OSCILLATION SOLUTIONS TO SNP

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SOLAR-NEUTRINO PROBLEM

1998

	DATA	SSM (BP-98)	DATA/SSM
GALLEX (SNU)	$77.5 \pm 6.2^{+4.3}_{-4.7}$	129^{+8}_{-6}	0.60 ± 0.06
SAGE (SNU)	$66.6^{+7.8}_{-8.1}$	129^{+8}_{-6}	0.52 ± 0.06
SUPERK $10^6 cm^{-2} s^{-1}$	$2.44 \pm 0.05^{+0.09}_{-0.07}$	$5.15^{+0.98}_{-0.72}$	0.474 ± 0.02
HOMESTAKE (SNU)	$2.56 \pm 0.16 \pm 0.15$	$7.7^{+1.2}_{-1.0}$	0.332 ± 0.028

ASTROPHYSICAL SOLUTION TO SNP IS EXCLUDED

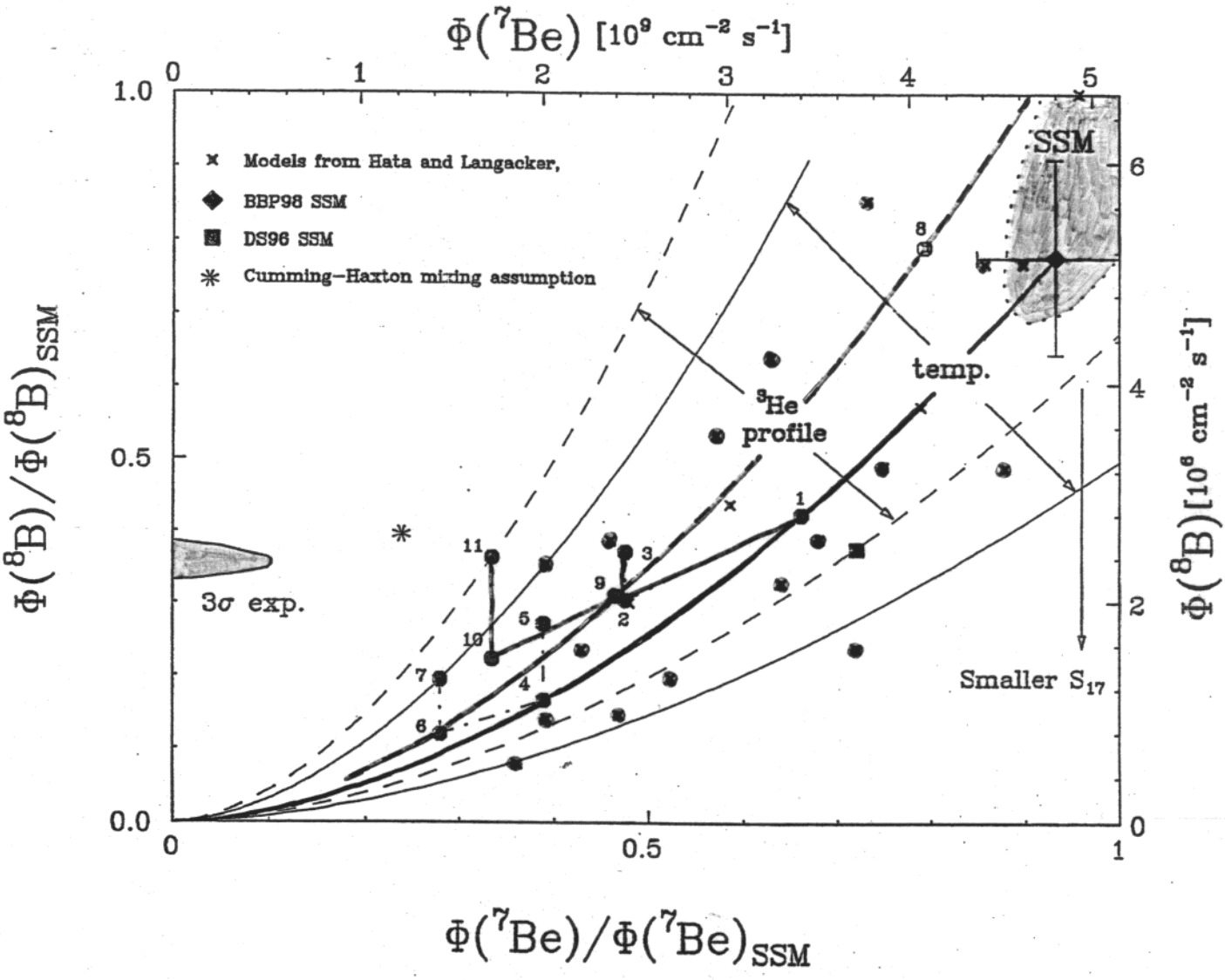
or at least

IS VERY STRONGLY DISFAVOURED

- COMPATIBILITY OF THREE OR ANY TWO SOLAR-NEUTRINO EXPERIMENTS NEEDS UNPHYSICAL RATIO $\Phi(Be)/\Phi(B) < 0$ (MODEL-INDEPENDENT RESULT).
- THERE IS NO NUCLEAR-PHYSICS (CROSS-SECTIONS) SOLUTION TO SNP.
- SEISMIC OBSERVATIONS CONFIRM SSM
- THERE IS NO ALLOWED TRACK FROM SSM PREDICTED TO THE OBSERVED NEUTRÍNO FLUXES.

V.B., FIORENTINI, LISSIA

ARBITRARY ^{3}He MIXING



PRESENT STATUS OF SOLAR-NEUTRINO EXPERIMENT IS A DISAPPEARANCE OSCILLATION EXPERIMENT:

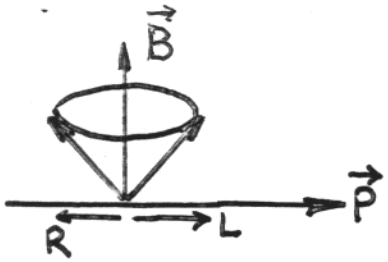
DETECTED ν_e-FLUX IS LESS THAN PRODUCED ONE (CALIBRATED BY SEISMIC DATA)

OSCILLATION SOLUTIONS TO SNP

	$\sin^2 2\theta$	Δm^2 (eV^2)	
1. MSW	$6.0 \cdot 10^{-3}$	$5.4 \cdot 10^{-6}$	
RESONANT $\nu_e \to \nu_i$	0.76	$1.8 \cdot 10^{-5}$	
CONVERSION INSIDE SUN	0.96	$7.9 \cdot 10^{-8}$	
2. VO	0.75	$8.0 \cdot 10^{-11}$	bf
	0.6 – 1.0	$0.5 - 2 \cdot 10^{-10}$	

$$P_{\nu_e \to \nu_i} = \sin^2 2\theta \sin^2 \frac{r \Delta m^2}{4E}$$

3. RSFP small $10^{-8} - 10^{-7}$



$\mu B \sim 10^{-11} \mu_B \times 50\,\text{kG}$

4. EIO maximal $10^{-3} \gg \Delta m^2 \gg 10^{-10}$

ENERGY-INDEPENDENT OSCILLATIONS

BSK : EXCLUDED AT 99.8% CL (?)

OBSERVATIONAL SIGNATURES

COMMON SIGNATURES OF NEUTRINO OSCILLATIONS:

- DISTORTION OF B-NEUTRINO SPECTRUM (SUPERK, SNO)
- ANOMALOUS NC/CC RATIO (SNO)

SPECIFIC SIGNATURES

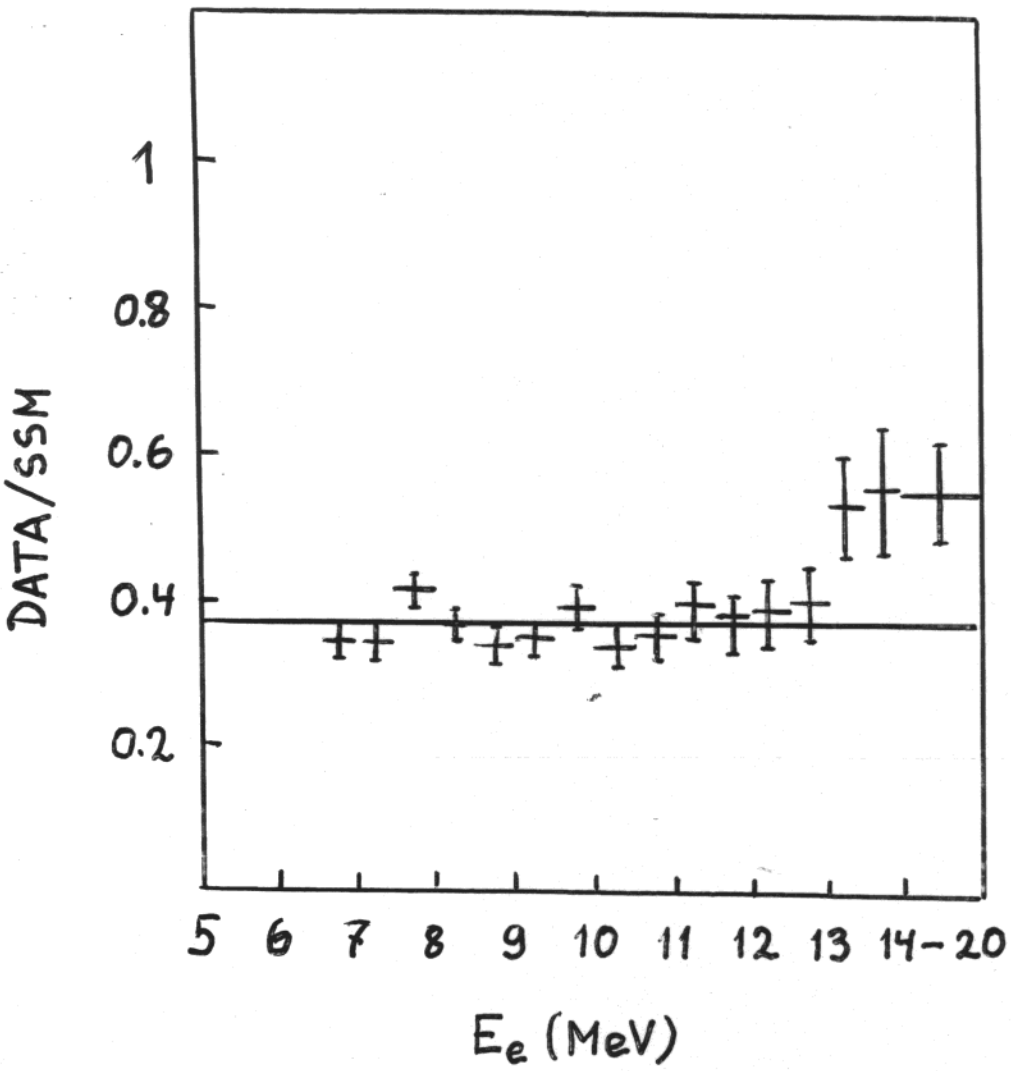
- MSW: DAY-NIGHT EFFECT
  (REGENERATION OF ν_e IN EARTH)
- VO: ANOMALOUS SEASONAL FLUX VARIATION (BOREXINO)

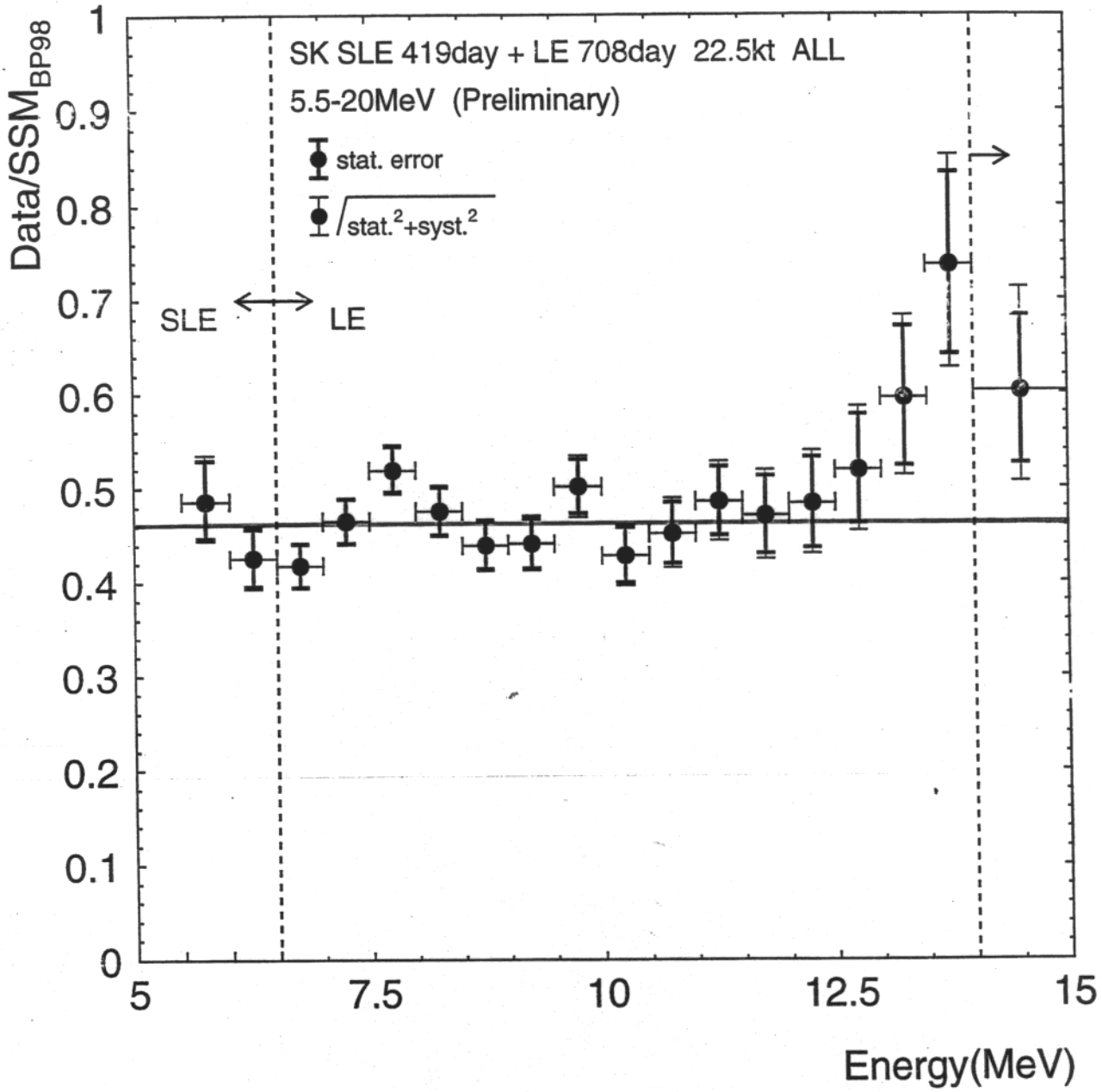
$$P_{\nu_e \to \nu_x} \sim \sin^2 \frac{r(t)\,\Delta m^2}{4E}$$

- RSFP: $\nu_e \xrightarrow{\text{RSFP}} \bar{\nu}_{\mu(\tau)} \xrightarrow{\text{VO}} \bar{\nu}_e$
  - $\bar{\nu}_e + p \to n + e^+$ (KamLAND)
  - 11 yr PERIODICITY OF ν_{Be}-FLUX

SUPERKAMIOKANDE SPECTRUM OF e

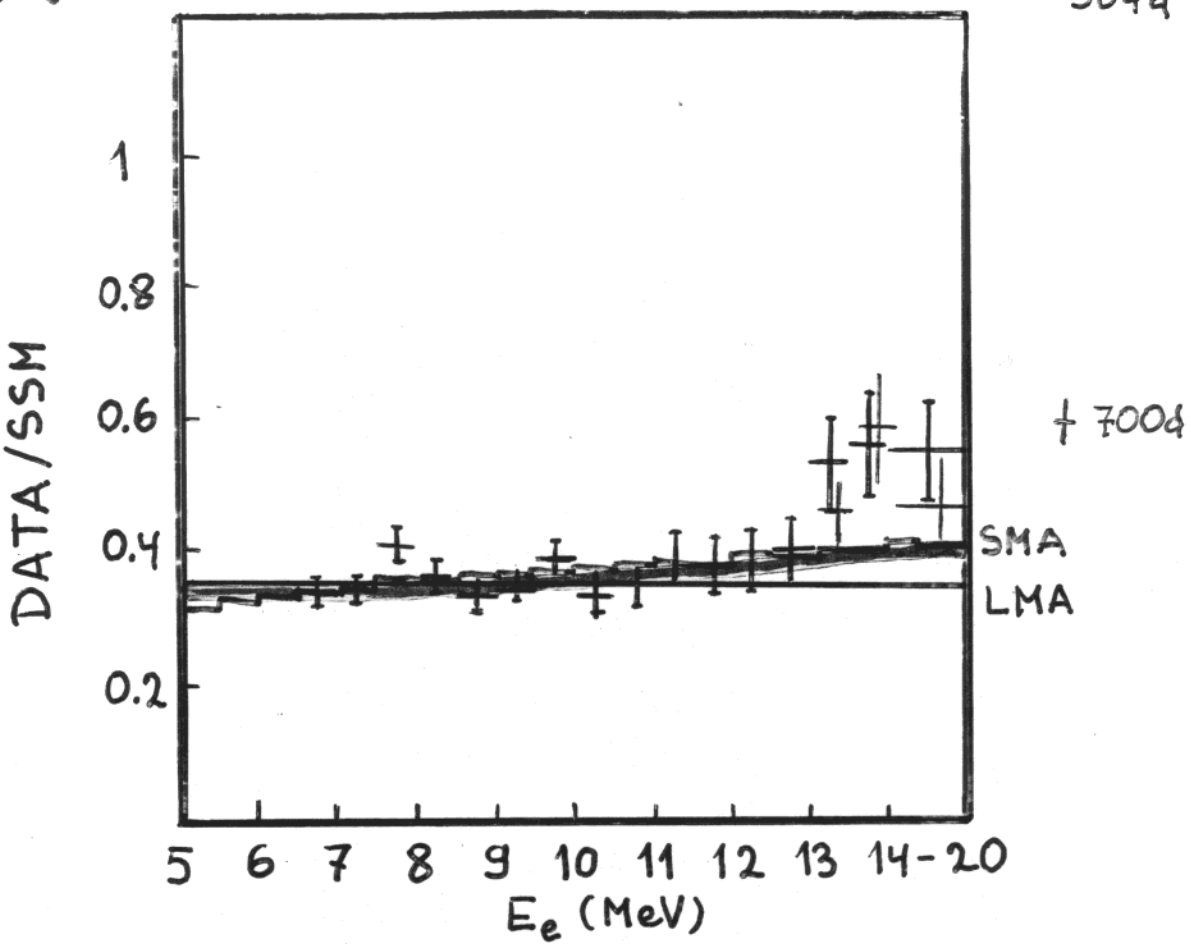
$\nu + e \rightarrow \nu + e$ (504d)

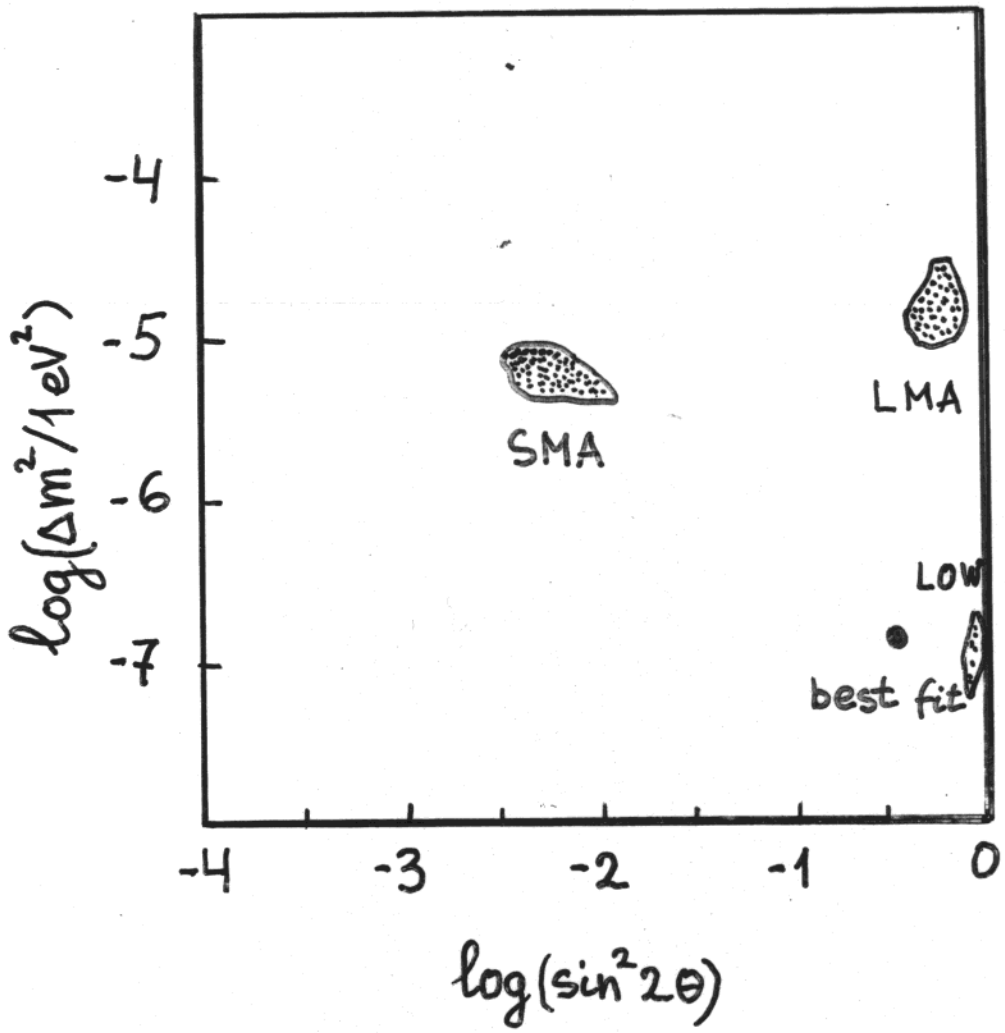



SK SLE 419day + LE 708day 22.5kt ALL
5.5-20MeV (Preliminary)
stat. error
$\sqrt{stat.^2+syst.^2}$
SLE
LE
Data/SSM$_{BP98}$
Energy(MeV)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
5
7.5
10
12.5
15

MSW

Y. SUZUKI (NEUTRINO-98)
504d

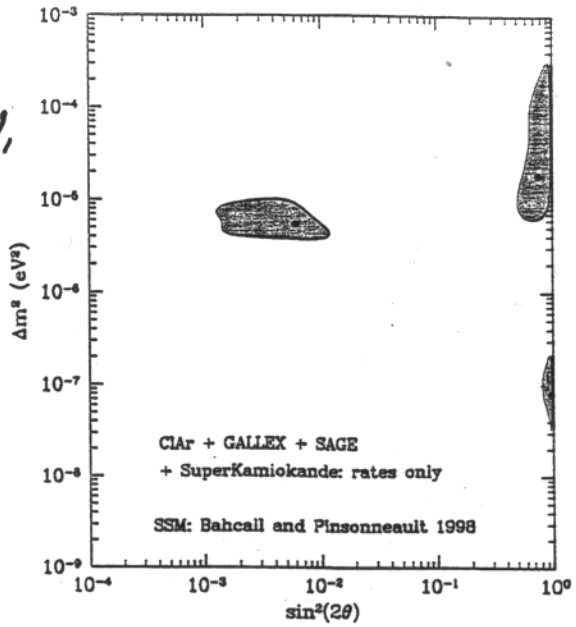


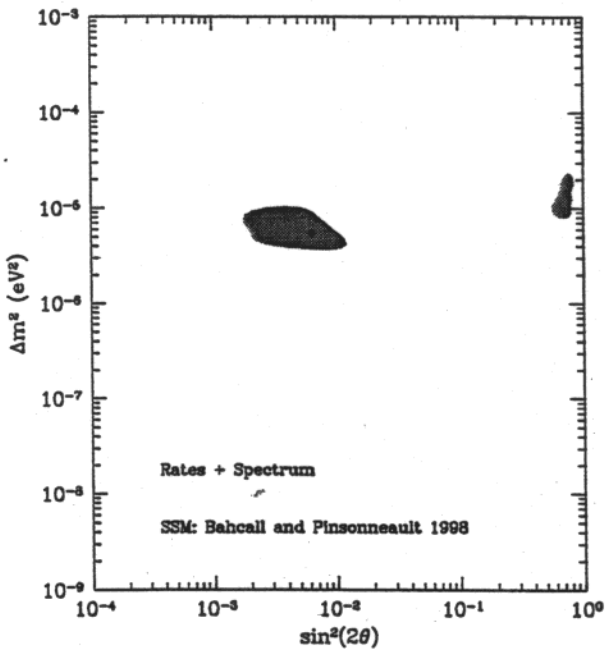


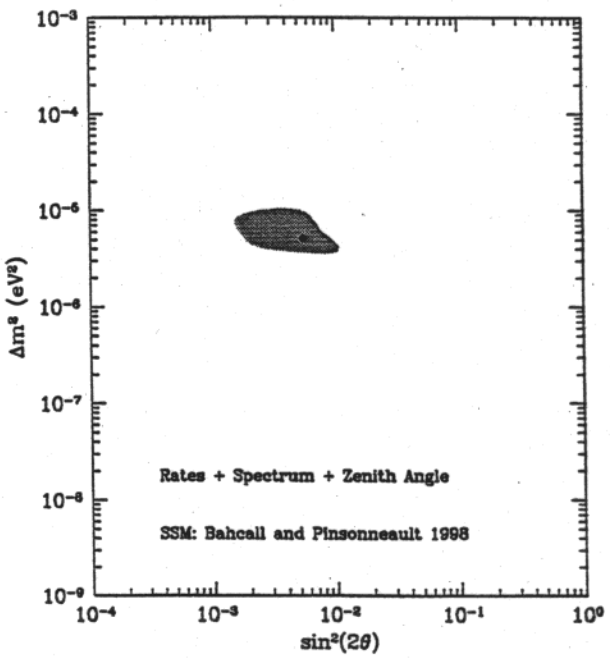
MSW:

BAHCALL, KRASTEV, SMIRNOV 1998

SUPERK 500d





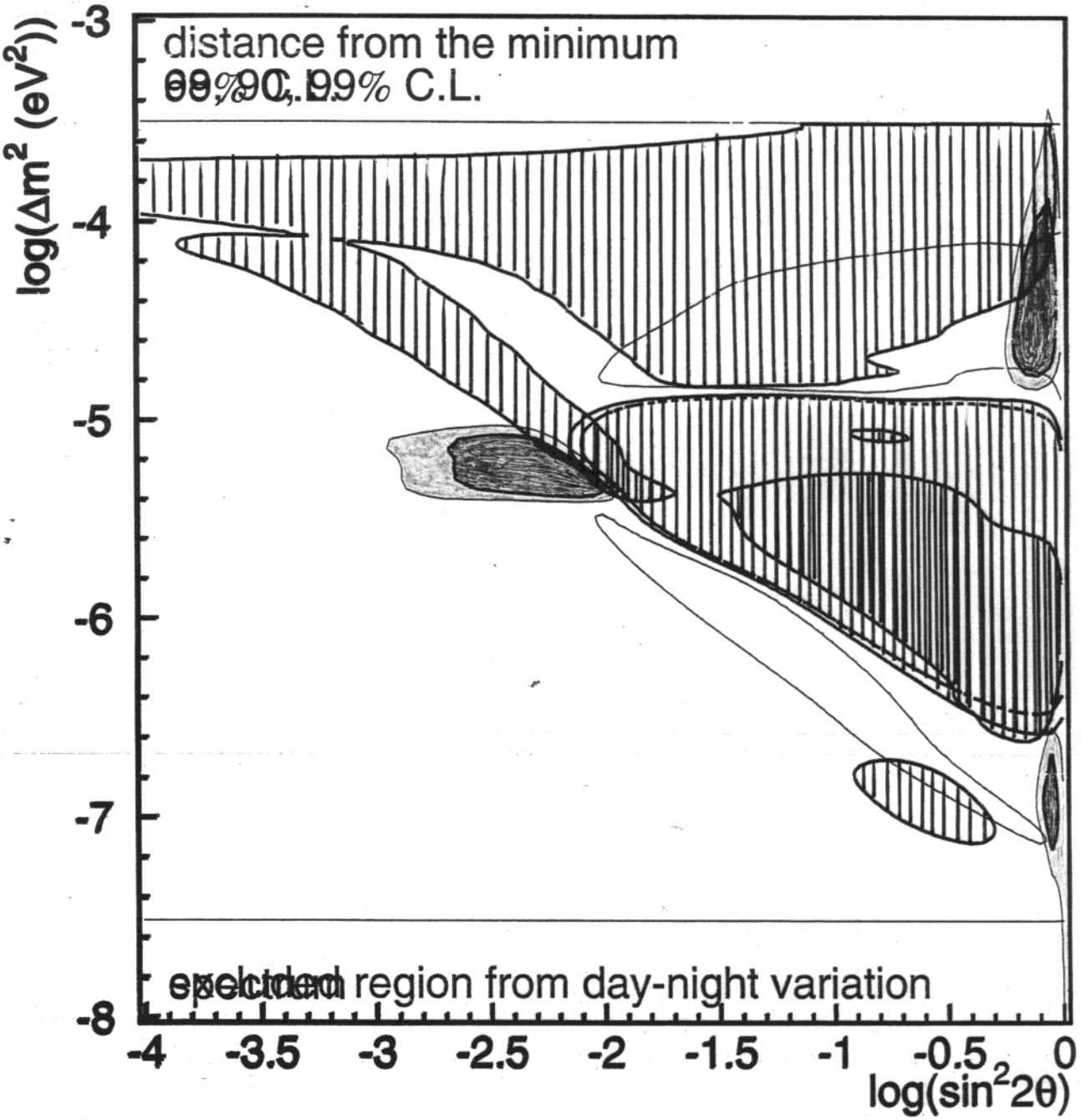


Y. TOTSUKA 93

MSW: GLOBAL RATES

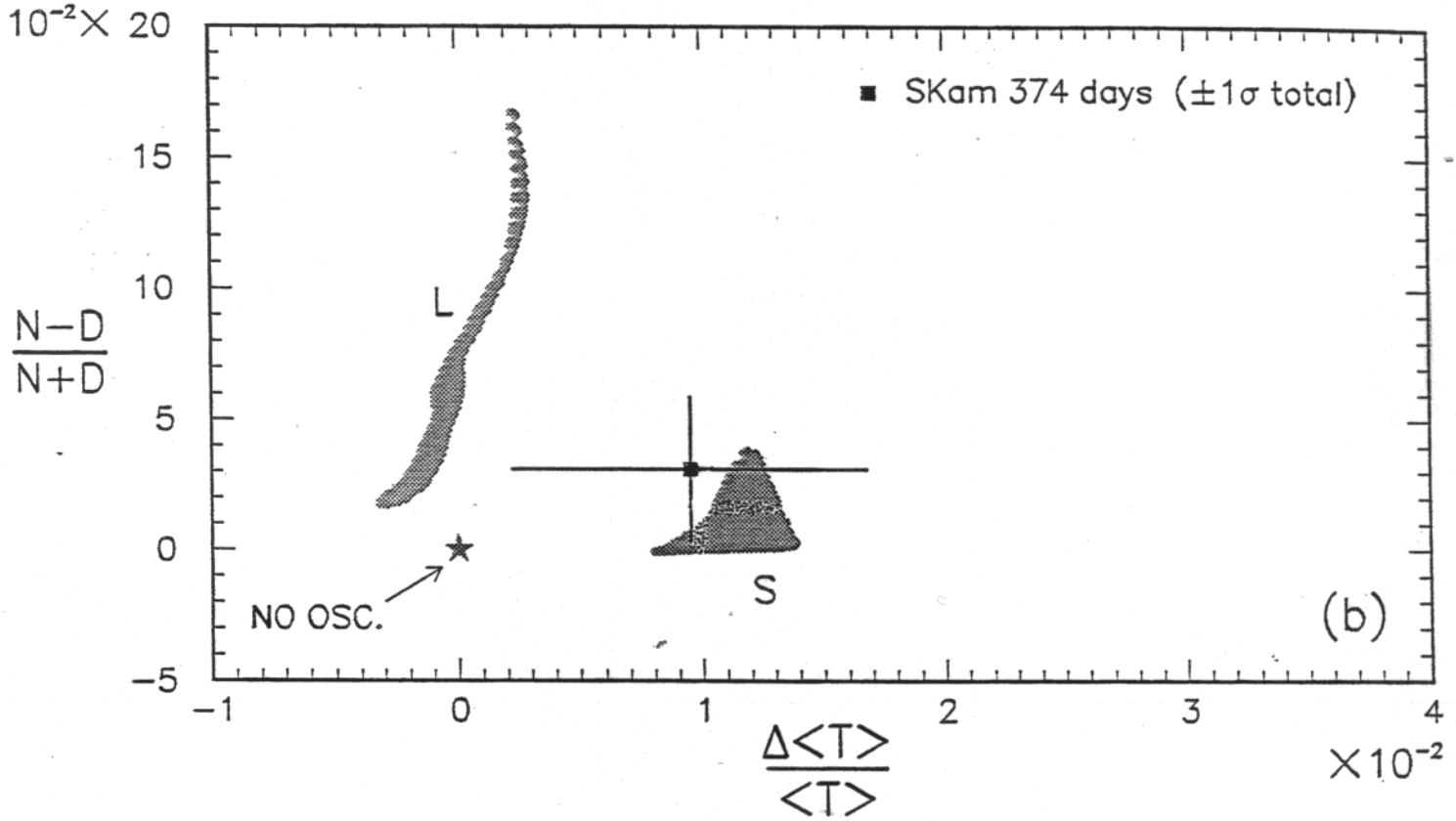
DAY-NIGHT SUPERK. 700d

SPECTRUM SUPERK. 700d



MSW: DAY/NIGHT EFFECT vs $\Delta T/T$

Fogli, Lisi, Montanio 1998



SK (374d): $\frac{N-D}{N+D}\times 100 = 3.1 \pm 2.8$

SK (504d): $2.3 \pm 2.0 \pm 1.4$

SK (708d): $\frac{N-D}{D}\times 100 = 6.0 \pm 3.6 \pm 2.8$

VO: VACUUM OSCILLATIONS WITH HIGH ENERGY SPECTRUM DISTORTION (HED VO)

V.B., FIORENTINI, LISSIA '98

$$\Phi_B = f_B \, \Phi_B^{SSM} \qquad R_{Cl} = f_{Cl} \, R_{Cl}^{Hom}$$

$$\underbrace{f_B = 0.8 \quad f_{Cl} = 1.3}_{} \quad (3.5\sigma \text{ deviation})$$

GLOBAL RATES ARE EXPLAINED BY VO WITH:

$$\Delta m^2 = 4.2 \cdot 10^{-10} \, eV^2, \quad \sin^2 2\theta = 0.93 \quad (\text{Y. SUZUKI } \nu\text{'98})$$

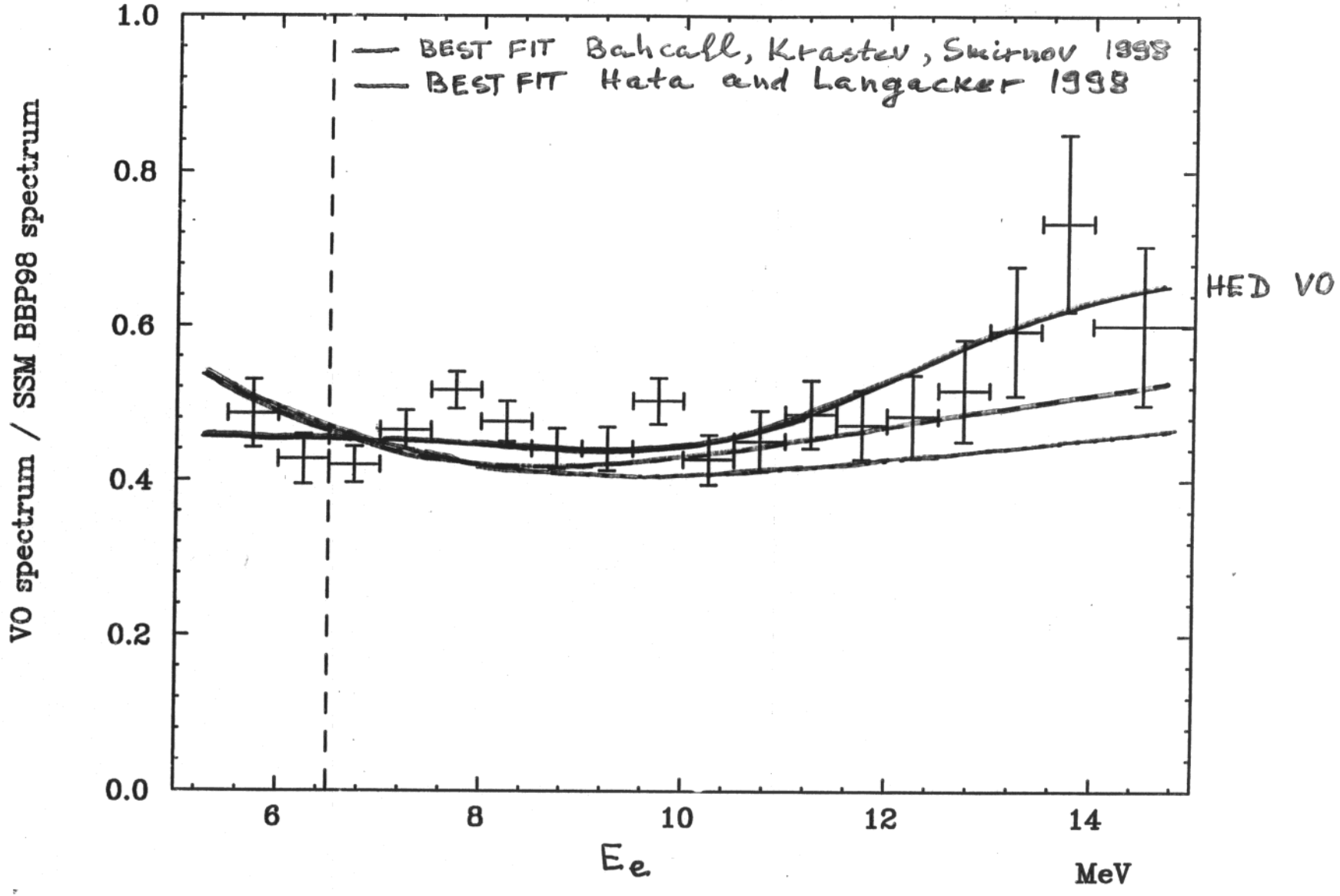
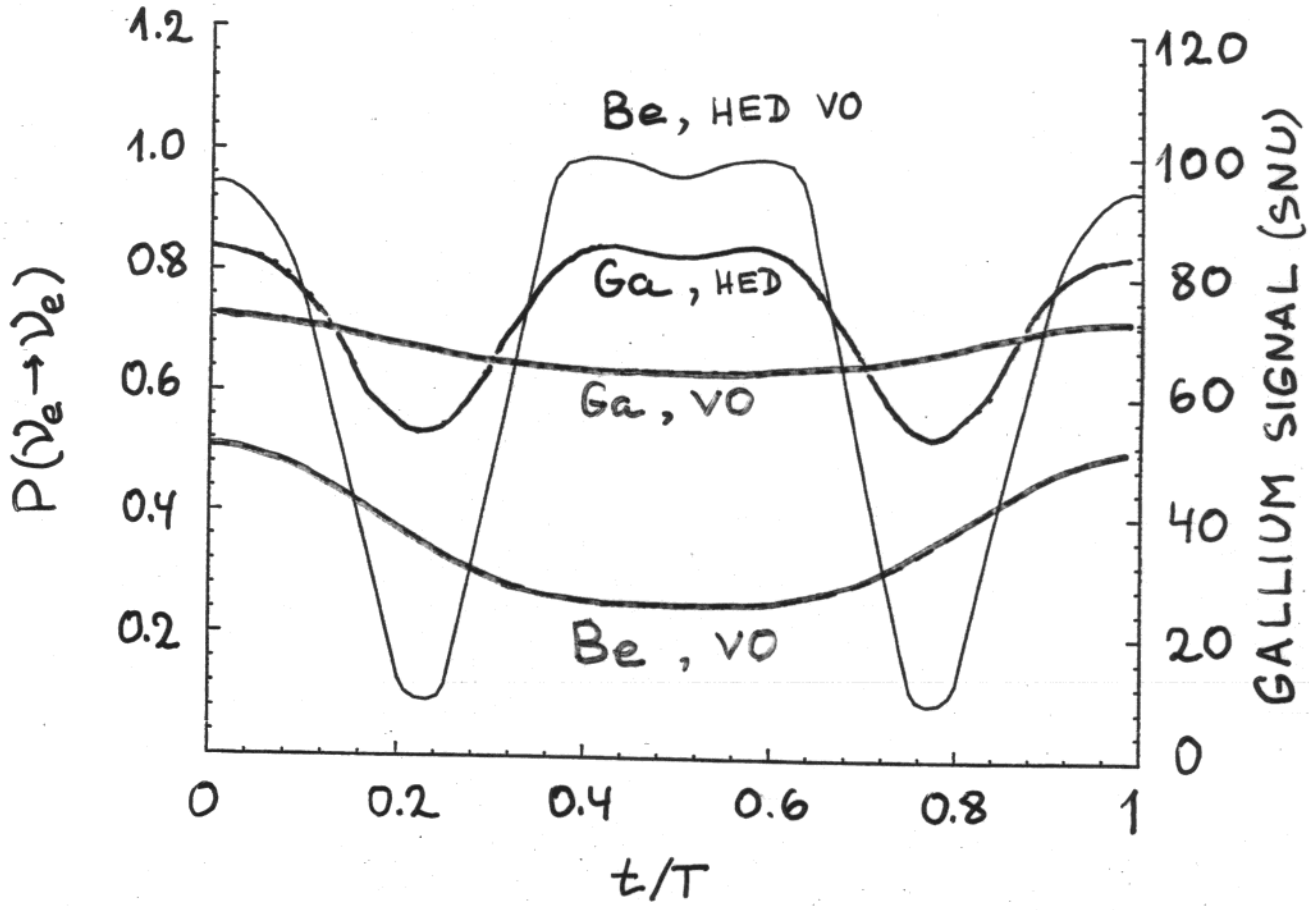
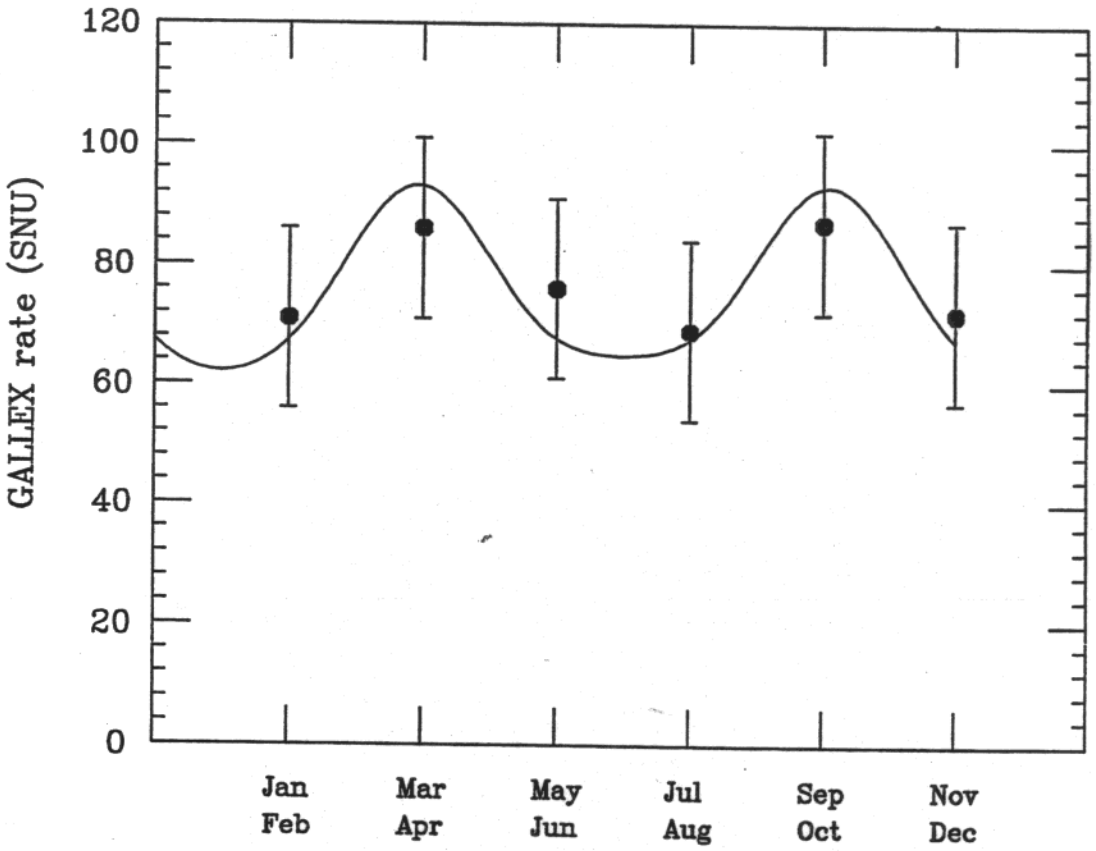

BEST FIT Bahcall, Krastev, Smirnov 1998
BEST FIT Hata and Langacker 1998
HED VO
VO spectrum / SSM BBP98 spectrum
1.0
0.8
0.6
0.4
0.2
0.0
6
8
10
12
14
Ee
MeV

Fig. 1

TIME VARIATION OF Be-FLUX AND Ga SIGNAL

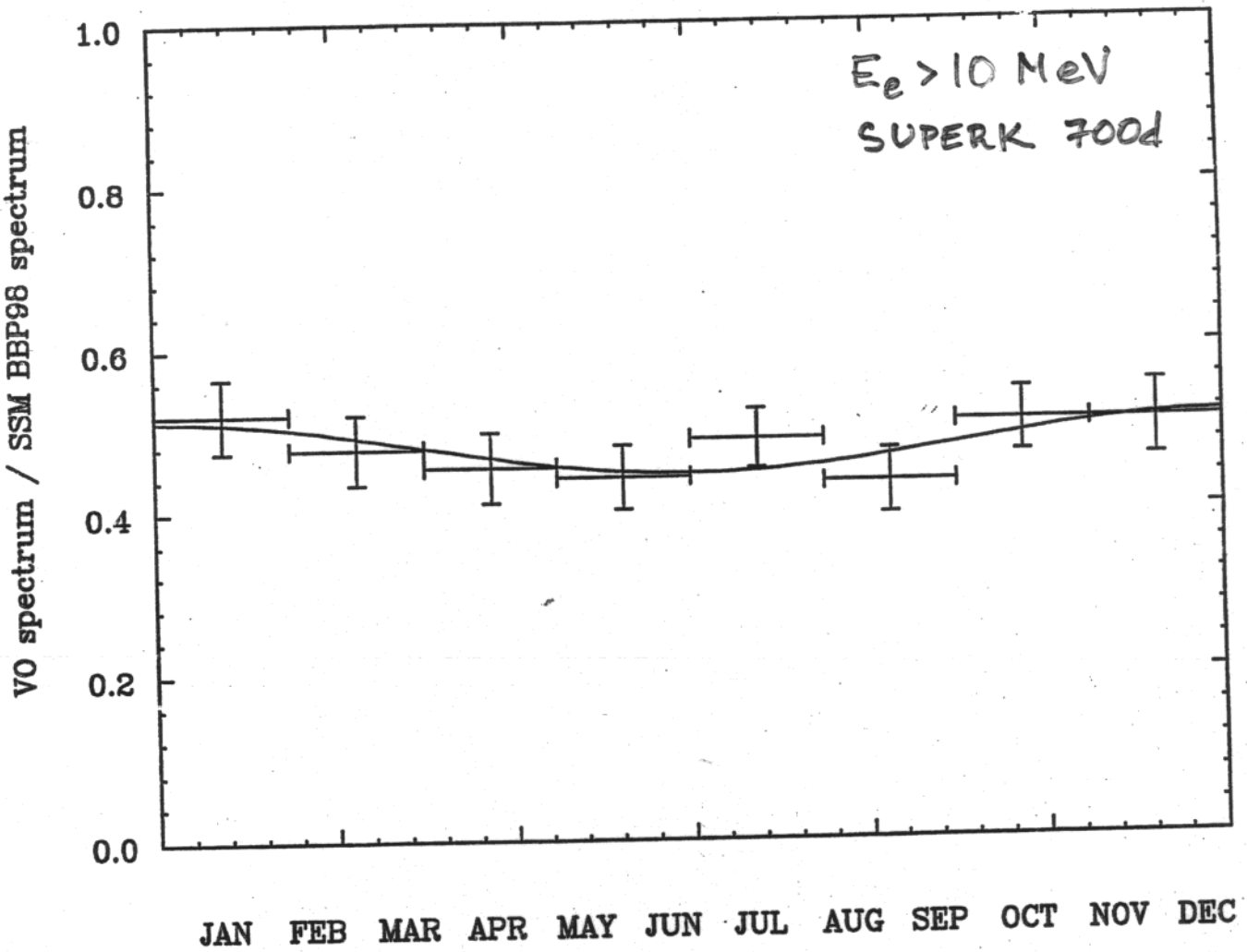


HEDVO and GALLEX DATA



HED VO TIME VARIATION

Y. Suzuki
A. Smirnov
B, F, L



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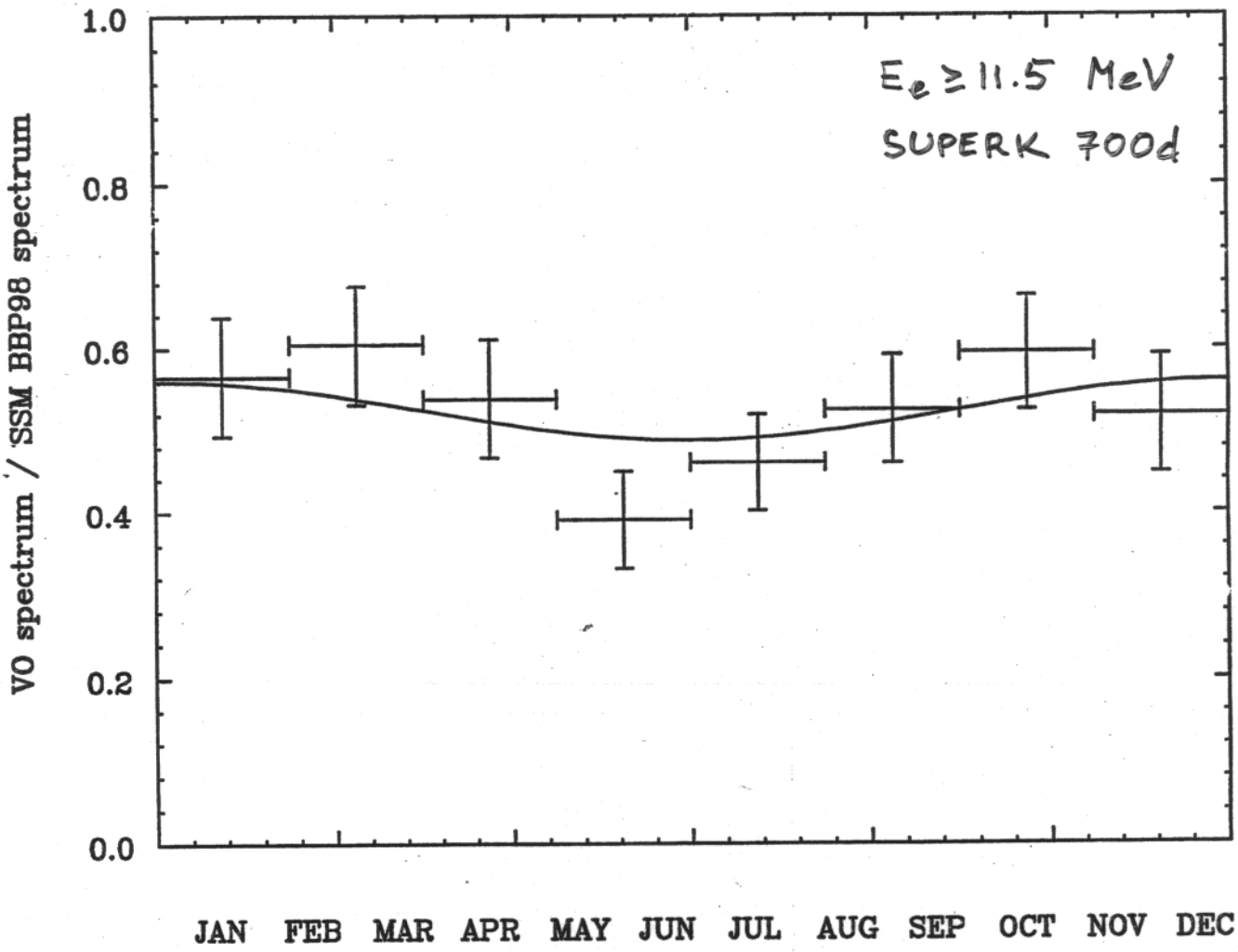


RSFP (RESONANT SPIN-FLAVOR PRECESSION)

Lim, Marciano PRD37(1988)1368
Akhmedov Phys. Lett. B213(1988) 64
Review Akhmedov hep-ph/9705451
Guzzo, Nunokawa 1998

RSFP = SFP STRENGTHENED BY MATTER RESONANCE

PARAMETERS:

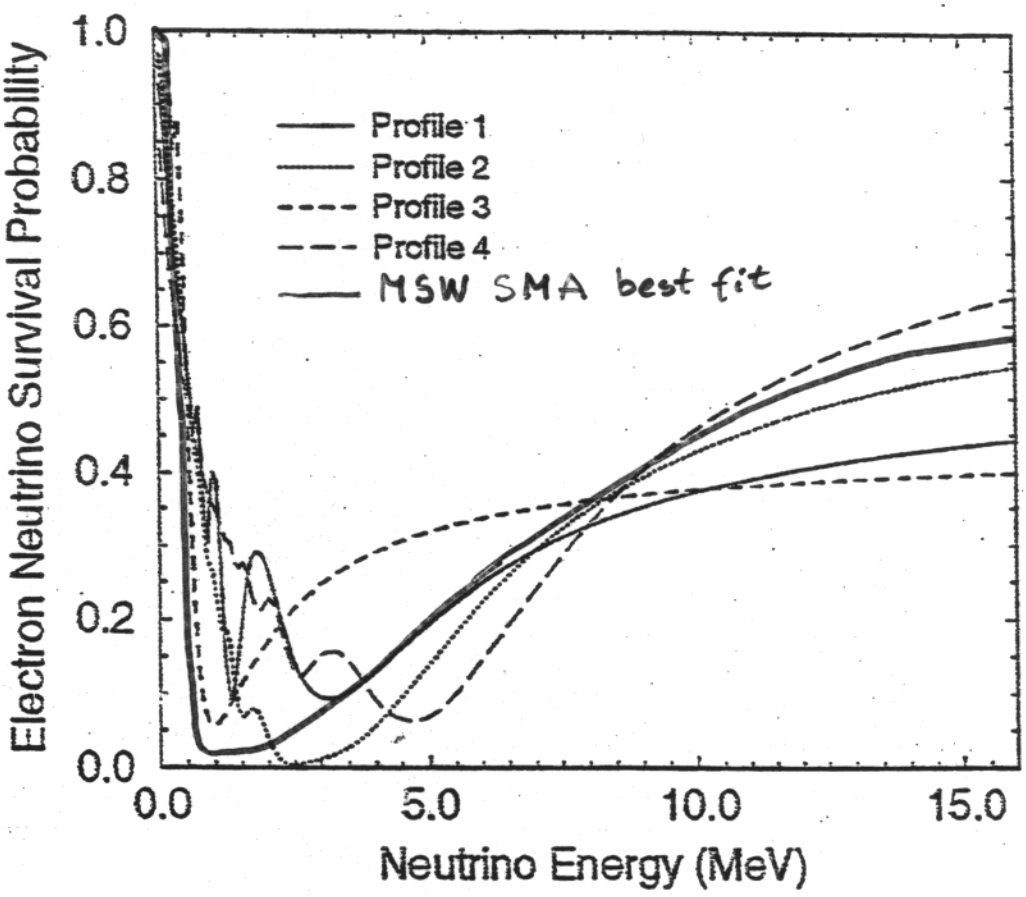
- MAGNETIC TRANSITION MOMENT $\mu \sim 10^{-11} \mu_B$
- MAGNETIC FIELD $B \sim$ a few $\cdot 10$ kG
- MAGNETIC FIELD PROFILE $B(r)$

ENERGY-DEPENDENT SUPPRESSION $P_{\nu_e \to \nu_e}(E)$ –
DUE TO ENERGY-DEPENDENT POSITION OF RESONANT LAYER AND $B(r)$

- MIXING ANGLE IS SMALL $\sin^2 2\theta < 0.3$ OR VERY SMALL.

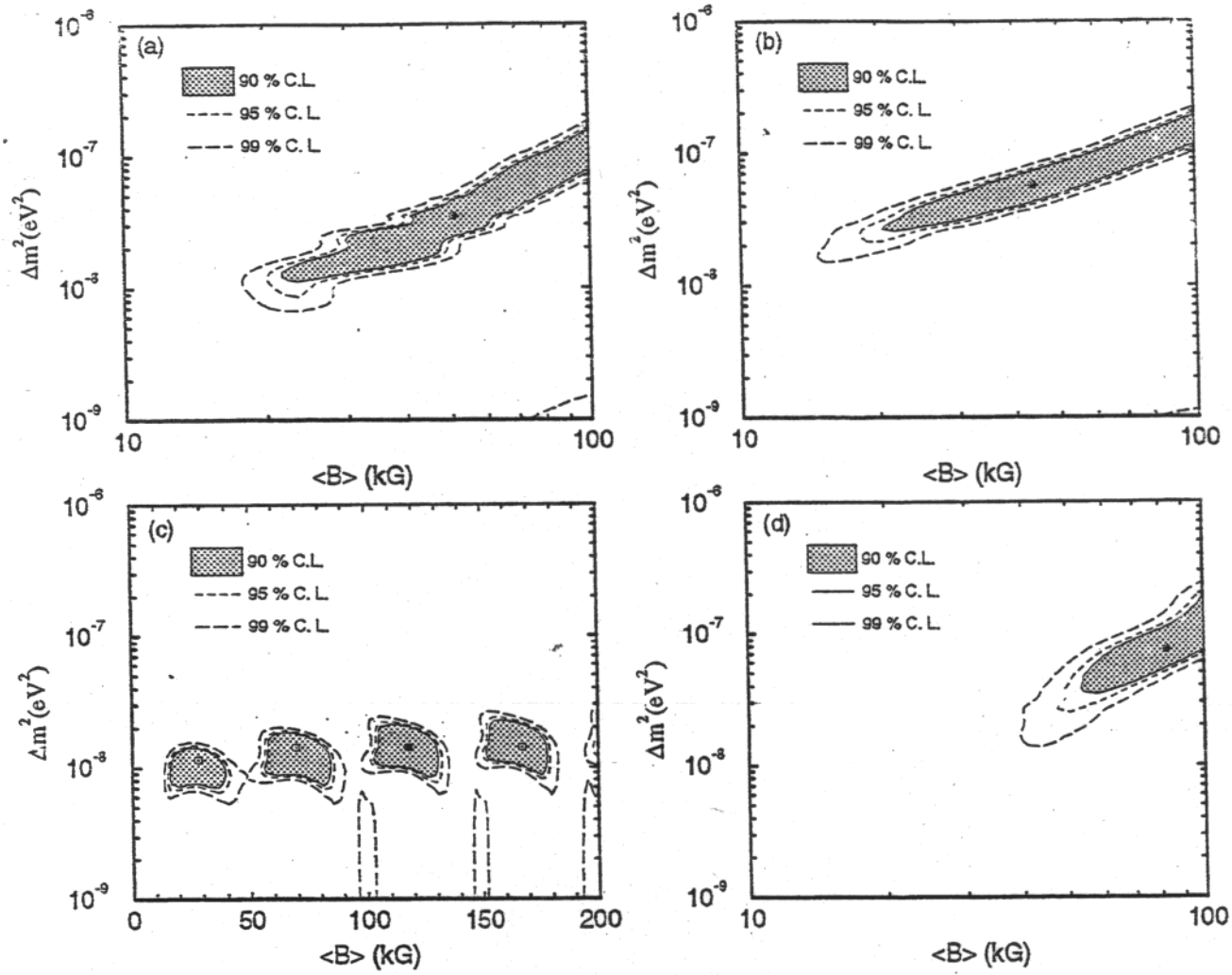
Guzzo, Nunokawa 1998

RSFP: SURVIVAL PROBABILITIES

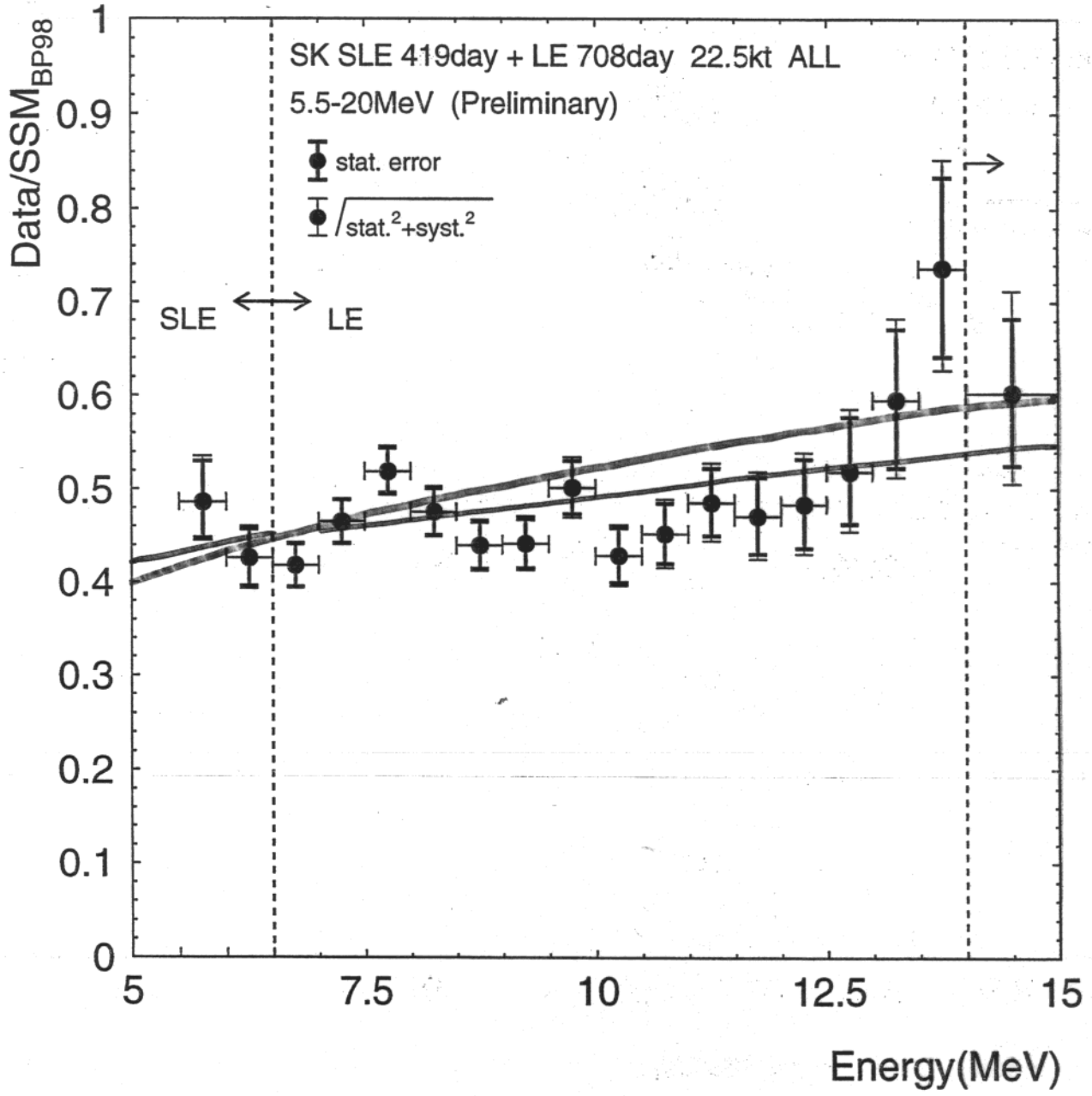


Guzzo, Nunokawa 98

RSFP: ALLOWED REGIONS



RSFP : Guzzo , Nunokawa 1999



CONCLUSIONS

- ASTROPHYSICAL SOLUTION TO SNP IS EXCLUDED (OR STRONGLY DISFAVORED).
  SOLAR NEUTRINO OBSERVATIONS HAVE A STATUS OF DISAPPEARANCE OSCILLATION EXPERIMENTS.

- AT PRESENT WE STILL DO NOT HAVE DIRECT PROOFS OF OSCILLATIONS.

- DISTORTION OF RECOIL-ELECTRON SPECTRUM AT $E_e \gtrsim 13$ MeV CAN BE EVIDENCE FOR OSCILLATION, THOUGH OTHER EXPLANATIONS ARE NOT EXCLUDED.

- HED VO SOLUTION WITH $f_B \approx 0.8$, $f_{Cl} \approx 1.3$, $\Delta m^2 = 4.2 \cdot 10^{-10}$ eV^2 $\sin^2 2\theta = 0.93$ EXPLAINS GLOBAL RATES (i.e. SNP) AND SPECTRUM (INCLUDING HE EXCESS). IT PREDICTS STRONG TIME VARIATION FOR Be-NEUTRINOS WITH T = 1/2 yr. THERE ARE SOME INDICATIONS TO THIS SOLUTION IN TIME-VARIATION OF SIGNAL (STATISTICALLY NOT SIGNIFICANT) IN GALLEX AND SUPERK.

- IF HE EXCESS OF EVENTS IN SUPERK IS NOT OF OSCILLATION ORIGIN, GLOBAL RATES IN FOUR SOLAR-NEUTRINO EXPERIMENTS AND LIMITS DUE TO DAY-NIGHT EFFECT AND SPECTRUM ALLOW SMA MSW, LMA MSW (AND PROBABLY LOW) AS SOLUTIONS TO SNP.

- RSFP EXPLAINS GLOBAL RATES AND SPECTRUM (INCLUDING HE EXCESS).

- EIO IS EXCLUDED AT 99.8% CL BY GLOBAL RATES, BUT PROBABLY SURVIVES IF Cl-RESULT IS EXCLUDED.

- VO, RSFP AND EIO HAVE SIGNATURES IN LOW-ENERGY SOLAR NEUTRINOS (pp AND Be) WHERE BOREXINO AND LENS WILL OPERATE IN FUTURE.