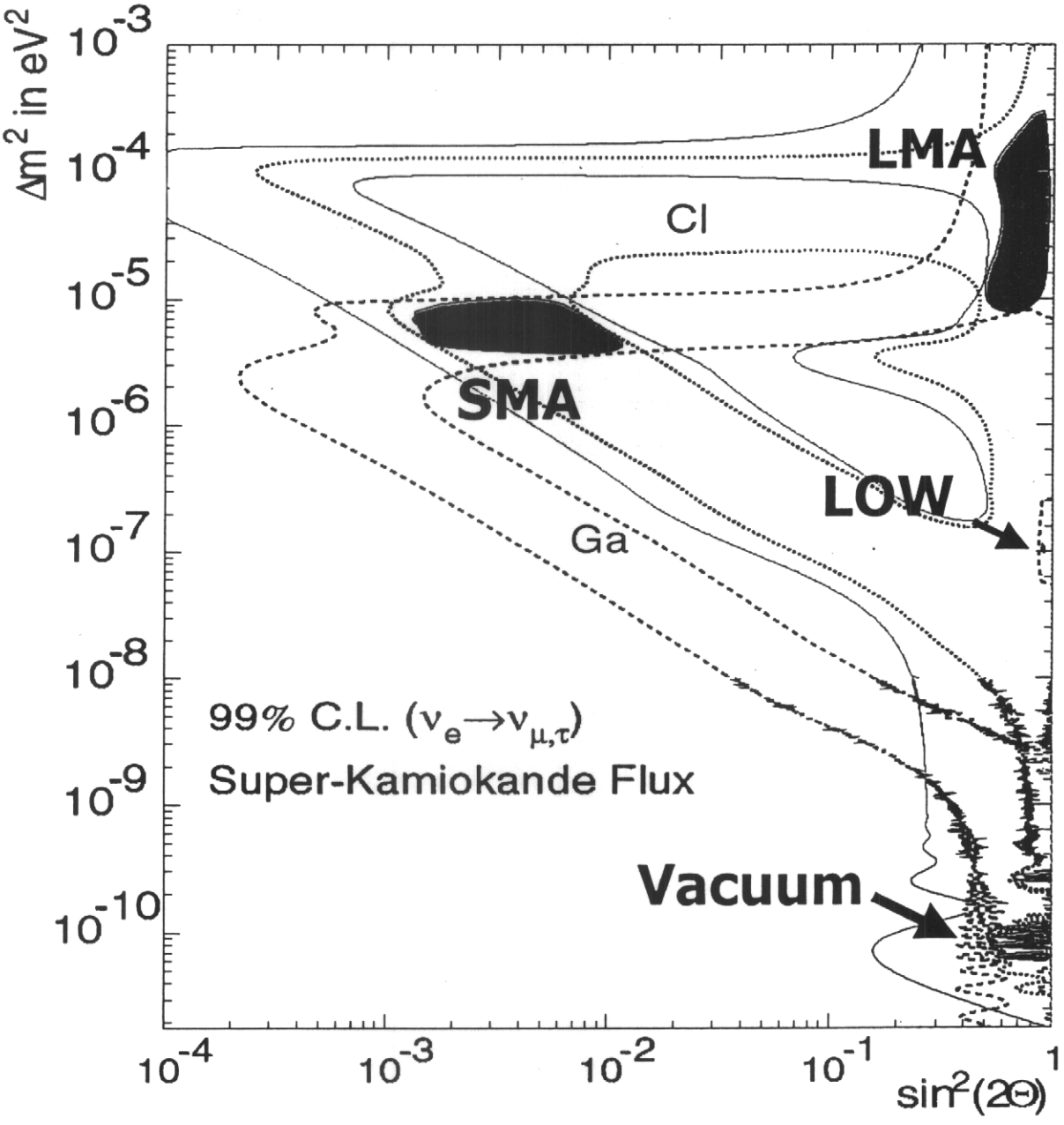
Neutrino detection flux is significantly less than calculation

↓

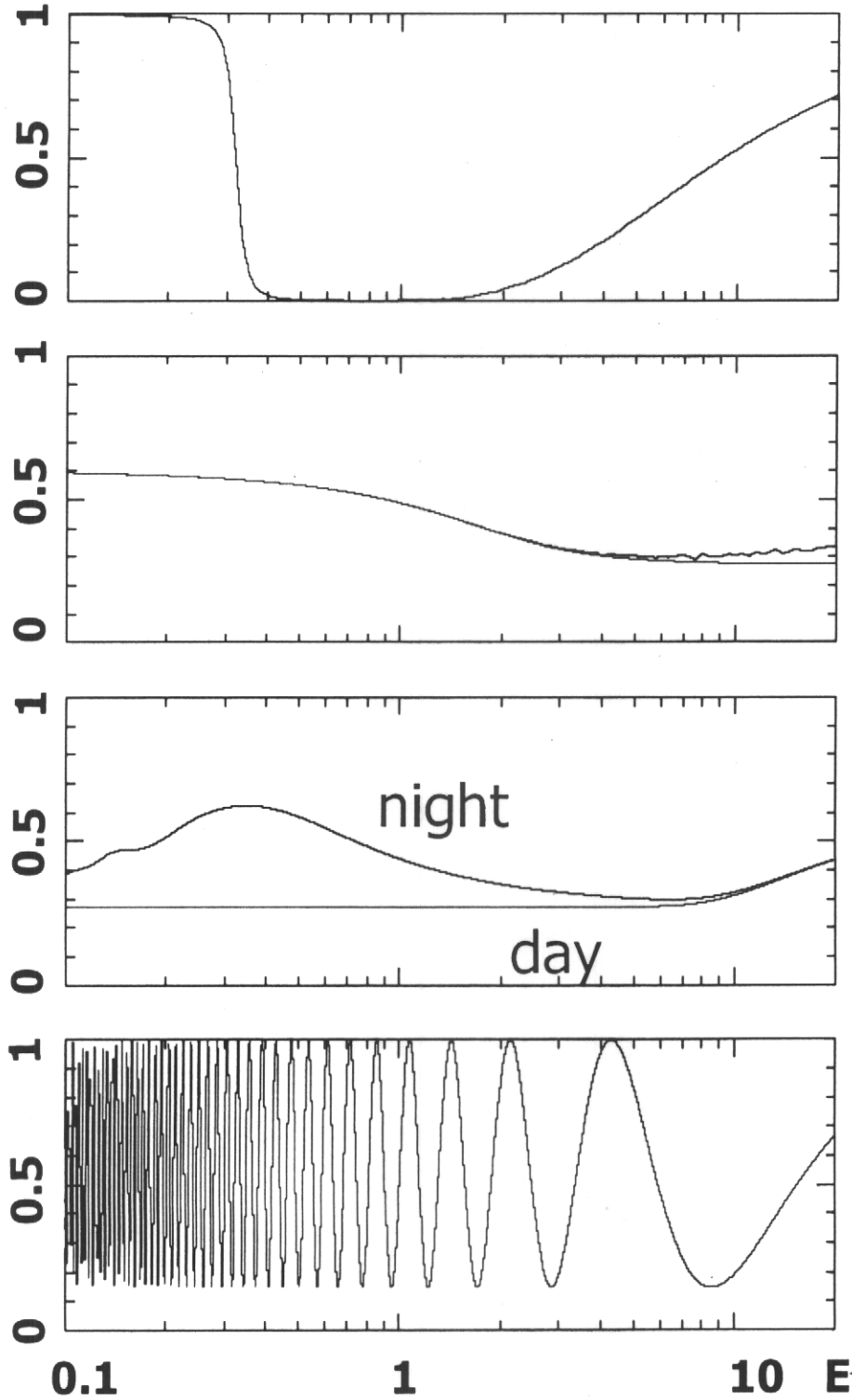
Solar neutrino problem

Neutrino oscillation

- Flux only analysis



Neutrino survival probability



SMA

Spectrum distortion

LMA

Day-Night differences

LOW

Day-Night differences

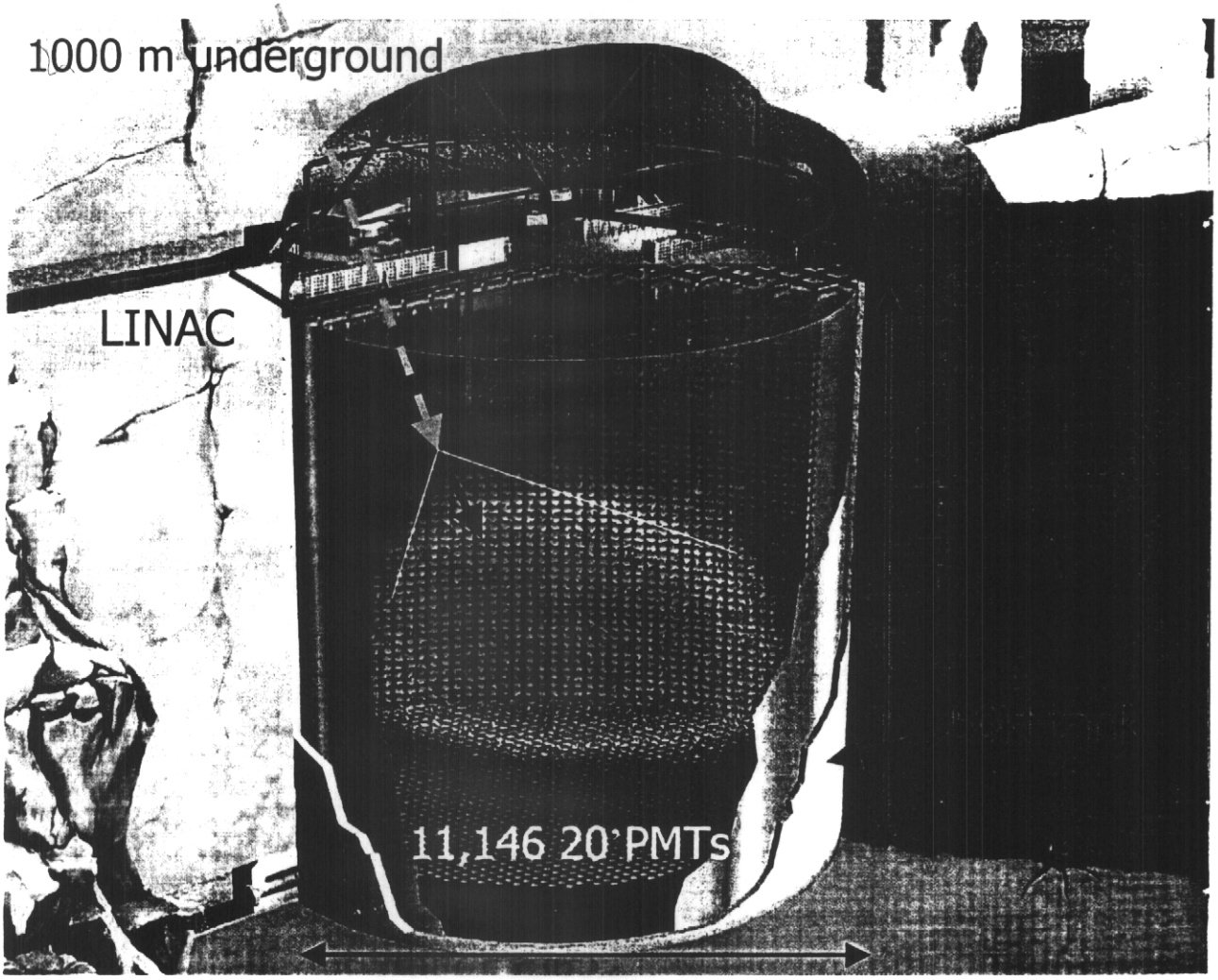
Vacuum

Spectrum distortion

Seasonal differences

Super-Kamiokande

Water Cherenkov detector

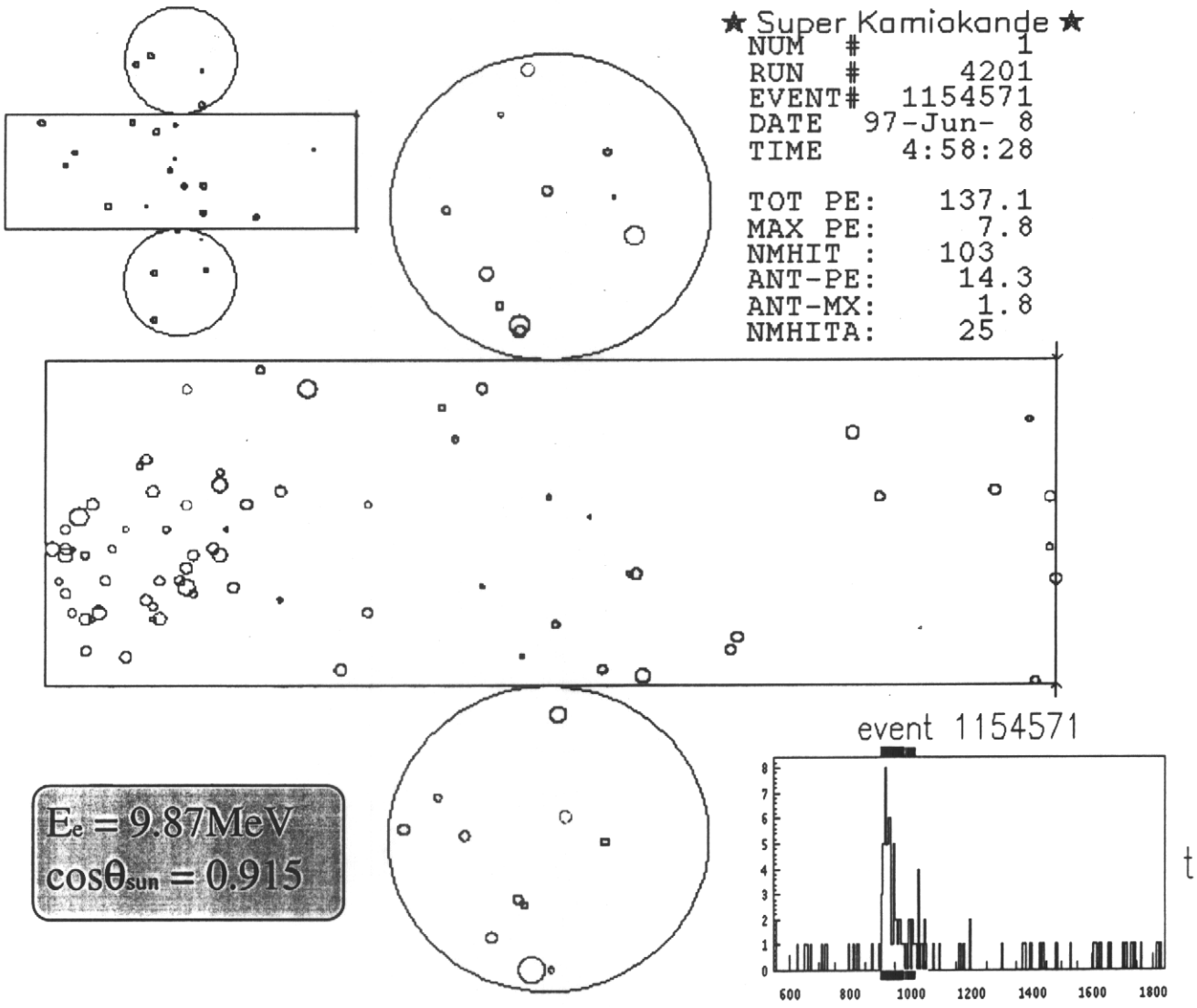


- 22.5kt fiducial volume for solar neutrino analysis
- for 10MeV electron (close to solar neutrino event)

Vertex resolution	87cm
Energy resolution	14%
Angular resolution	26 degree

Detection method

$\nu_{solar} + e \rightarrow \nu + e$ elastic scattering



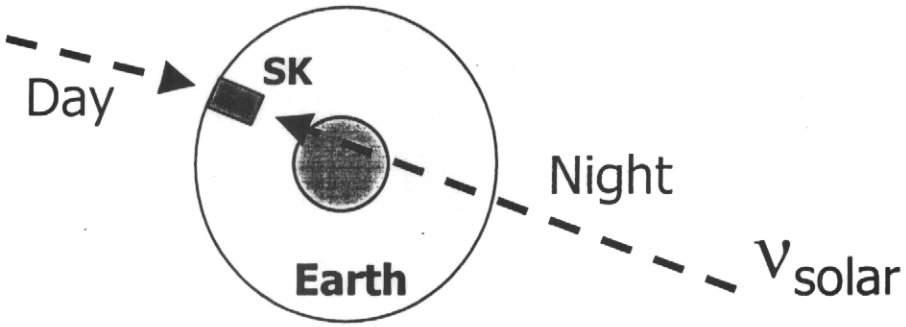
$E_e = 9.87\text{MeV}$

$\cos\theta_{sun} = 0.915$

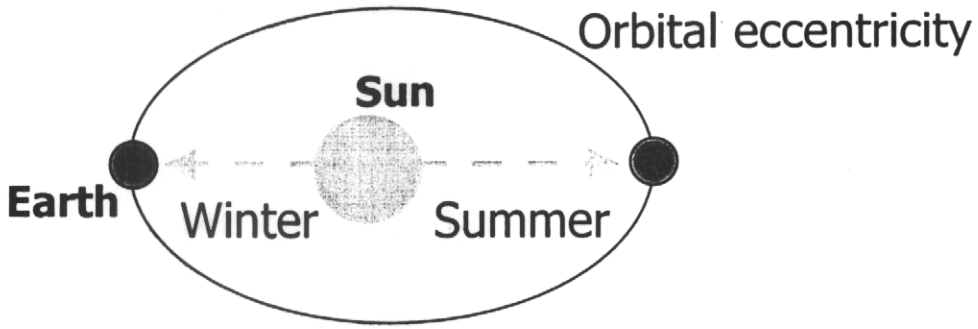
- Timing information — vertex position
- Ring pattern — direction
- number of hit PMTs — energy

Properties

- Direction measurable
  - → Find solar direction
- Real time measurement
  - Day/Night effect



  - Seasonal effect



- Energy measurable (recoil electron)

  Absolute energy scale uncertainties

  $\sim \pm 0.5\%$

  (from LINAC calibration ; NIM A421(1999)113)

  ^{16}N from DT calibration : NIM (2001)

What's new (1)

- Data update

  Total live time (1258days)

  1996/05/31-2000/10/06

- Lowering threshold

  5.5MeV ⟶ 5.0MeV

  .....

  (800days ⟶ 1100days)

  - Improve analysis

    6.5-20MeV: B.G. –63% Signal –20%

  - Re-tune MC

    Water parameter by new LINAC data

  - Improve water purification system

    new reverse osmosis system (Mar. 00)

    new membrane degasify system (Jan. 01)

  - Lowering threshold

    6.5MeV ⟶ 5.5MeV

What's new (2)

- New solar model

  BP98 → BP2000 SSM (astro-ph/0010346)

^8B	$5.15(1.00^{+0.20}_{-0.16})\times10^6/cm^2/s$
hep	$9.3\times10^3/cm^2/s$ (BP98: 2.1)

- Different ^8B spectrum

  Bahcall et al. 1996 → Ortiz et al. 2000

  PRL 85(2000)2909

- New oscillation analysis

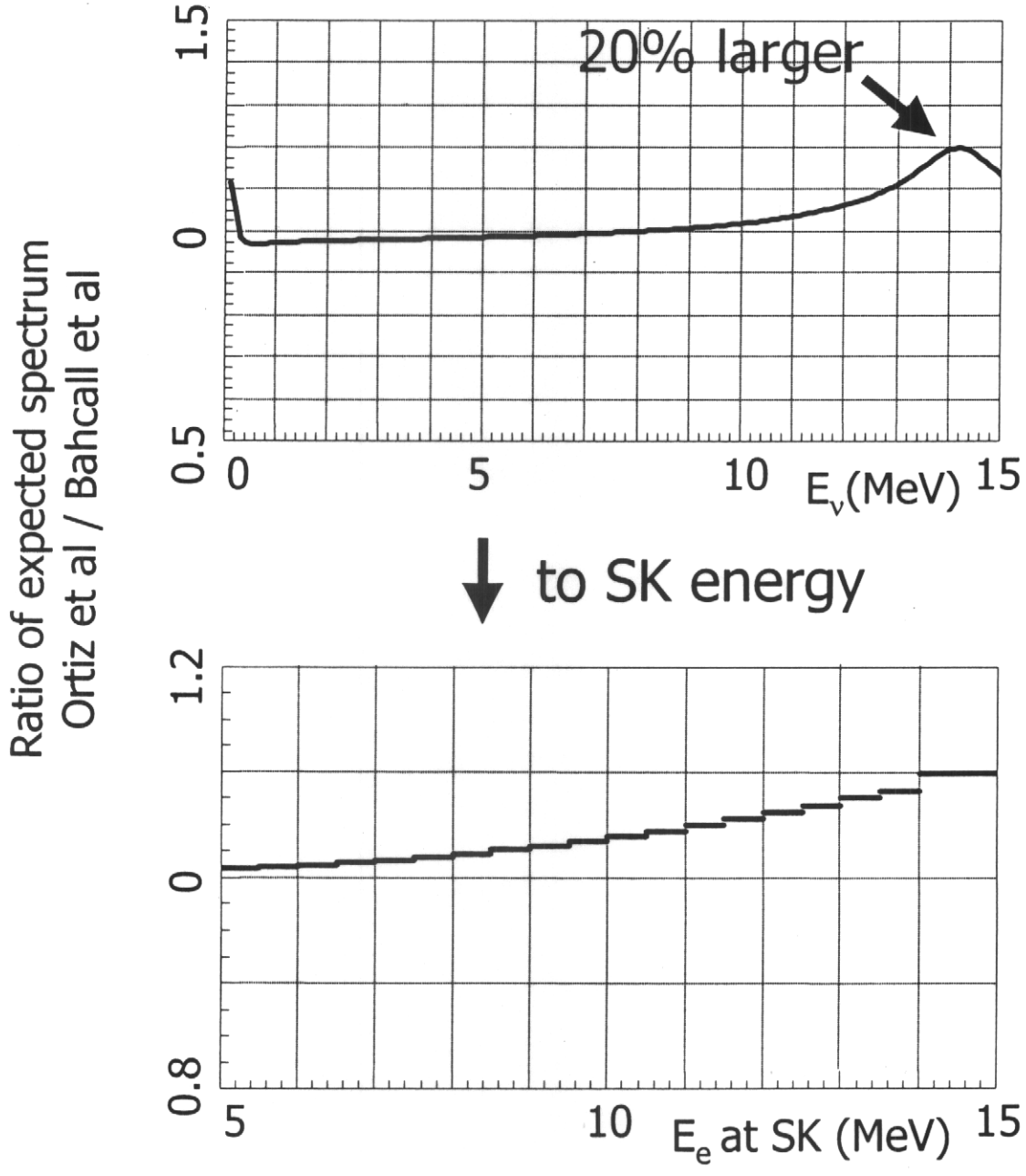
  Day/Night 2bin × Energy 19bin & D/N 7bin × E 8bin

  D/N spectrum

  Zenith spectrum

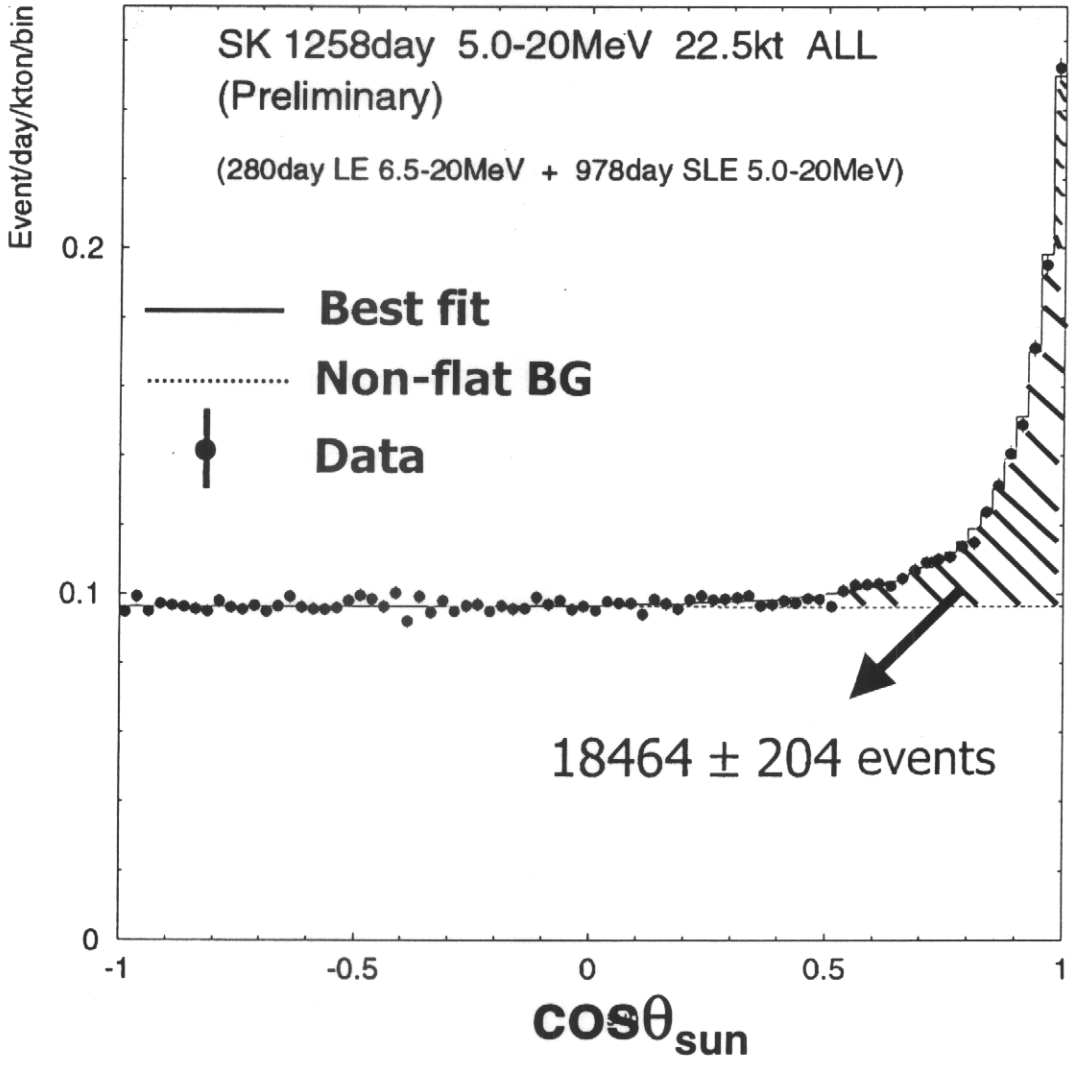
Different ^{8}B spectrum

New measurement of α spectrum from the ^{8}B decay



Results

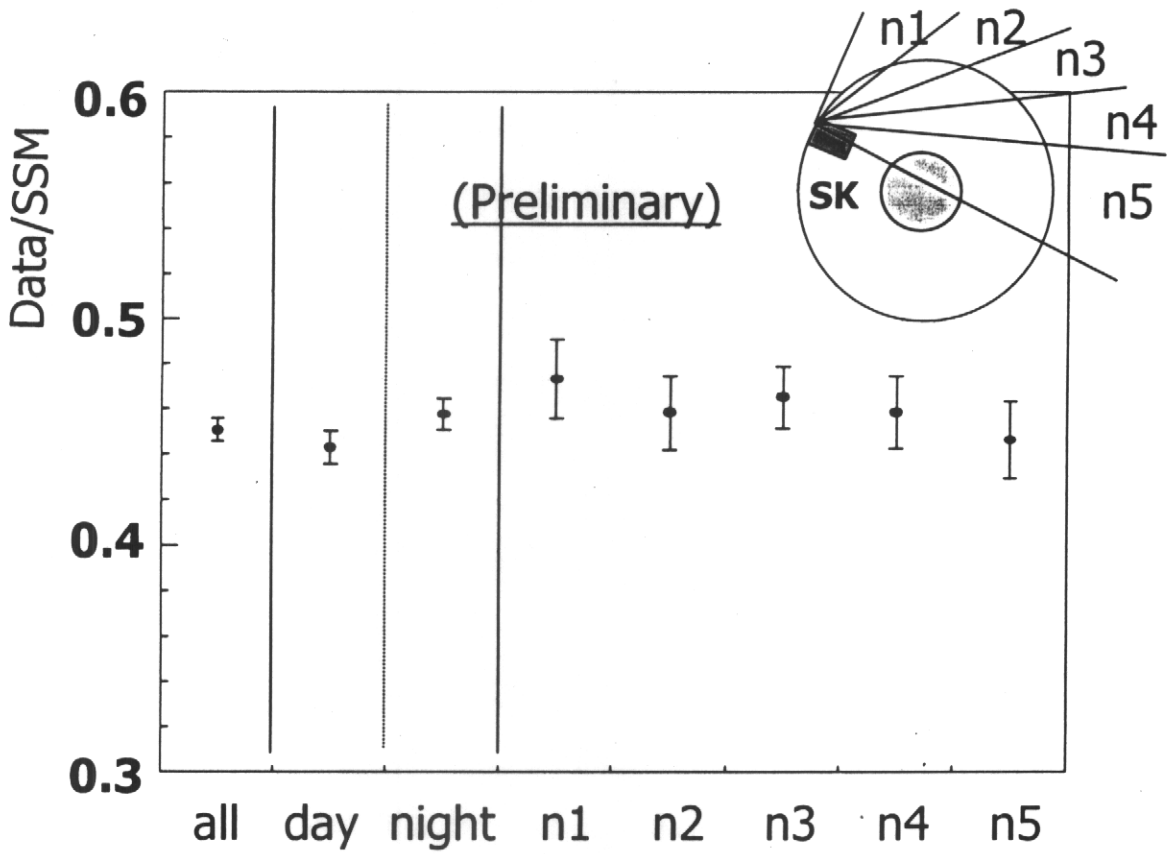
- ^{8}B flux



$$^8\text{B Flux} = 2.32 \pm \frac{0.03}{0.03}(\text{stat.}) \pm \frac{0.08}{0.07}(\text{syst.}) \ [\text{x}10^6/\text{cm}^2/\text{s}]$$

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

- Day/Night flux differences



Day: 622 effective days

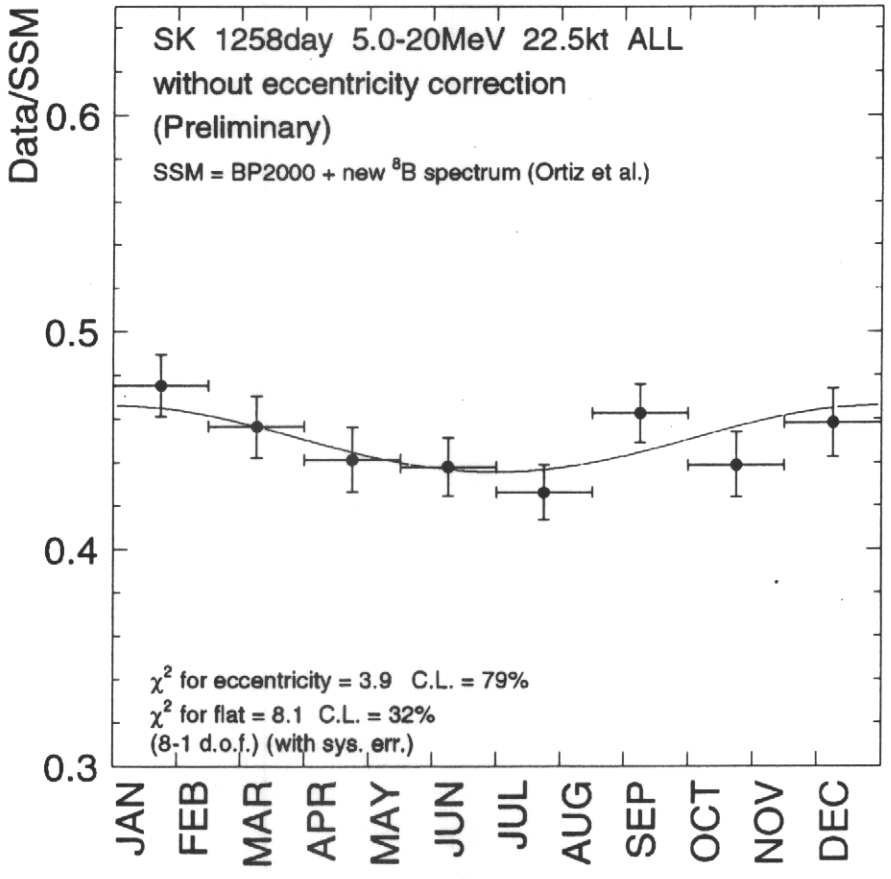
$$\phi(^8B) = 2.28 \pm 0.04 \pm \begin{matrix}0.08\\0.07\end{matrix} \ [\times 10^6/cm^2/s]$$

Night: 636 effective days

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

$$\frac{\mathbf{N-D}}{\mathbf{(N+D)/2}} = \mathbf{0.033 \pm 0.022(stat.) \pm \begin{matrix}0.013\\0.012\end{matrix} (sys.)}$$

- Seasonal flux variation

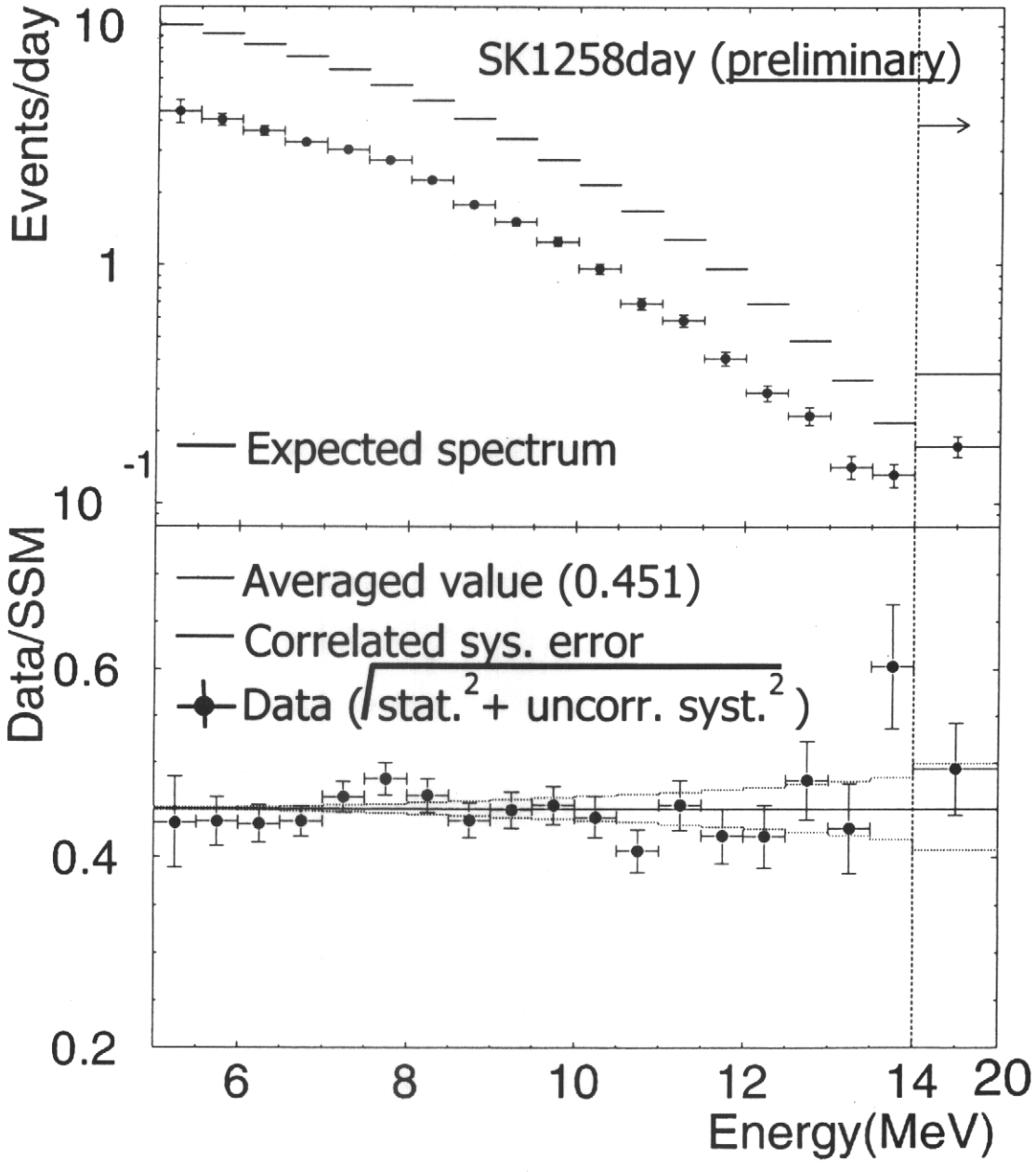


χ^2 for eccentricity	3.9 / 7 (79%)
χ^2 for flat	8.1 / 7 (32%)

(with sys. Error)

Need more statistics

- Energy spectrum



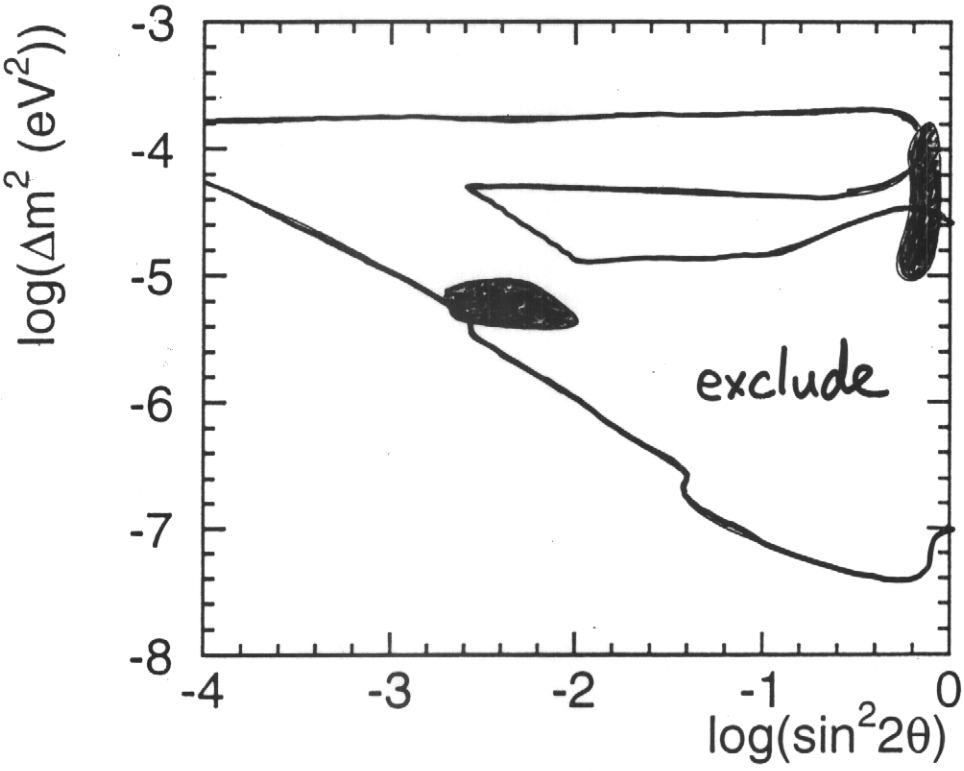
χ^2 for flat = 19.08 / 18 (d.o.f) 39% C.L.

$\nu_e \rightarrow \nu_{\mu,\tau}$ (95% C.L.)

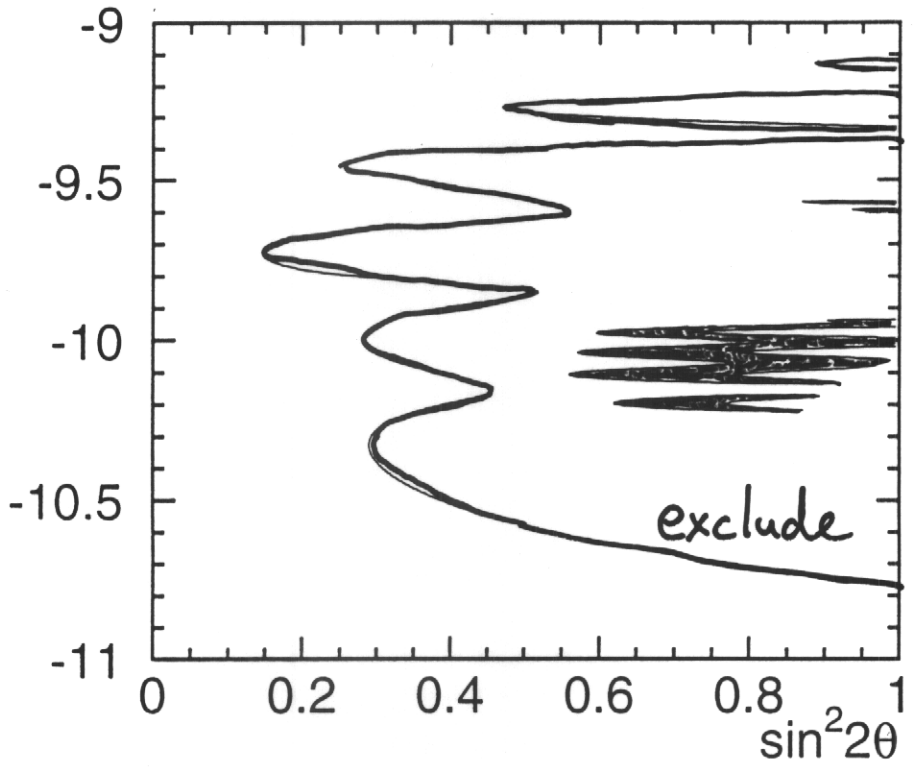
preliminary

Zenith-spectrum.

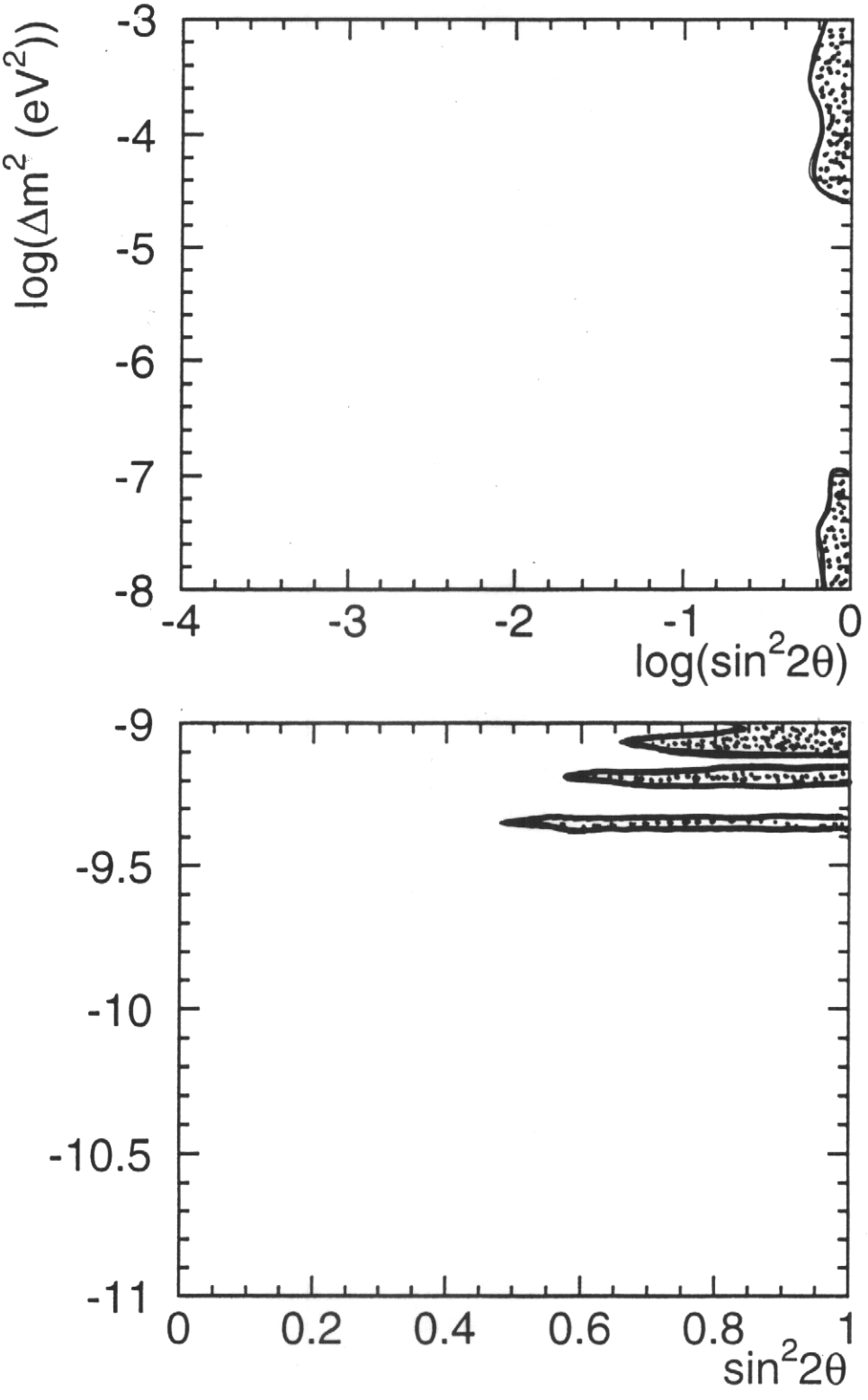
(hep free)



^{8}B flux free



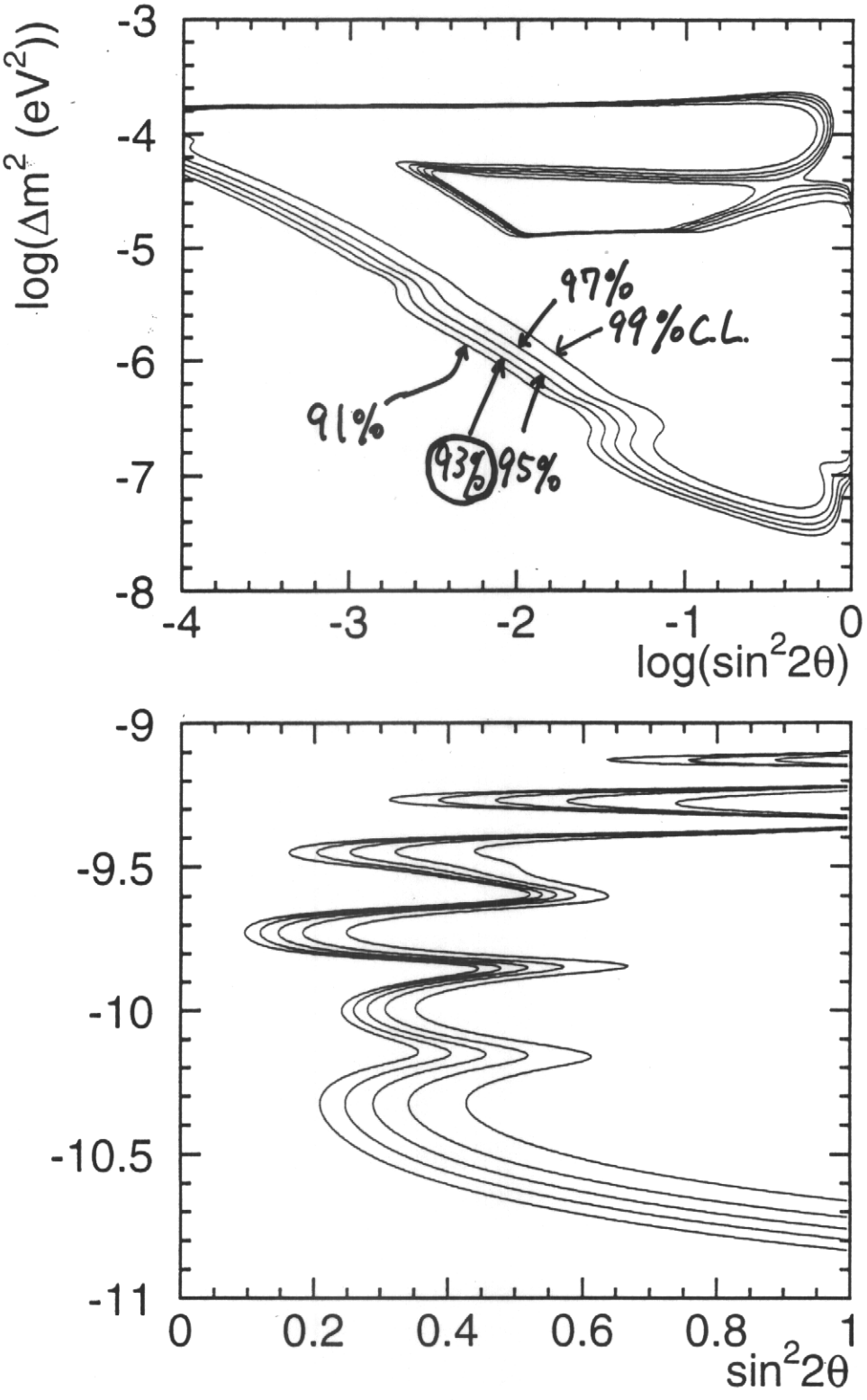
preliminary



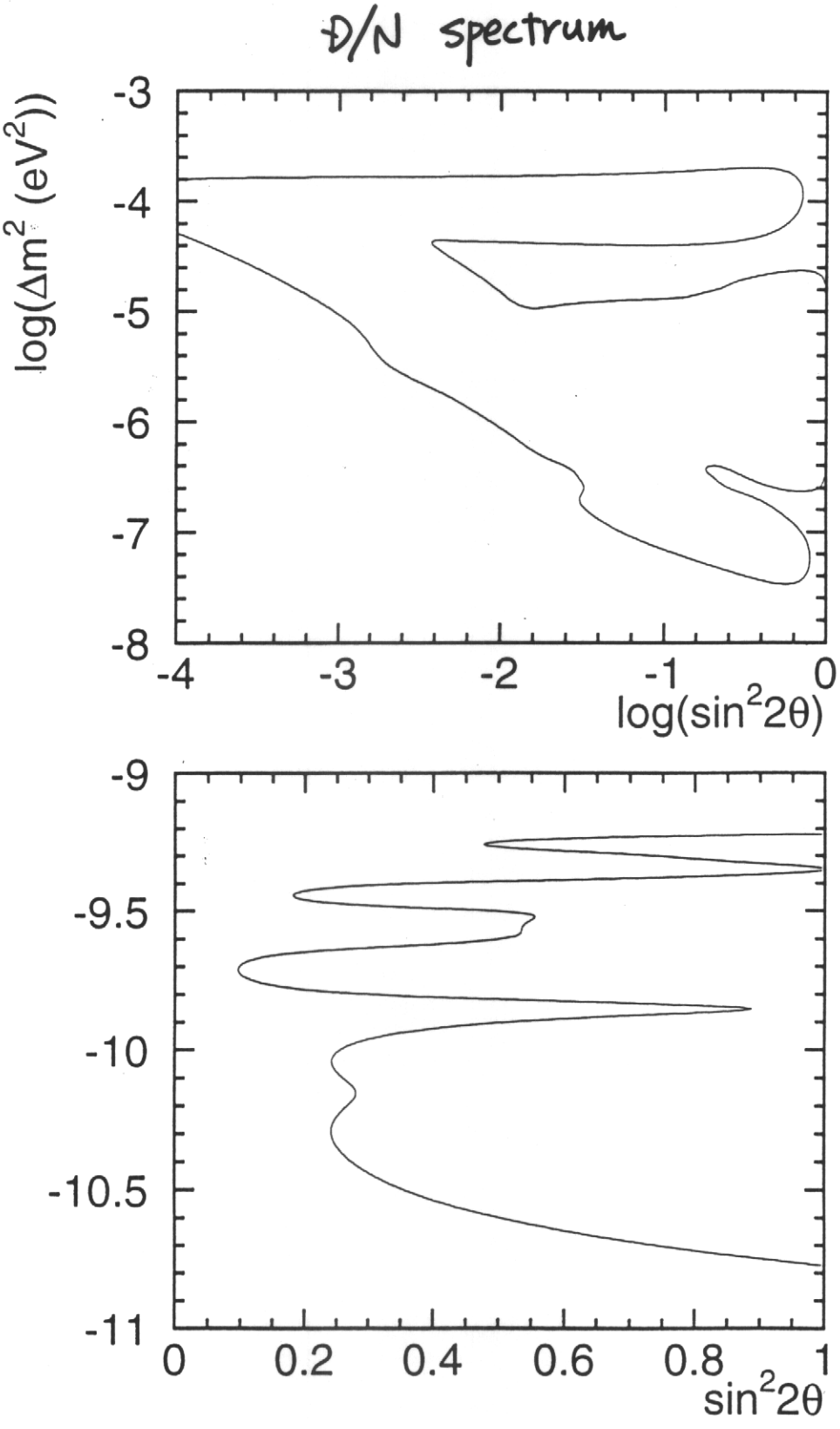
(allowed region.)

^{8}B flux constraint

preliminary

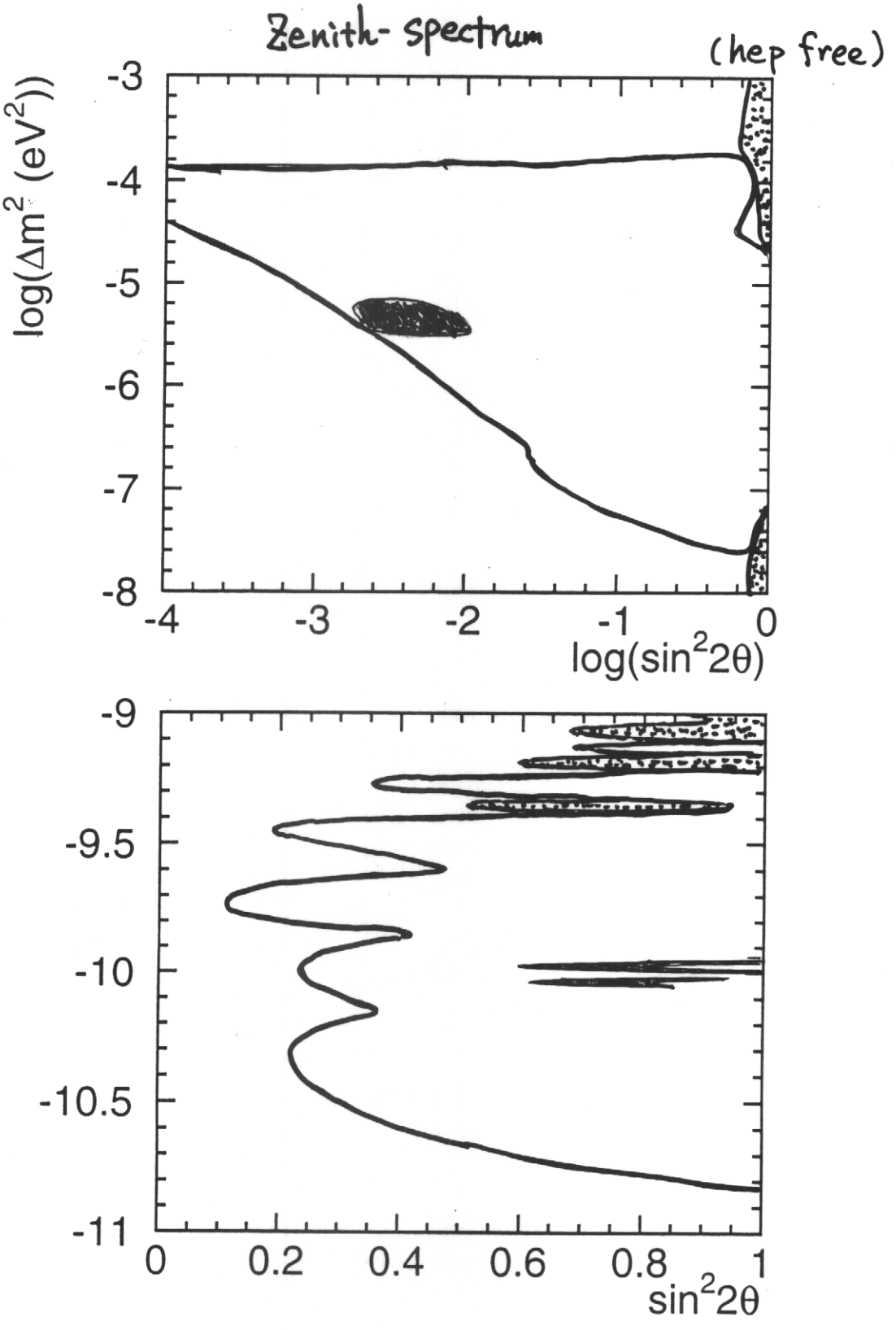


preliminary



preliminary

$\nu_e \rightarrow \nu_{sterile}$ (95% C.L.)



Summary

- We have studied solar neutrinos using 1258days of Super-Kamiokande data.
- Analysis is improved.
- Energy region is wider. (5.0 – 20.0MeV)
- Results

^{8}B Flux=$2.32 \pm 0.03(\text{stat.}) \pm {}^{0.08}_{0.07}(\text{syst.})$ [x10_6/cm$_2$/s]

Day/Night asymmetry is found to be 1.3σ.

No significant seasonal effect is found.

Spectrum : $\chi 2$ for flat = 19.08/18 (39% C.L.)

Hep flux < 3.9 [x10^3/cm^2/s] (90%C.L.)

- Oscillation analysis

New data binning is used.

- SMA and Vacuum solutions are disfavored from Super-K spectrum and day/night. (~95%C.L.)
- SK favors large mixing angle solution.
- 2-flavor sterile solutions are disfavored.