# SK ⊕ SNO$_{cc}$

## How to extract the $\nu_\mu$ contribution to SK solar neutrino signal

F.L. VILLANTE – UNIVERSITA' DI FERRARA

FLV, G. FIORENTINI, E. LISI
Phys. Rev. D 59 (1999) 013006

G.L. FOGLI, E. LISI, A. PALAZZO, FLV
hep-ph/0102288
Phys. Rev. D 63 (2001) 113016

# Is it possible to use CC at SNO to tell NC at SK?

- For simplicity, we assume $P_{ee} \equiv \text{const}$

SK

$$r_{SK} = r_{SK}^{e} + r_{SK}^{\mu}$$

$$r_{SK}^{e} = f_B P_{ee} \qquad f_B = \frac{\phi_B}{(\phi_B)_{SSM}}$$

$$r_{SK}^{\mu} = f_B P_{e\mu} \beta \qquad \beta = \frac{\sigma_{\mu}^{SK}}{\sigma_e^{SK}}$$

SNO

$$r_{SNO} = f_B P_{ee}$$

$$\boxed{\begin{aligned} r_{SK}^{\mu} &= r_{SK} - r_{SNO} \\ f_B &= \frac{1}{\beta} r_{SK} - \frac{1-\beta}{\beta} r_{SNO} \end{aligned}}$$

→ If SK and SNO energy thresholds are chosen appropiately, the previous relations hold <u>for any $P_{ee}(E_\nu)$.</u>

# Notations

$$r_{SK}^{e} \equiv \frac{R_{SK}^{e}}{(R_{SK})_{SSM}} = f_B \langle P_{ee} \rangle_{SK}$$

$$r_{SK}^{\mu} \equiv \frac{R_{SK}^{\mu}}{(R_{SK})_{SSM}} = f_B \langle P_{e\mu} \rangle_{SK} \, \beta \qquad \beta = \frac{\sigma_{\mu}^{SK}}{\sigma_{e}^{SK}}$$

$$r_{SNO} \equiv \frac{R_{SNO}}{(R_{SNO})_{SSM}} = f_B \langle P_{ee} \rangle_{SNO}$$

where:

$$\langle P_{ej} \rangle_i = \int dE_\nu \, P_{ej}(E_\nu) \, \rho_{ij}(E_\nu, T_i)$$

$j = e, \mu$

$i = SK, SNO$

$$\rho_{ij}(E_\nu, T_i) \propto \phi(E_\nu) \int_{T_i}^{\infty} dT \int dT' \, r_i(T, T') \, \frac{d\sigma_{ij}}{dT'}(E_\nu, T')$$

$\downarrow$

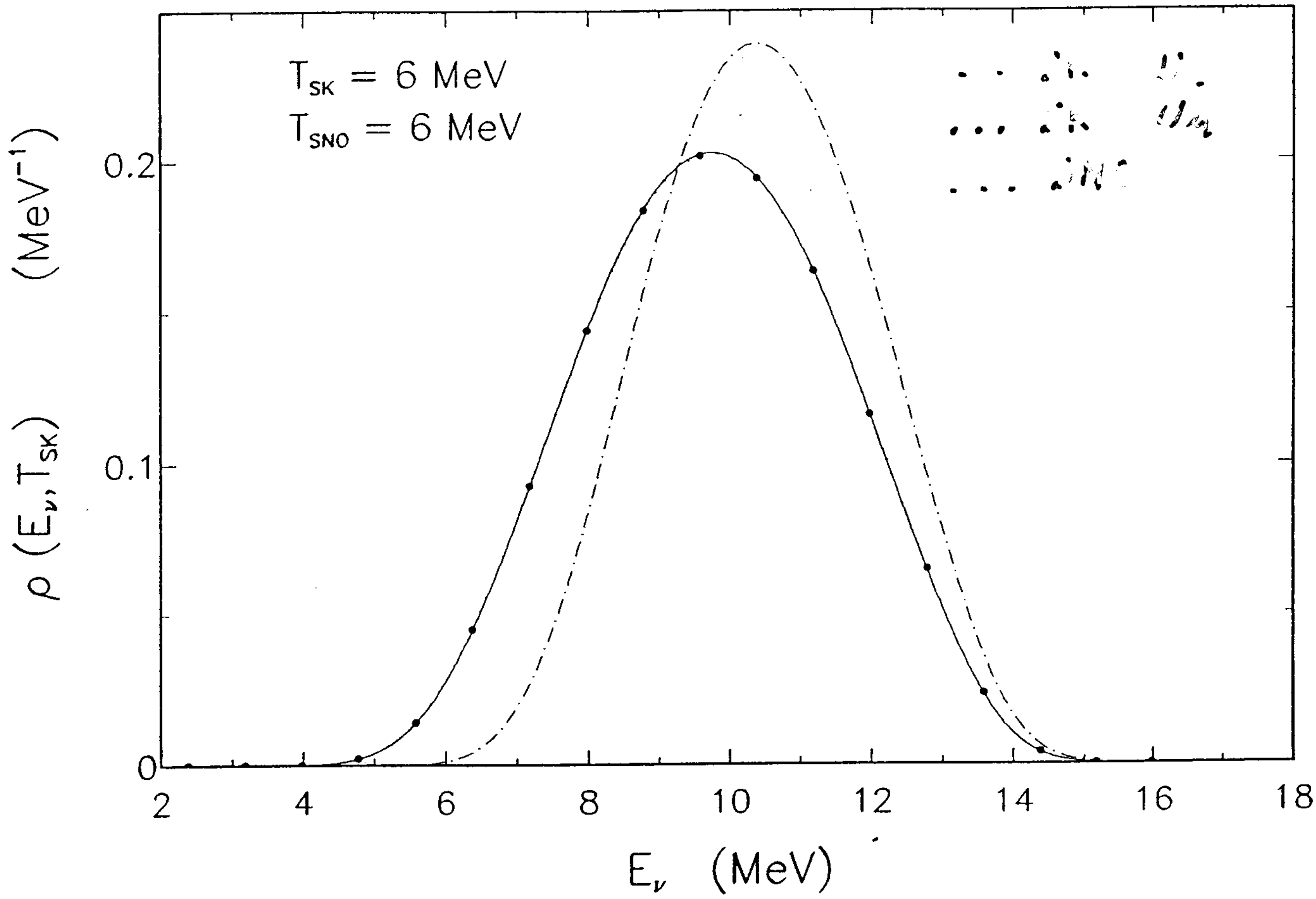
**Response function** for detection of $\nu_j$ in the $i$-experiment

(NORMALIZED TO UNITY)

$\phi(E_\nu)$ - Standard $^8B$ neutrino spectrum

$r_i(T, T')$ - Resolution functions of the two experiments

# Response functions




In general:

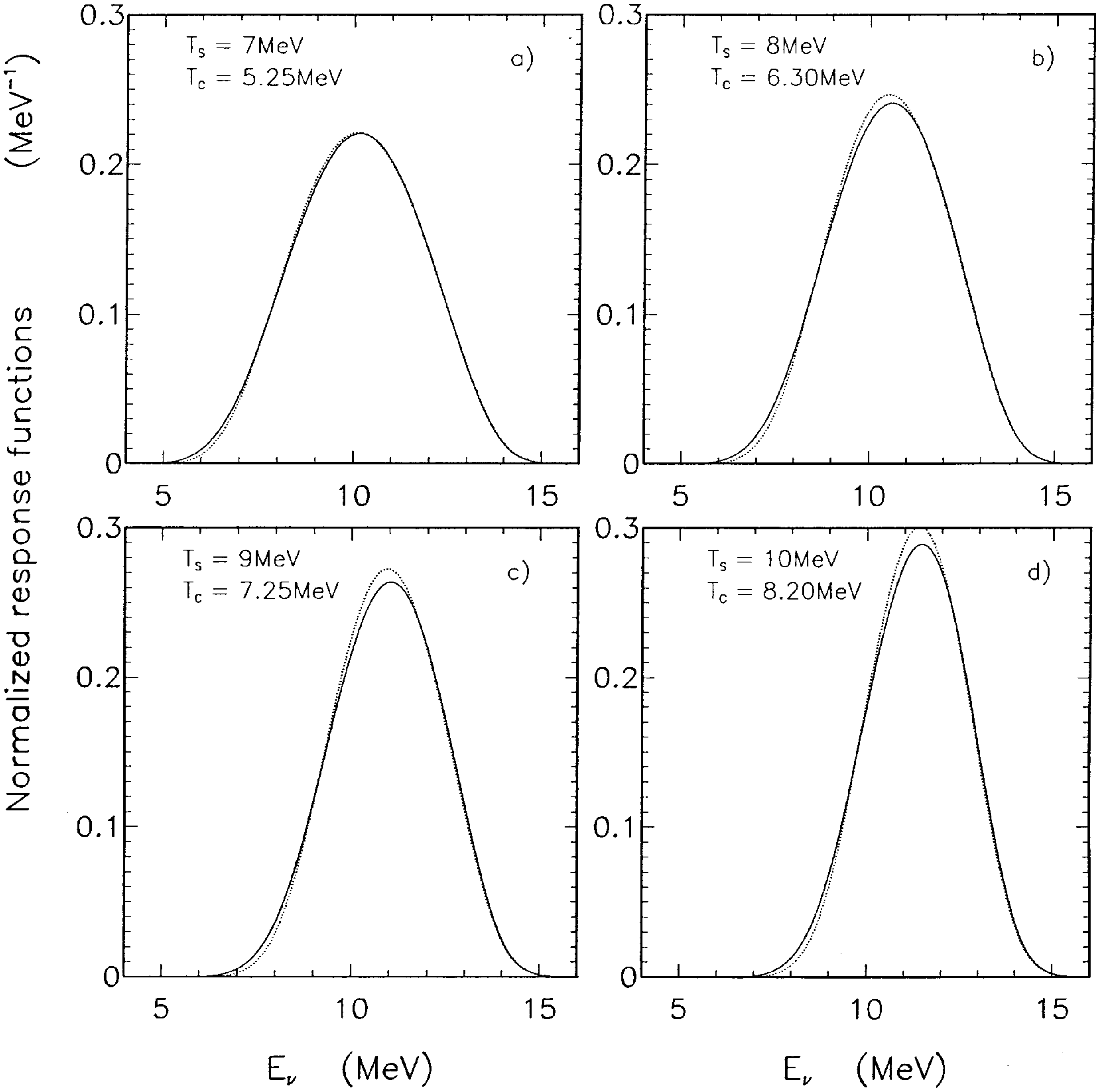
$$\rho_{SK,e}(E_\nu, T_{SK}) = \rho_{SK,\mu}(E_\nu, T_{SK})$$

but :

$$\rho_{SK,e}(E_\nu, T_{SK}) \neq \rho_{SNO}(E_\nu, T_{SNO})$$

$$\langle P_{ee} \rangle_{SK} \neq \langle P_{ee} \rangle_{SNO}$$

# How to equalize SK and SNO response function:




$$T_{SNO} \simeq T_{SK} - 1.7 \text{ MeV}$$

FLV, G. FIORENTINI, E. LISI

Phys. Rev. D 59 (1999) ...

Why is it possible to "equalize" SK and SNO?

It is a <u>lucky but "quite natural"</u> circumstance:

$$\rho_i(E_\nu,T) \propto \phi(E_\nu)\int_{T_i}^{\infty} dT \int dT' \; r_i(T,T') \; \frac{d\sigma_i}{dT'}(E_\nu,T')$$

$i = SK, SNO$

$\phi(E_\nu)$ - Standard $^8B$ neutrino spectrum

$r_i(T,T')$ - Resolution functions

- The energy ranges over which the two experiments are sensitives can be matched:

$$\rho_{SK}(E_\nu,T_{SK}) \neq 0 \quad \text{for} \quad E_\nu \simeq \left[T_{SK}+\frac{m_e}{2},\ 15\right] \text{MeV}$$

$$\rho_{SNO}(E_\nu,T_{SNO}) \neq 0 \quad \text{for} \quad E_\nu \simeq \left[T_{SNO}+Q,\ 15\ \text{MeV}\right]$$

$$\Rightarrow \boxed{T_{SK} - T_{SNO} \simeq Q - m_e/2 \simeq 1.4\ \text{MeV}}$$

- $\rho_{SK}$ and $\rho_{SNO}$ are two bell-shaped functions:

  - High energy $\longrightarrow$ dominated by $\phi(E_\nu)$
  - low energy $\longrightarrow$ dominated by $r_i(T,T')$

$$r_{SK}(T,T') \simeq r_{SNO}(T,T')$$

# Is this just an academic exercise?

for any $P_{ee}(E_\nu)$

$$\boxed{\begin{aligned} r^{\mu}_{SK}(T_{SK}) &= r_{SK}(T_{SK}) - r_{SNO}(T_{SNO}) \\ f_B &= \frac{1}{\beta(T_{SK})}\, r_{SK}(T_{SK}) - \frac{1-\beta(T_{SK})}{\beta(T_{SK})}\, r_{SNO}(T_{SNO}) \end{aligned}}$$

"Pre-SNO" perspective:

$$r_{SK} = 0.465 \pm 0.005 \, {}^{+0.015}_{-0.013}$$

$$(r_{SNO})_{\text{EXPECTED}} \cong 0.37$$

$$(r^{\mu}_{SK})_{\text{EXPECTED}} \cong 0.1$$

$$\delta_{SNO} \equiv \frac{\Delta r_{SNO}}{r_{SNO}} = \,?$$

$\mapsto$ Theoretical (CROSS SECTION $\nu_e + d \to p + p + e$, $\sim 6\%$ (3% ?)) + Exp. Uncertainties (STATISTICS + BACKGROUND)

$\delta_{SNO} = 10\% \longrightarrow \begin{cases} r^{\mu}_{SK} > 0 \text{ at } \underline{2.5 \text{ sigmas}} \\ f_B = \underline{1 \pm 0.22} \end{cases}$

"OPTIMISTIC":

$\delta_{SNO} = 5\% \longrightarrow \begin{cases} r^{\mu}_{SK} > 0 \text{ at } \underline{4.2 \text{ sigmas}} \\ f_B = \underline{1 \pm 0.14} \end{cases}$

Is it possible to equalize solar neutrino event spectra?

Up to now we considered the total event rates of SK and SNO. We show now that:

- The SK detector response in each bin of the electron energy spectrum can be approximated by the SNO detector response in an appropriate energy range

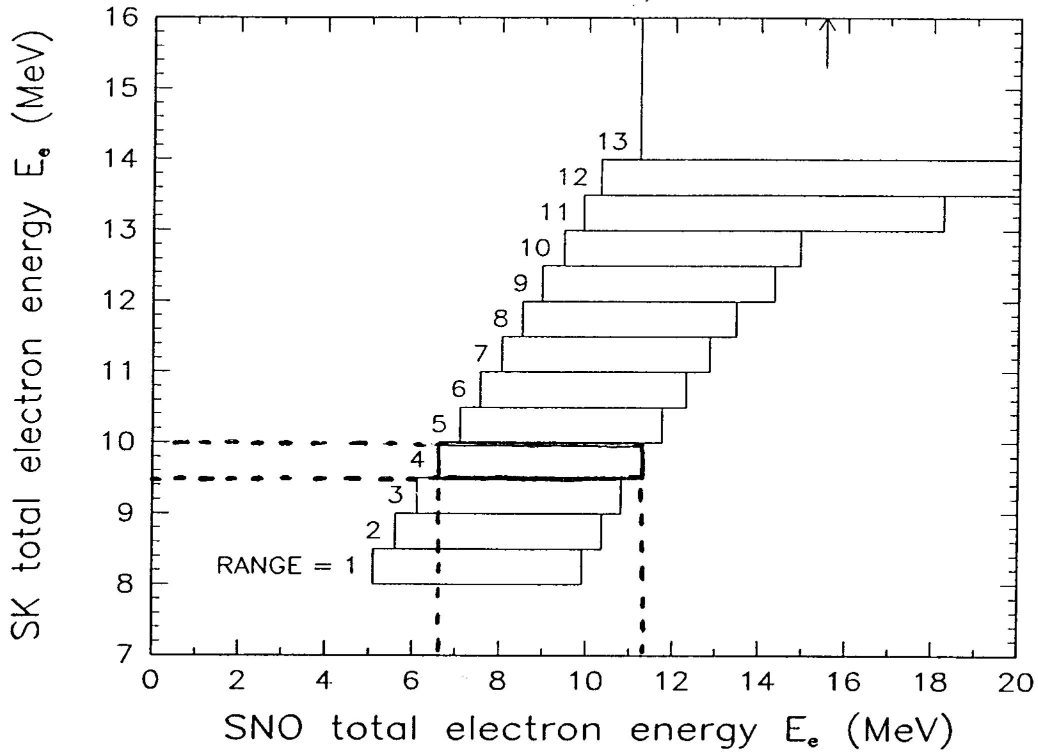
$$(r^{M}_{SK})_i = (r_{SK})_i - (r_{SNO})_i$$

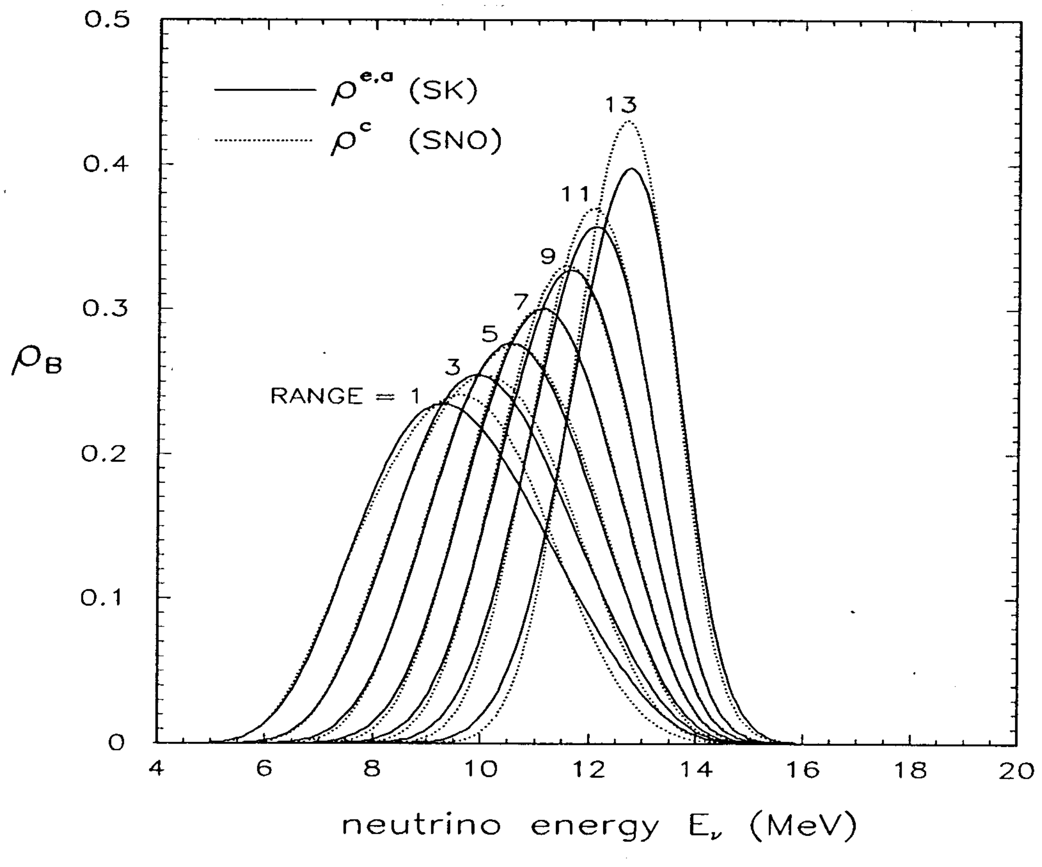
$$f_B = \frac{1}{\beta_i}(r_{SK})_i - \frac{1-\beta_i}{\beta_i}(r_{SNO})_i$$

$i \to$ energy ranges

- for any $P_{ee}(E_\nu)$ -

# SK - SNO corresponding energy ranges



Why could this be important?

for any $P_{ee}(E_\nu)$

(1) $$(r^{NC}_{SK})_i = (r_{SK})_i - (r_{SNO})_i$$

(2) $$f_B = \frac{1}{\beta_i}(r_{SK})_i - \frac{1-\beta_i}{\beta_i}(r_{SNO})_i$$

$i \rightarrow$ energy range

→ the value of $f_B$ is overconstrained

If r.h.s. of eq. (2) turns out to be "i-dependent":

hep neutrinos ?

(3) $$\frac{1}{\beta_i}(r_{SK})_i - \frac{1-\beta_i}{\beta_i}(r_{SNO})_i = f_B + \varepsilon_i f_{hep}$$

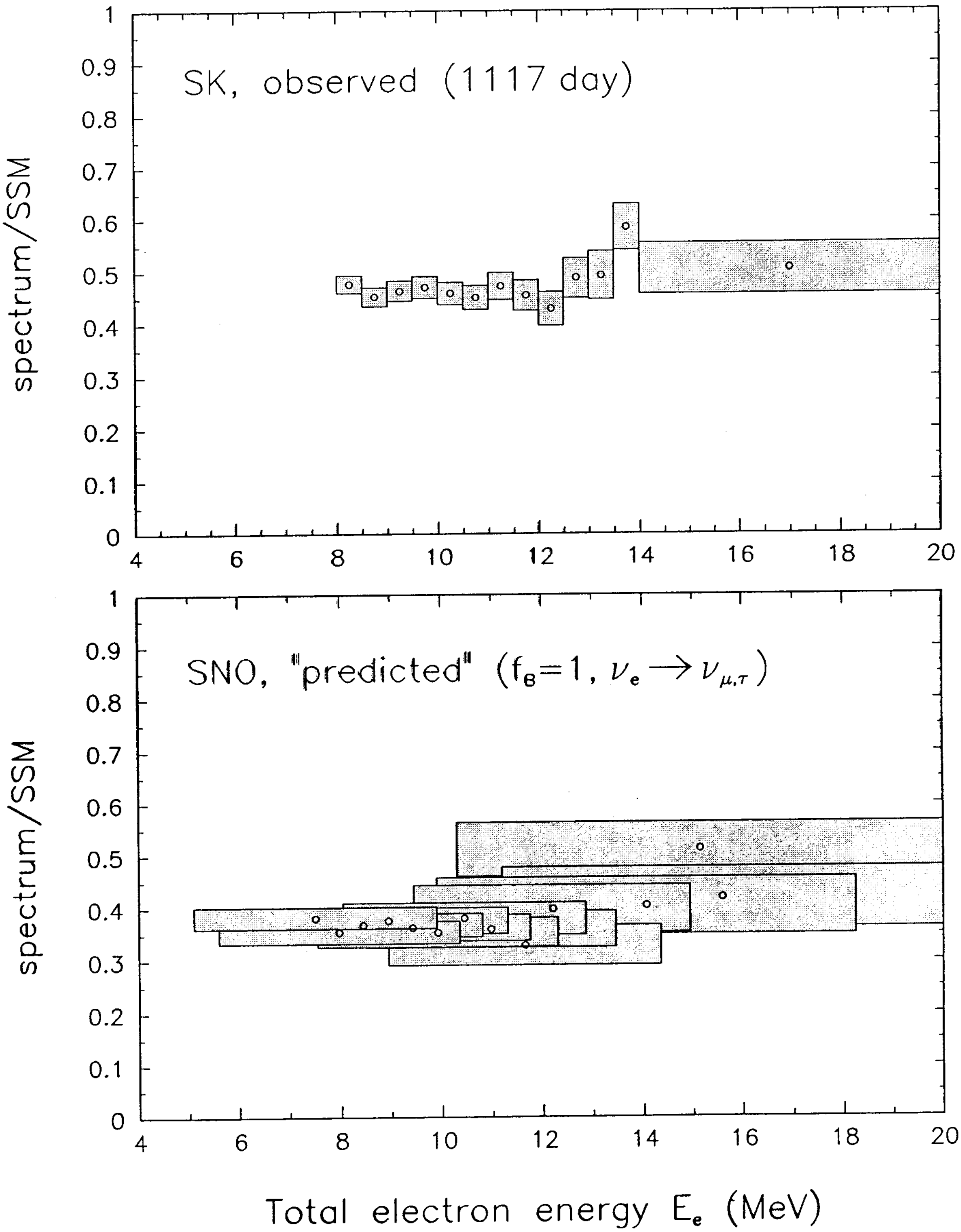
$\varepsilon_i \rightarrow$ hep relative contribution in each energy range

sterile neutrinos ?

(4) $$\frac{1}{\beta_i}(r_{SK})_i - \frac{1-\beta_i}{\beta_i}(r_{SNO})_i = f_B\left(1 - \langle P_{es}\rangle_i\right)$$

→ Eqs. (3) and (4) require high level of accuracy. A very careful estimate of uncertainties is needed

# SK and SNO electron energy spectra



"Pre-SNO" and "Post-SNO"

# Conclusions

If SK and SNO energy thresholds are chosen appropiately

- An approximate equality exists between SK and SNO response functions

By taking advantage of this property, one can use $r_{SK}$ and $r_{SNO}$ to determine in a **model-independent way**.

$\Delta r_{SNO} / r_{SNO} \sim 7$

~~$\Delta r_{SNO} / r_{SNO} \sim 10$~~

- The $\nu_\mu$ contribution to SK signal ~~~ 2.5~~ 6 3.1 6

- The $^8B$ neutrino flux in the sun ~~~ 20 %~~ 19 %

This ~~could provide~~ have provided the first "smoking gun" evidence for solar $\nu$ oscillations and the first "appearance evidence" for solar $\nu_\mu$

# SK

- Detection process:

$$\nu_{e\mu\tau} + e^- \longrightarrow \nu_{e\mu\tau} + e^-$$

CHARGED CURRENT + NEUTRAL CURRENT

1117 days
$E_{SK} = 5.5$ MeV

$$r_{SK} \equiv \frac{R_{SK}}{(R_{SK})_{SSM}} = 0.465 \pm 0.005 \,^{+0.015}_{-0.013}$$

- No strong smoking gun evidence for oscillations

- If SSMs are correct and $\nu_e \to \nu_\mu$ :

$$r^e_{SK} \cong 0.37 \qquad r^\mu_{SK} \cong 0.1$$

6 TIMES LARGER THAN EXP. ERROR

# SNO

- Detection process:

$$\nu_e + d \longrightarrow p + p + e^-$$

CHARGED CURRENT

- SNO first phase of measurments will provide an accurate determination of $\nu_e$ flux