Anna Rossi
PADOVA UNIV.

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NON-STANDARD NEUTRINO INTERACTIONS after SNO: the PERSPECTIVES of BOREXINO

in collaboration with Z. Berezhiani
R. Raghavan

to appear soon

a) At last evidence of

NEUTRINO APPEARANCE

SUN is a source of
ν_μ and ν_τ

b) study of NON-STANDARD
ν_τ INTERACTIONS

what can tell us (SK & SNO)

c) Testing NS interactions
in BOREXINO
energy spectrum from ^7Be

Strong evidence that NEUTRINOS are massive and mixed

$$\nu_\alpha = \mathbf{V}_{\alpha i}\, \nu_i \ ,$$

$\alpha = e, \mu, \tau, \quad i = 1, 2, 3$

mixing matrix

$$\mathbf{V} = \begin{pmatrix} V_{e1} & \underline{V_{e2}} & V_{e3} \\ V_{\mu 1} & V_{\mu 2} & \underline{V_{\mu 3}} \\ V_{\tau 1} & V_{\tau 2} & V_{\tau 3} \end{pmatrix} = \begin{pmatrix} c_{12}c_{13} & \underline{s_{12}c_{13}} & s_{13} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13} & c_{12}c_{23} - s_{12}s_{23}s_{13} & \underline{s_{23}c_{13}} \\ s_{12}s_{23} - c_{12}c_{23}s_{13} & -c_{12}s_{23} - s_{12}c_{23}s_{13} & c_{23}c_{13} \end{pmatrix}$$

- **ATMOSPHERIC ν DATA**

$\nu_\mu \longrightarrow \nu_\tau$ oscillation

probe $V_{\mu 3} \sim s_{23}$ $\qquad \theta_{23} \sim 45°$

$\delta m^2_{Atm} \simeq 10^{-3} - 10^{-2}\ eV^2$

- **SOLAR ν DATA**

$\nu_e \longrightarrow \nu' = c_{23}\nu_\mu - s_{23}\nu_\tau$

probe $V_{e2} \sim s_{12}$ $\qquad \theta_{12}$ small? large?

several solutions

$\delta m^2 \sim (10^{-12} - \ldots\ldots 10^{-4})\, eV^2$

- **REACTOR ν DATA (CHOOZ)**

probe $V_{e3} \simeq s_{13}$ $\qquad \theta_{13}$ small

WHAT CONCLUSION?

SUN copious source of ν_τ!

Solar $\nu_e \longrightarrow \frac{1}{\sqrt{2}}(\nu_\mu - \nu_\tau)$

ν_μ, ν_e : well known flavour states

ν_τ : much poorly known

can we test ν_τ properties
e.g non-standard interactions
with matter ?

remainder

CC detectors (^{37}Cl, ^{71}Ga, $\nu_e d \to e^- pp$)
ONLY ν_e sensitive

$$S = P \otimes \Phi \otimes \sigma^{cc}_{\nu_e}$$

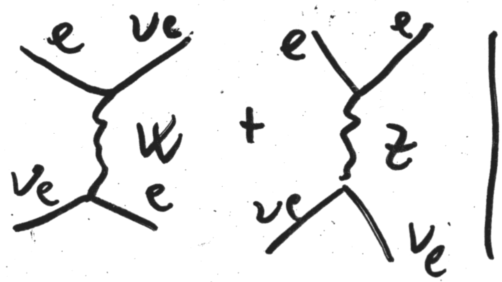
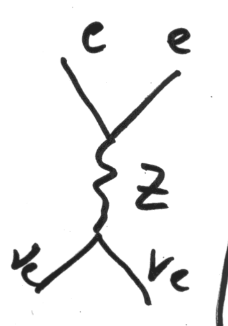
P = survival probability

NC detectors $\nu e \to \nu e$ SK
$\nu d \to \nu pn$ Borexino . .

ALL ν_e, ν_μ, ν_τ sensitive

$$S = \Phi \otimes \left[P \otimes \sigma_{\nu_e} + (1-P)\left(c^2_{23}\,\sigma_{\nu_\mu} + s^2_{23}\,\sigma_{\nu_\tau}\right)\right]$$

$\nu e \to \nu e$ example Standard Model

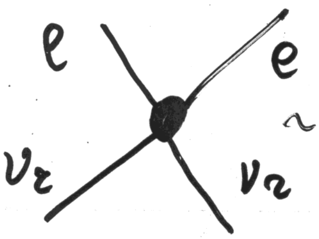
$\sigma_{\nu e} \sim \Big|$  $\Big|^2$, $\sigma_{\nu_\mu} = \sigma_{\nu_\tau} = \Big|$  $\Big|^2$

$\sigma_{\nu_\mu} = \sigma_{\nu_\tau} \sim \frac{1}{6}\,\sigma_{\nu_e}$

<u>NO SENSITIVITY</u> TO RESOLVE ν_τ
OR θ_{23}

DISTINGUISHING ν_τ by NON-STANDARD weak-strength INTERACTIONS with electrons

(Z. Berezhiani, A. Rossi 1994)



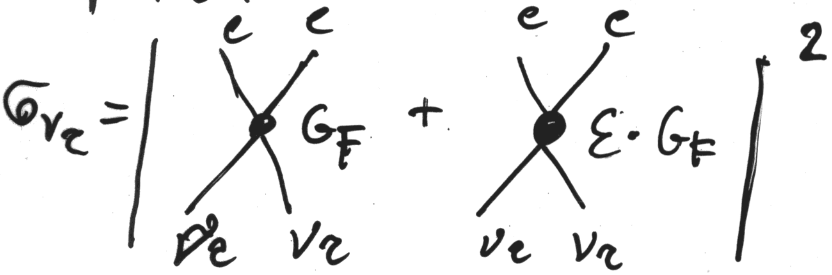
obtained by exchanging $\sim \varepsilon G_F$ NEW degrees of freedom (extra scalars – R SUSY ...)

$$\mathcal{L}_{eff} = \frac{G_F}{\sqrt{2}} \bar{\nu}_\tau \gamma^\mu (1-\gamma^5)\nu_\tau \cdot \left[\underline{\varepsilon_{\tau R}}\, \bar{e}\gamma_\mu(1+\gamma_5)e + \underline{\varepsilon_{\tau L}}\, \bar{e}\gamma_\mu(1-\gamma_5)e \right]$$

$\varepsilon_R \lesssim O(1)$, $\varepsilon_L \lesssim 10^{-1}$ (lepton universality, contact interactions) from the $SU(2)_w$ related operators

exp bounds

THEN



$\sigma_{\nu_\tau} \neq \sigma_{\nu_\mu}$

FC as well a FD NS ν interactions explain SN problem
Wolfenstein (1978)
E. Roulet (1991)
GUZZO, MASIERO, PETCOV (91)
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$$\frac{d\sigma_{\nu x}}{dT} = \frac{2G_F^2 m_e}{\pi}\left[g_{xL}^2 + g_{xR}^2\left(1-\frac{T}{E}\right)^2 - g_{xR}\,g_{xL}\cdot \frac{m_e T}{E^2}\right]$$

$$\begin{cases} g_{eL} = \frac{1}{2} + \sin^2\theta_w \\ g_{eR} = \sin^2\theta_w \end{cases} \quad \begin{cases} g_{\mu L} = -\frac{1}{2} + \sin^2\theta_w \\ g_{\mu R} = \sin^2\theta_w \end{cases} \quad \begin{cases} g_{\tau L} = g_{\mu L} + \varepsilon_L \\ g_{\tau R} = g_{\mu R} + \varepsilon_R \end{cases}$$

WHERE TO LOOK for sizeable effects? →
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relevant observables

- $\varepsilon_L, \varepsilon_R \neq 0$ affect energy dependence

e^- spectrum distortion

$$S(T) = \int dE\, \phi(E) \left[P(E) \frac{d\tilde{\sigma}_{\nu_e}}{dT} + (1-P(E)) \cdot \left(c_{23}^2 \frac{d\tilde{\sigma}_{\nu_\mu}}{dT} + s_{23}^2 \frac{d\tilde{\sigma}_{\nu_\tau}(\varepsilon)}{dT} \right) \right]$$

↓ ↓ ↓

source of
energy distortion

* $P(E)$: the probability depends on ν energy in most of the solutions

** $\frac{d\tilde{\sigma}_{\nu_e}(\varepsilon)}{dT}$: introduce another effect

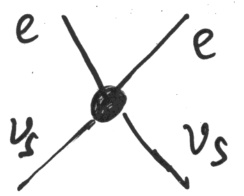
BUT BOTH get smeared by $\int dE\, \phi(E)$ for continuous ν flux (as ^8B, pp...)

Best case : mono energetic ν flux
^7Be (0.86 MeV) best candidate

- no spectrum deformation in the corresponding energy window from oscillation (or any conversion) effect
(the effect goes on the total rate)

•• The $\frac{d\tilde{\sigma}}{dT}(\varepsilon)$ -induced distortion can be "clean"

Taking the same attitude for
STERILE ν_s — SM singlet
$g_{sL} = g_{sR} = 0$



$\sim \varepsilon_s \cdot G_F$

$\varepsilon_{sL}, \varepsilon_{sR} \neq 0$

ν_s "active" with NS interactions

reconsider (less favoured) $\nu_e \to \nu_s$

- FIRST STEP

PRESENT solar neutrino data & NS - interactions

$$Z_{SNO} = \frac{R^{cc}_{SNO}}{R^{SSM}_{SNO}} = 0.347 \pm 0.027 \qquad Z_{SK} = \frac{R_{SK}}{R^{SSM}_{SK}} = 0.459 \pm 0.017$$

- only ^8B neutrinos – most uncertain $\phi_B = f_B \cdot \phi_B^{SSM}$
- no clear evidence of spectrum deformation
  $P = \text{constant}$

$$Z_{SNO} = f_B \cdot P$$

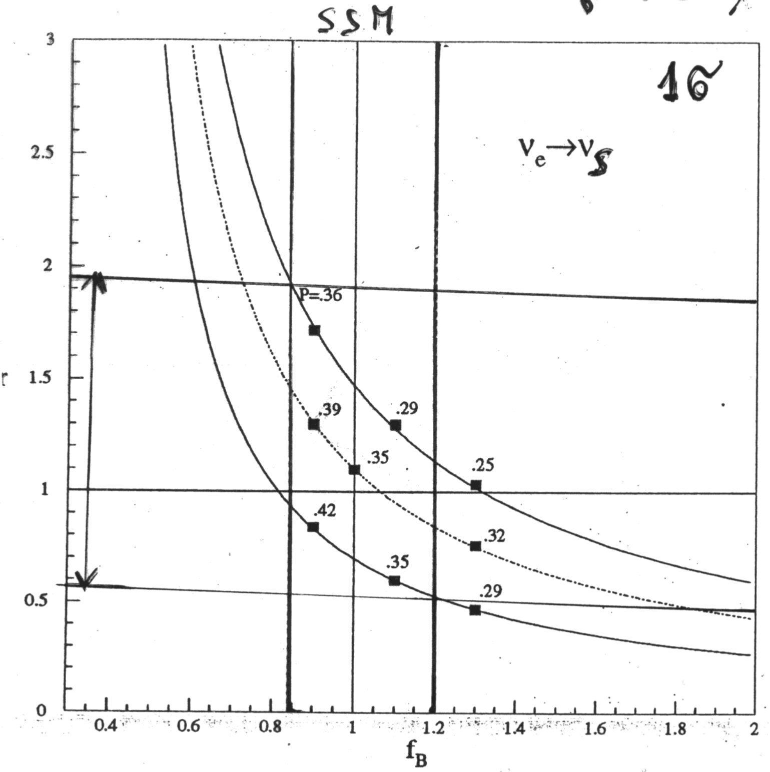
$$Z^a_{SK} = f_B \cdot \left[P + (1-P) \frac{\tilde{\sigma}_{\nu_\mu}}{\tilde{\sigma}_{\nu_e}} \cdot \left(c^2_{23} + s^2_{23} \cdot \frac{\tilde{\sigma}_{\nu_\tau}(\varepsilon)}{\tilde{\sigma}_{\nu_\mu}} \right) \right]$$

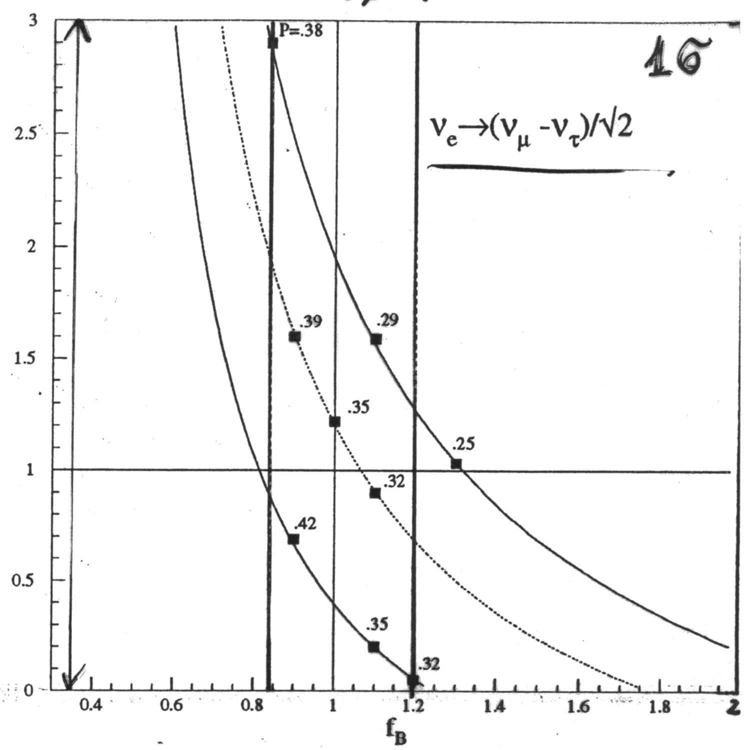
$$Z^s_{SK} = f_B \cdot \left[P + (1-P) \frac{\tilde{\sigma}_{\nu_\mu}}{\tilde{\sigma}_{\nu_e}} \cdot \left(\frac{\tilde{\sigma}_{\nu_s}(\varepsilon)}{\tilde{\sigma}_{\nu_\mu}} \right) \right]$$

2 free parameters : f_B , $r = \dfrac{\tilde{\sigma}_{\nu_{\tau,s}}(\varepsilon)}{\tilde{\sigma}_{\nu_\mu}}$

Z_{SNO} & Z_{SK} model-independent analysis

$\left(f_B \,,\; r = \tilde{\sigma}_{\nu_{s,\tau}}(\varepsilon) / \tilde{\sigma}_{\nu_\mu} \right)$



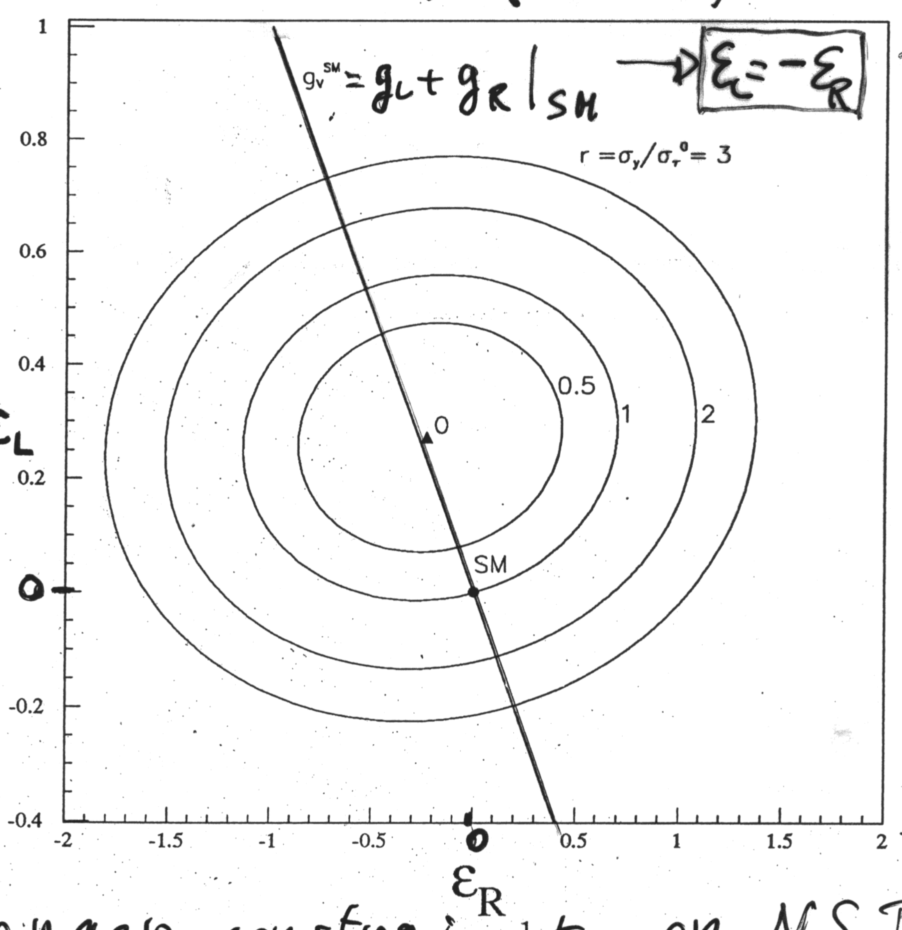


$\tilde{\sigma}_{\nu_s} \sim (0.5 - 2)\, \tilde{\sigma}_{\nu_\mu}$

$\tilde{\sigma}_{\nu_\tau} \sim (0 \div 3)\, \tilde{\sigma}_{\nu_\mu}$

strict sterile conversion disfavoured

$r \leftrightarrow (\varepsilon_R, \varepsilon_L)$



no matter effects for $\nu_\mu \to \nu_\tau$

No stronger constraints on NSI from SN data

Present SK experiment: constraints on NS interactions with electrons

$\nu_e \to \nu_s$

$$\begin{cases} f_B \sim 0.84 \div 1.2 \\ \tilde{\sigma}_{\nu_s} \sim \left(\frac{1}{2} \div 2\right) \tilde{\sigma}_{\nu_\mu} \end{cases}$$

confirm that

- sterile conversion ($\tilde{\sigma}_{\nu_s} = 0$) is strongly disfavoured
- but space for NS interactions

$\nu_e \to \frac{1}{\sqrt{2}}(\nu_\mu - \nu_\tau)$

$$\begin{cases} f_B = 0.84 \div 1.2 \\ \tilde{\sigma}_{\nu_\tau} \lesssim 3\, \tilde{\sigma}_{\nu_\mu} \end{cases}$$

- ν_τ allowed to have NS interactions
  - bigger cross section
- could become "sterile" $\tilde{\sigma}_{\nu_\tau} \to 0$ for larger ^8B flux

Conclusion:

$|\varepsilon_R| \lesssim O(1)$ — comparable to exist. bounds

$\varepsilon_L \sim (-0.2 \div 0.8)$ → looser than existing bounds

SK energy spectrum does not impose severe constraints, too.

It makes sense to explore further...

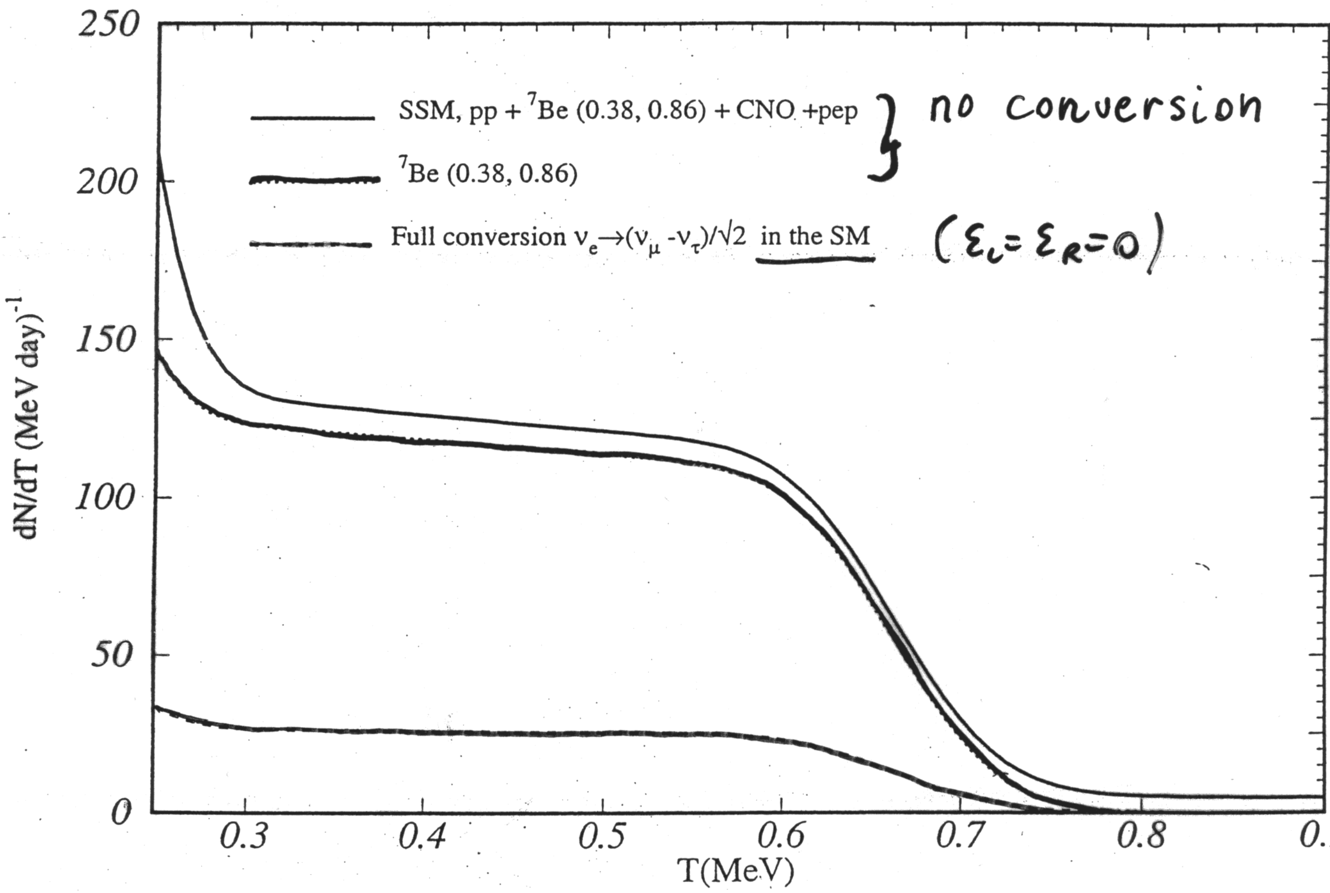
Second Step: PERSPECTIVE of BOREXINO

$\nu e \to \nu e$ $\qquad T_{th} = 0.25$ MeV

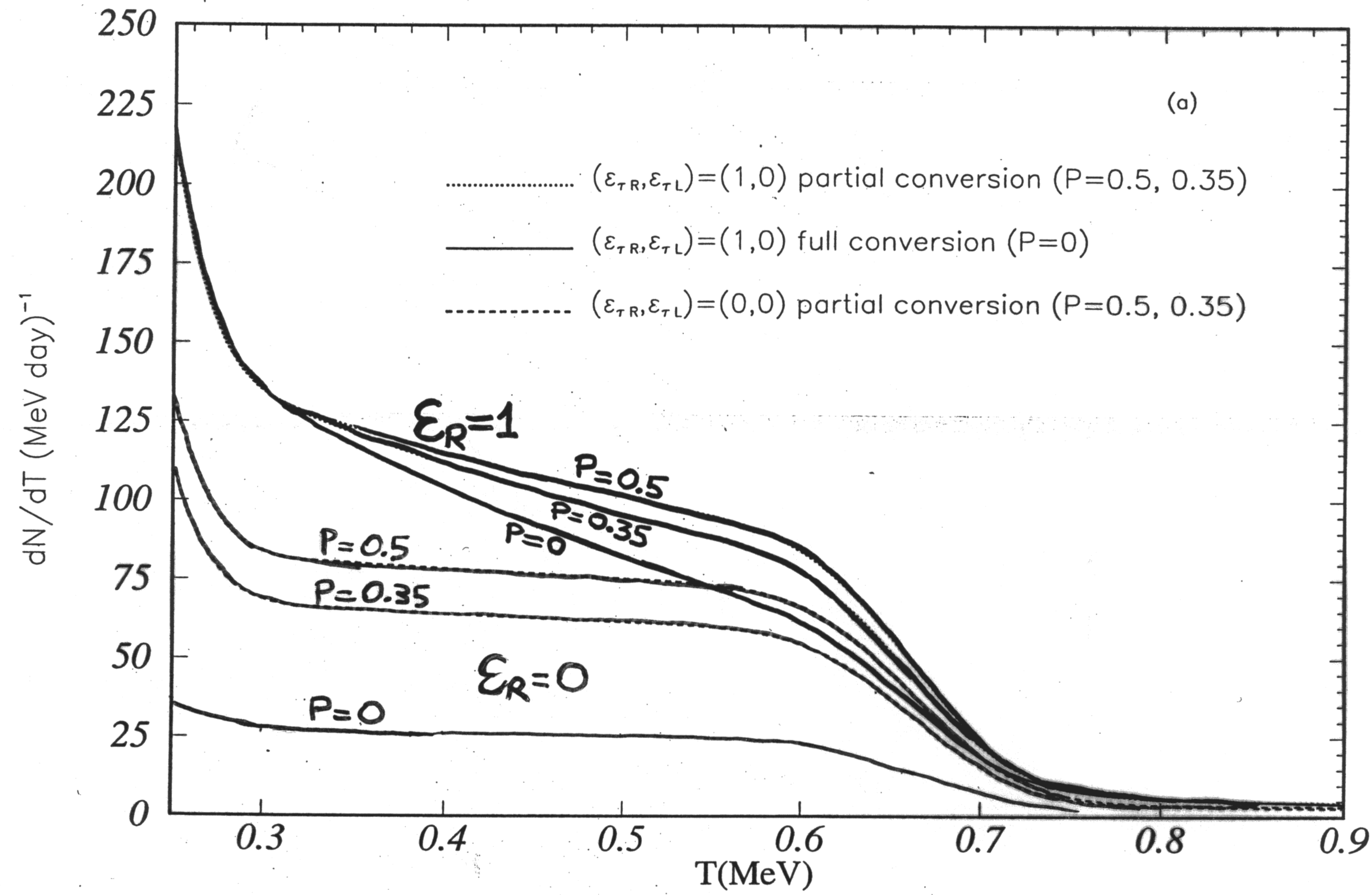
80% signal from ^7Be : $T = (0.25 \div 0.67)$ MeV

electron spectrum

$$S(T) = \phi_{Be} \cdot \left[P \cdot \frac{d\tilde{\sigma}_{\nu_e}}{dT} + (1-P) \cdot \left(c_{23}^2 \frac{d\tilde{\sigma}_{\nu_\mu}}{dT} + s_{23}^2 \frac{d\tilde{\sigma}_{\nu_\tau}}{dT}(\varepsilon) \right) \right]$$



ν_τ with NS ints :
BOREXINO potential

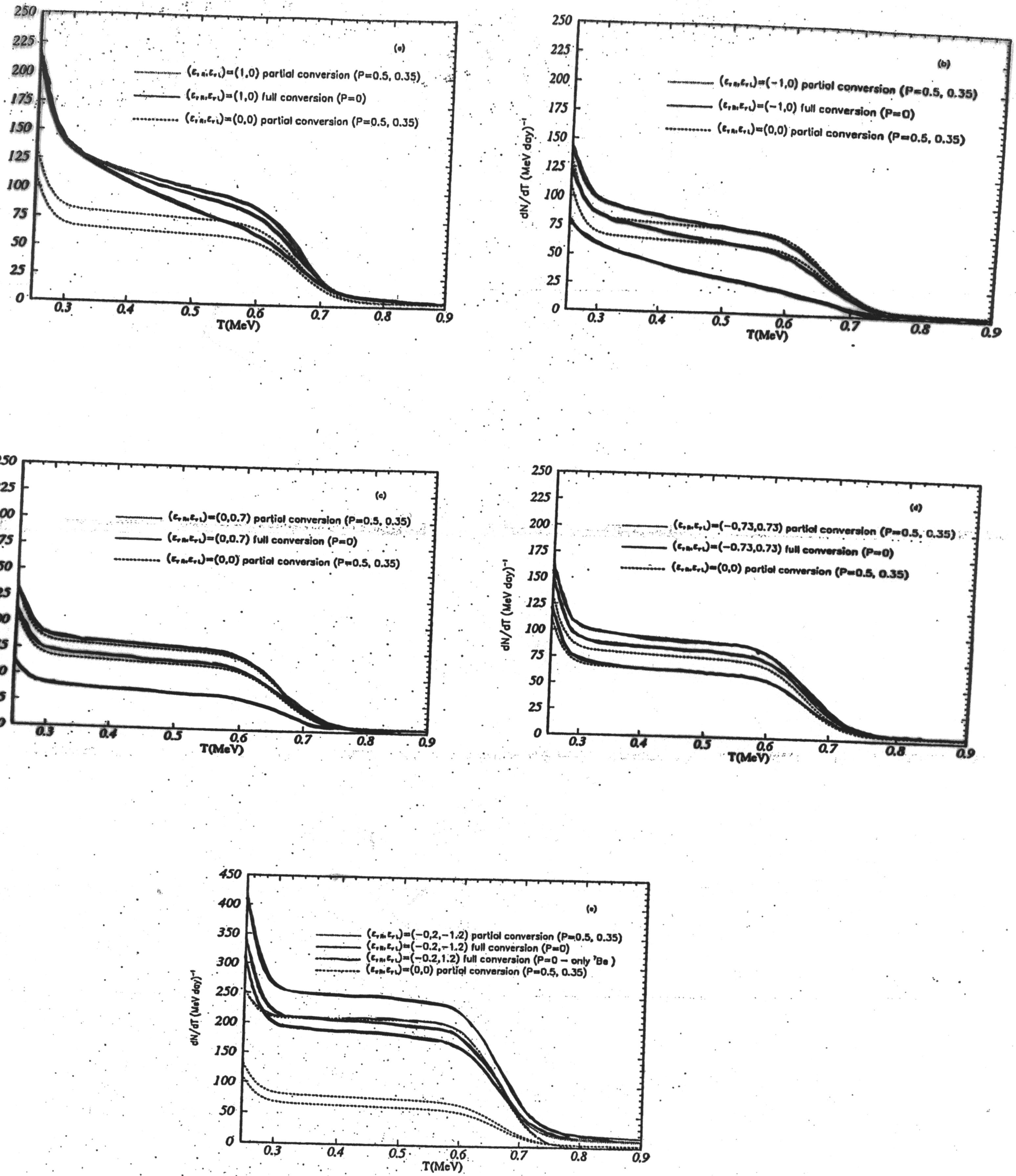


sizeable distortion in the window $T = (0.3 \div 0.6)$ MeV

also increase in the "integral" number of events

$\varepsilon_R \neq 0$ more sensitive case

compare different $(\varepsilon_R, \varepsilon_L)$ cases



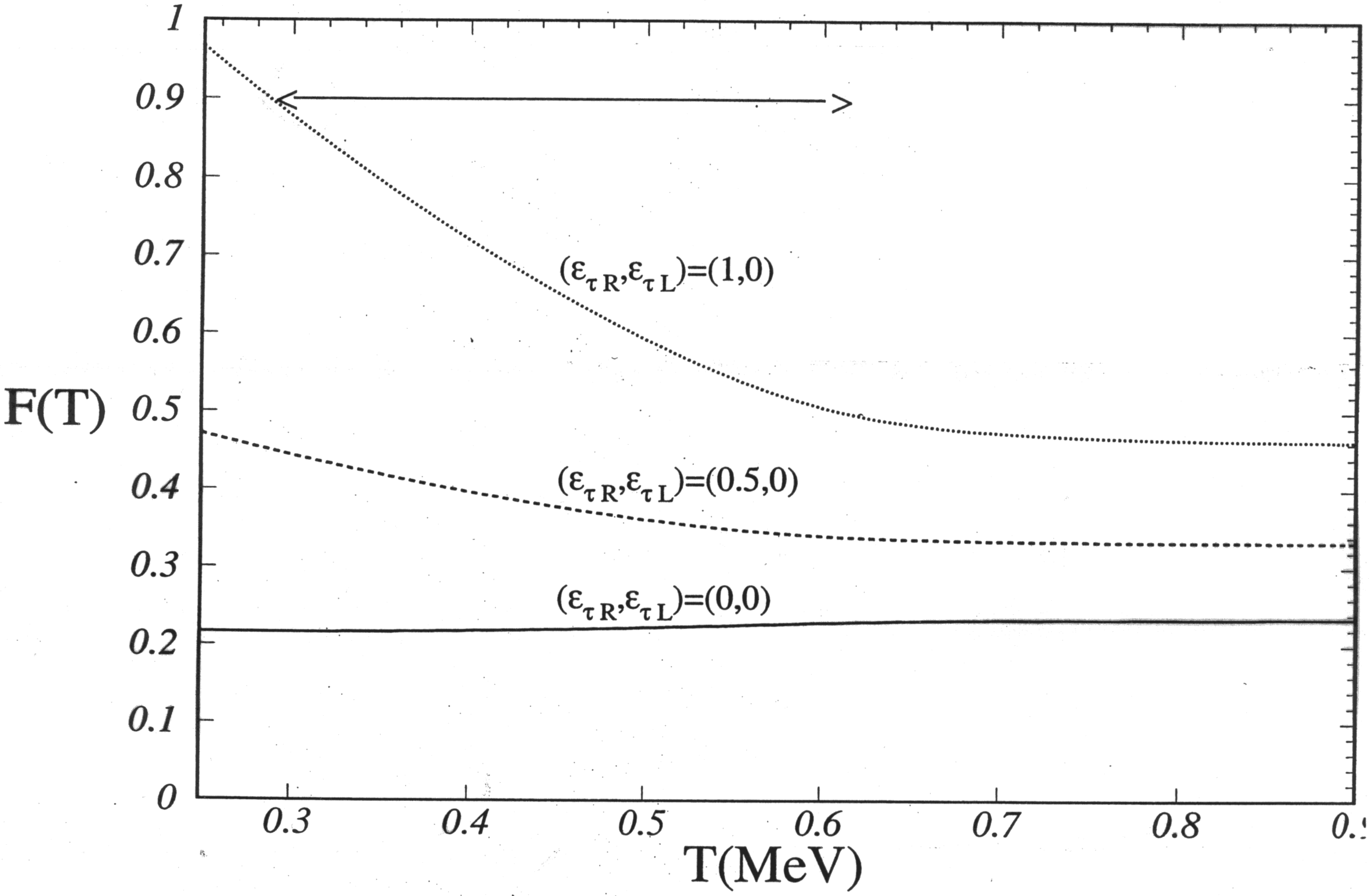
switching on $\varepsilon_L \neq 0$ makes the distortion weaker — but increase much the global rate

'Futurable' situation:

- Borexino & low-E ν_e sensitive detect. LENS

measure ϕ^{+}_{Be}

$$F(T) = \left(c_{23}^2 \frac{d\tilde{\sigma}_{\nu_\mu}(T)}{dT} + s_{23}^2 \frac{d\tilde{\sigma}_{\nu_\tau}(T,\varepsilon)}{dT} \right) \Big/ d\tilde{\sigma}_{\nu_e}(T)/dT$$



Concluding

- The Sun is a good source of ν_τ ~ 30% of solar ν_e

•• Presently, solar neutrino exps cannot exclude NON-STANDARD ν_τ interactions with electrons

••• Potential of BOREXINO

- deformation of energy spectrum

<u>unique signature</u>

of NS ints for ν_τ

→ test of $\theta_{23} \sim 45^\circ$ atmospheric $\nu_\mu \longrightarrow \nu_\tau$ oscillations

→ further identification of ν_τ flavour