Neutrino Astrophysics & the First KamLAND Result

Alexei Smirnov

ICTP, Trieste, Italy & INR, Moscow, Russia

Solar Neutrinos:
- Large mixing MSW
- Solar neutrinos versus KamLAND
- Beyond LMA

Supernova Neutrinos:
- revisiting SN 1987A
- 1-3 mixing and mass hierarchy
- monitoring shock wave

"... for the detection of cosmic neutrinos"

The Nobel Prize in Physics 2002
``for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos"

Raymond Davis Jr.:	Solar neutrinos
Masatoshi Koshiba:	Neutrinos from supernova 1987A Solar neutrinos

not the whole story:

- Deficit of solar neutrinos
  The solar neutrino problem
- Puzzles of the neutrino burst from SN1987A (consistency of spectra)

has triggered major experimental and theoretical developments in neutrino physics and astrophysics

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...two days before the ceremony

KamLAND collaboration has announced the first result

- Evidence of the disappearance of $\bar{\nu}_e$ from the atomic reactors
- Consistent with $\bar{\nu}_e$ oscillations
- In agreement with predictions from the LMA MSW solution of the solar neutrino problem

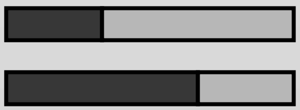
⇒

1) has confirmed the LMA solution and practically excluded all other possible solutions
2) shed some light on the SN1987A neutrino puzzle

B.Pontecorvo:

* discussed experiments with neutrinos from atomic reactors
* suggested neutrino oscillations
* considered oscillations of reactor neutrinos
* considered maximal mixing
* suggested Cl - Ar method
* ``predicted'' the solar neutrino problem
* suggested its oscillation solution

Mixing and flavor states



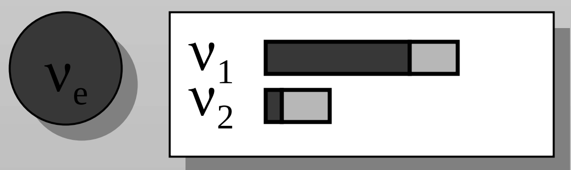
$\nu_2 = \sin\theta\, \nu_e + \cos\theta\, \nu_\mu$

$\nu_1 = \cos\theta\, \nu_e - \sin\theta\, \nu_\mu$

vacuum mixing angle

$$\nu_e = \cos\theta\, \nu_1 + \sin\theta\, \nu_2$$

coherent mixture of mass eigenstates



wave packets

Interference of the parts of wave packets with the same flavor depends on the phase difference $\Delta\phi$ between ν_1 and ν_2

$$\Delta\phi = \frac{\Delta m^2}{2E}\, l$$

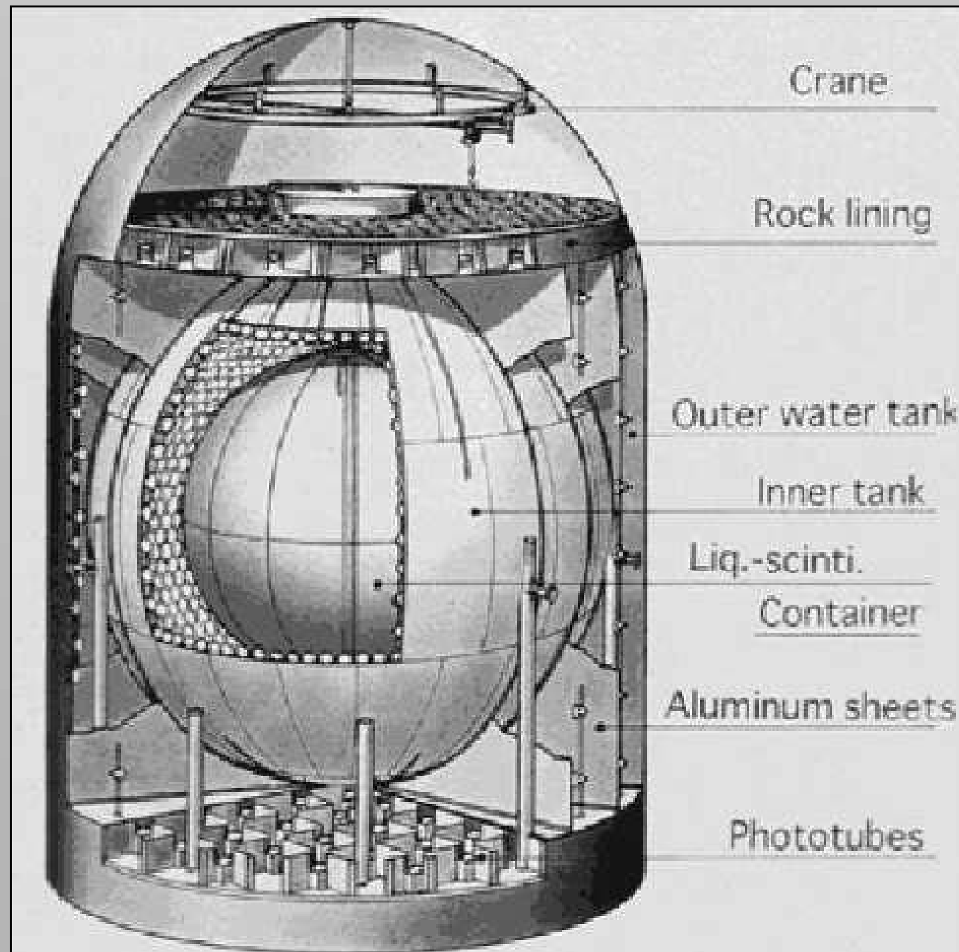
$$\Delta m^2 = m_2^2 - m_1^2$$

KamLAND

Kamioka
Large Anti-Neutrino Detector

- Reactor long baseline experiment
  150 - 210 km
  Liquid scintillation detector

1 kton of LS



- $\bar{\nu}_e + p \longrightarrow e^+ + n$

  $E_{pr} > 2.6$ MeV

- Total rate
  energy spectrum of events

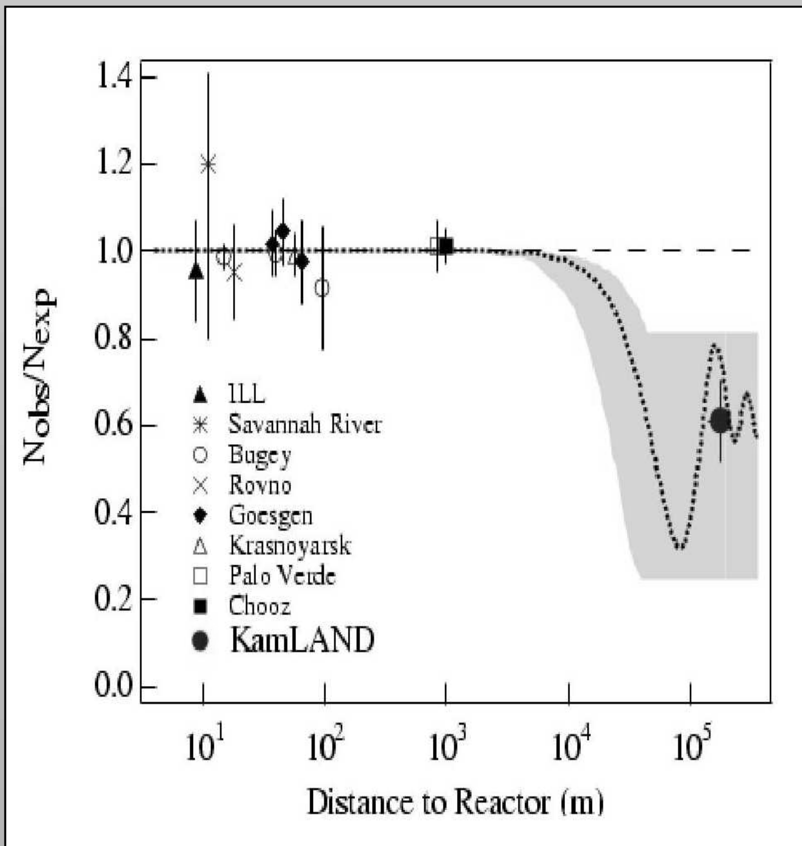
- LMA ⇨
  precise determination of
  the oscillation parameters
  10% accuracy

- Detection of the Geo-neutrinos
  $E_{pr} > 1.3$ MeV

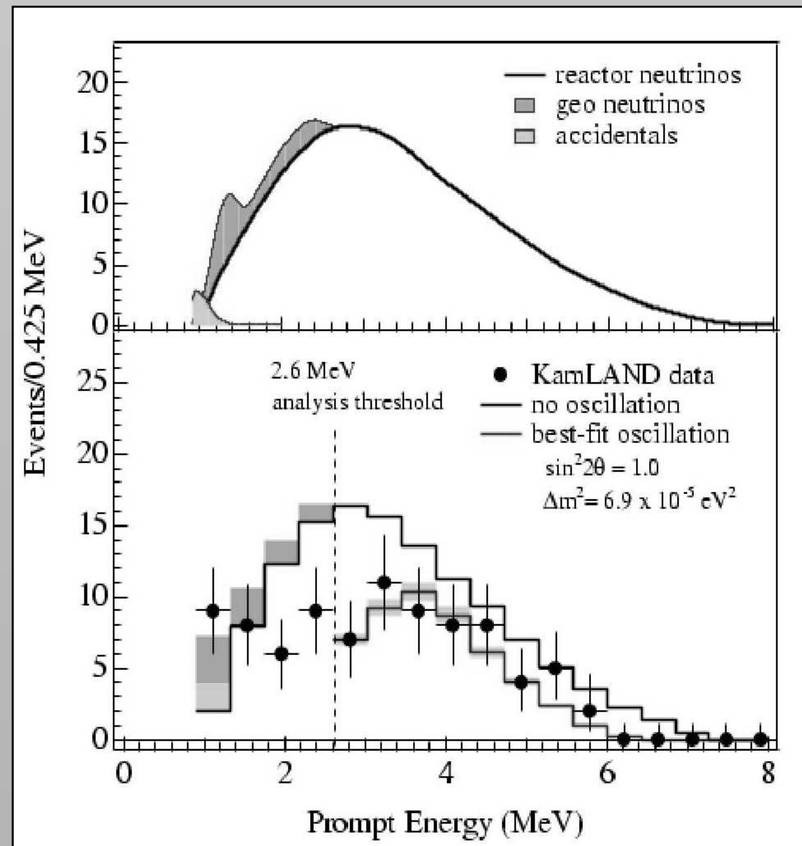
KamLAND results

K. Eguchi et al.,
Phys. Rev. Lett., 90, 021802 (2003)

Rate



Spectrum



N_{obs} = 54, N_{bg} ~ 1

N_{exp} = 86.8 $\pm$ 5.6

⇨

N_{obs}/N_{exp} = 0.611 $\pm$ 0.094

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Solar Neutrinos

$4p + 2e^- \Rightarrow {}^4He + 2\nu_e + 26.73$ MeV

Adiabatic convers[...]
in matter of the Su[...]

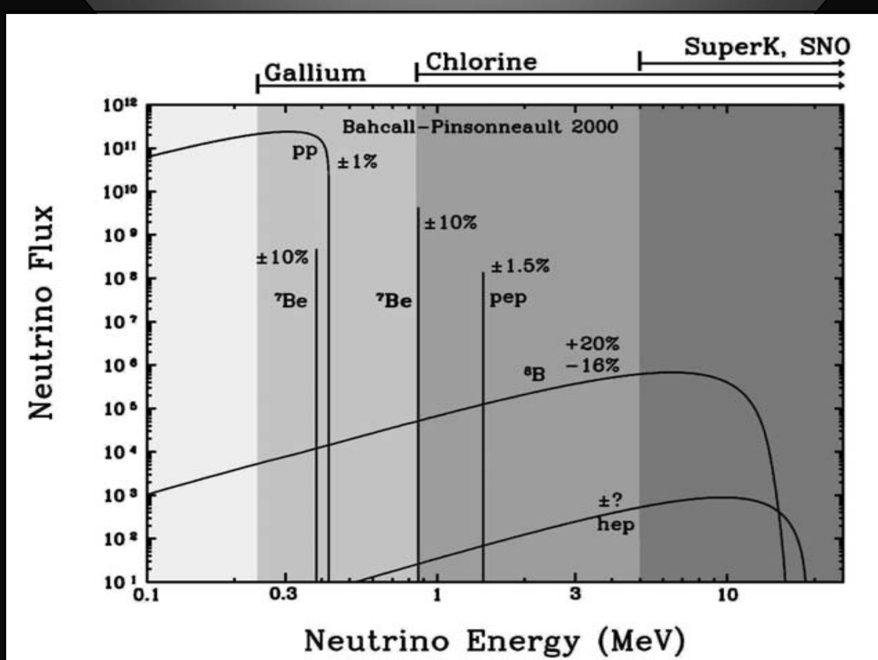
$F = 6\ 10^{10}\ cm^{-2}\ c^{-1}$

ρ : (150 $\Rightarrow$ 0) g/cc

Oscillations
in vacuum

ν

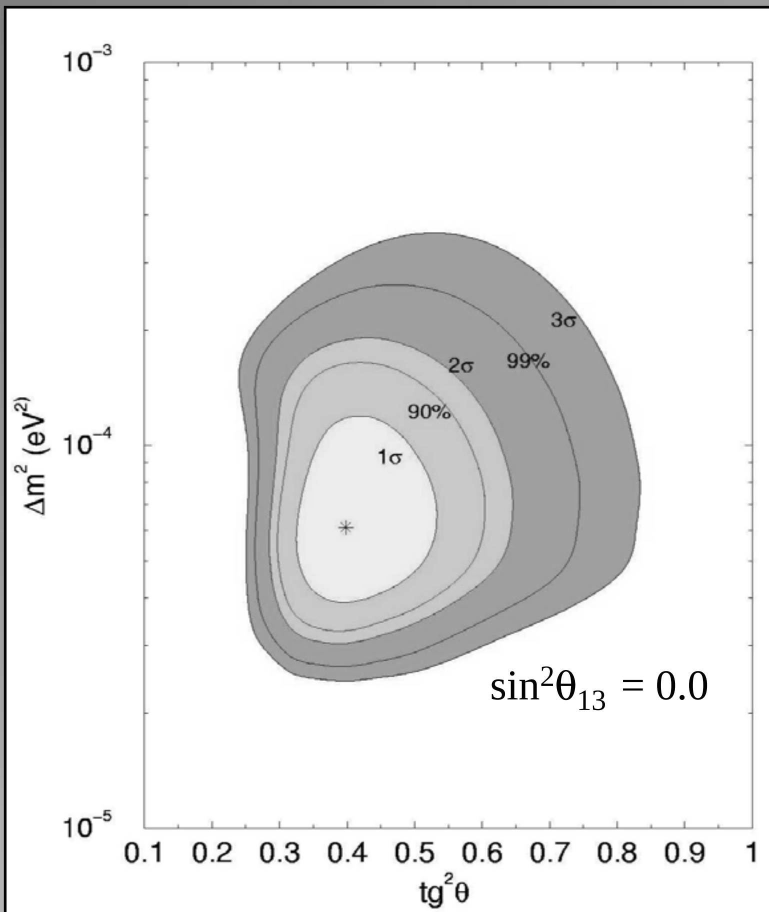
Oscillations
in matter
of the Earth



J.N. Bahcall

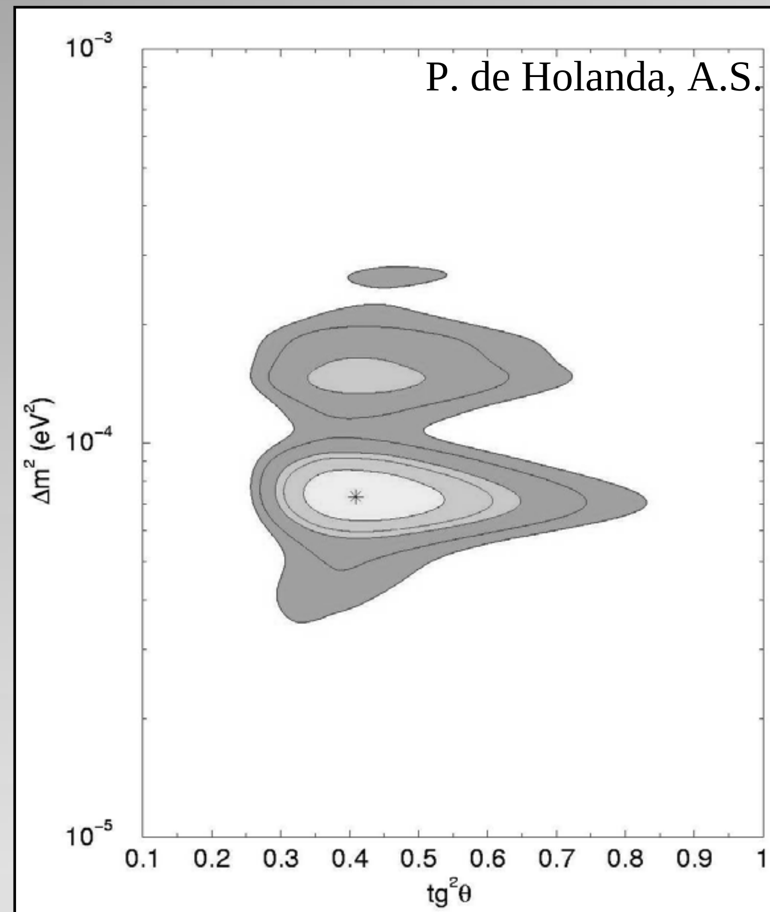
Large mixing MSW solution

solar data



$\Delta m^2 = 6.8\ 10^{-5}\ eV^2$
$\tan^2\theta = 0.40$

solar data + KamLAND

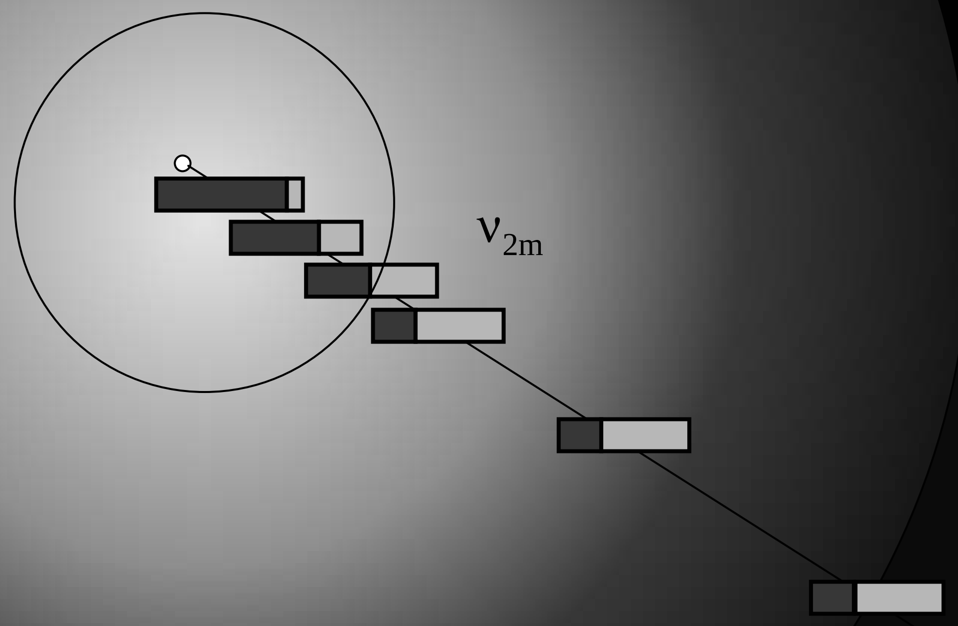


$\Delta m^2 = 7.3\ 10^{-4}\ eV^2$
$\tan^2\theta = 0.41$

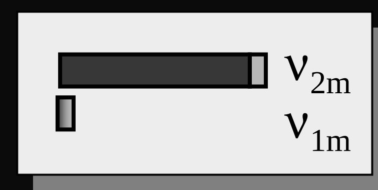
LMA MSW solution

An example: E = 10 MeV

Resonance layer:
ρY_e = 20 g/cc
R = 0.24 R_{sun}

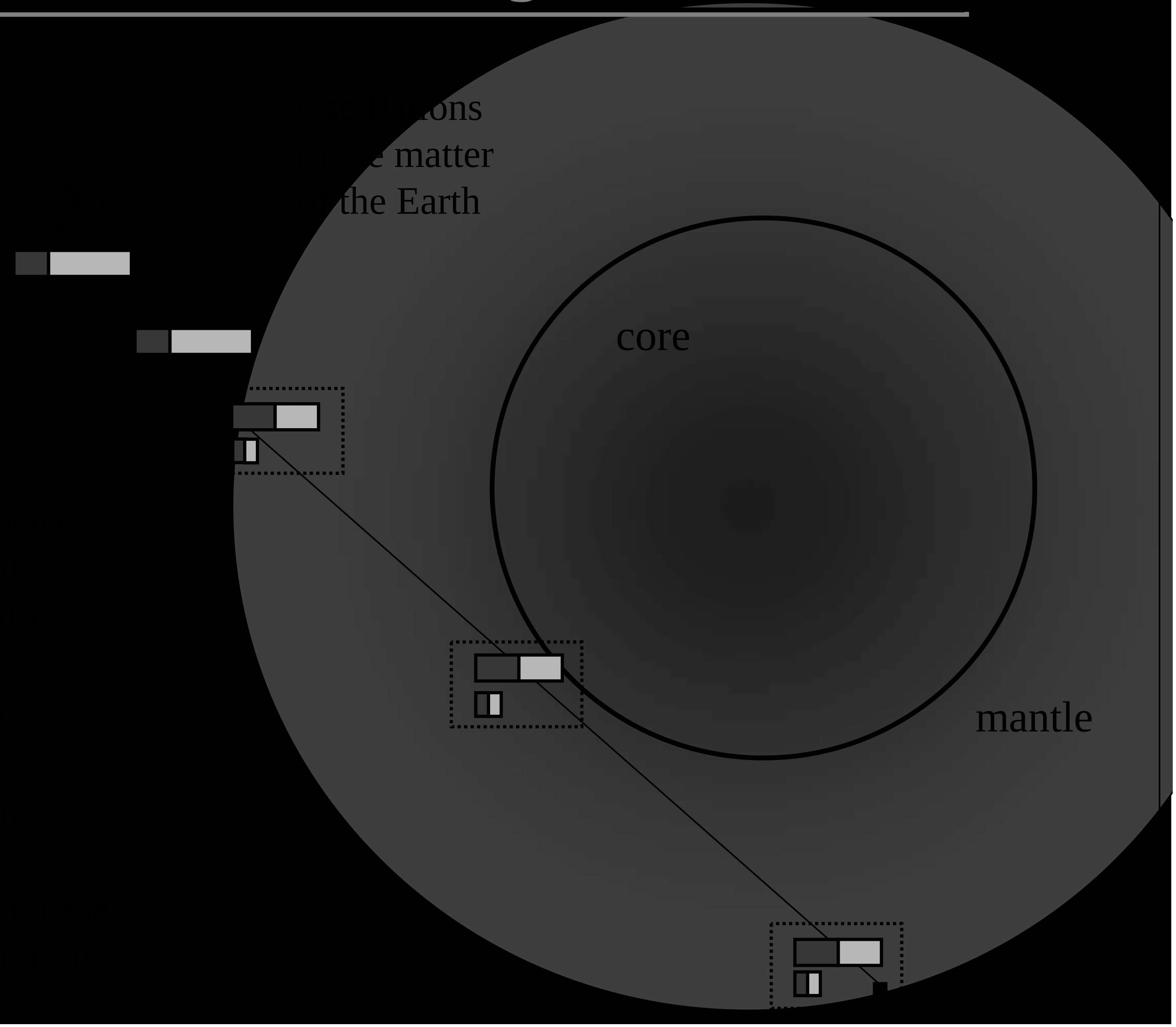


In the production point:
$\sin^2\theta_m^0$ = 0.94
$\cos^2\theta_m^0$ = 0.06

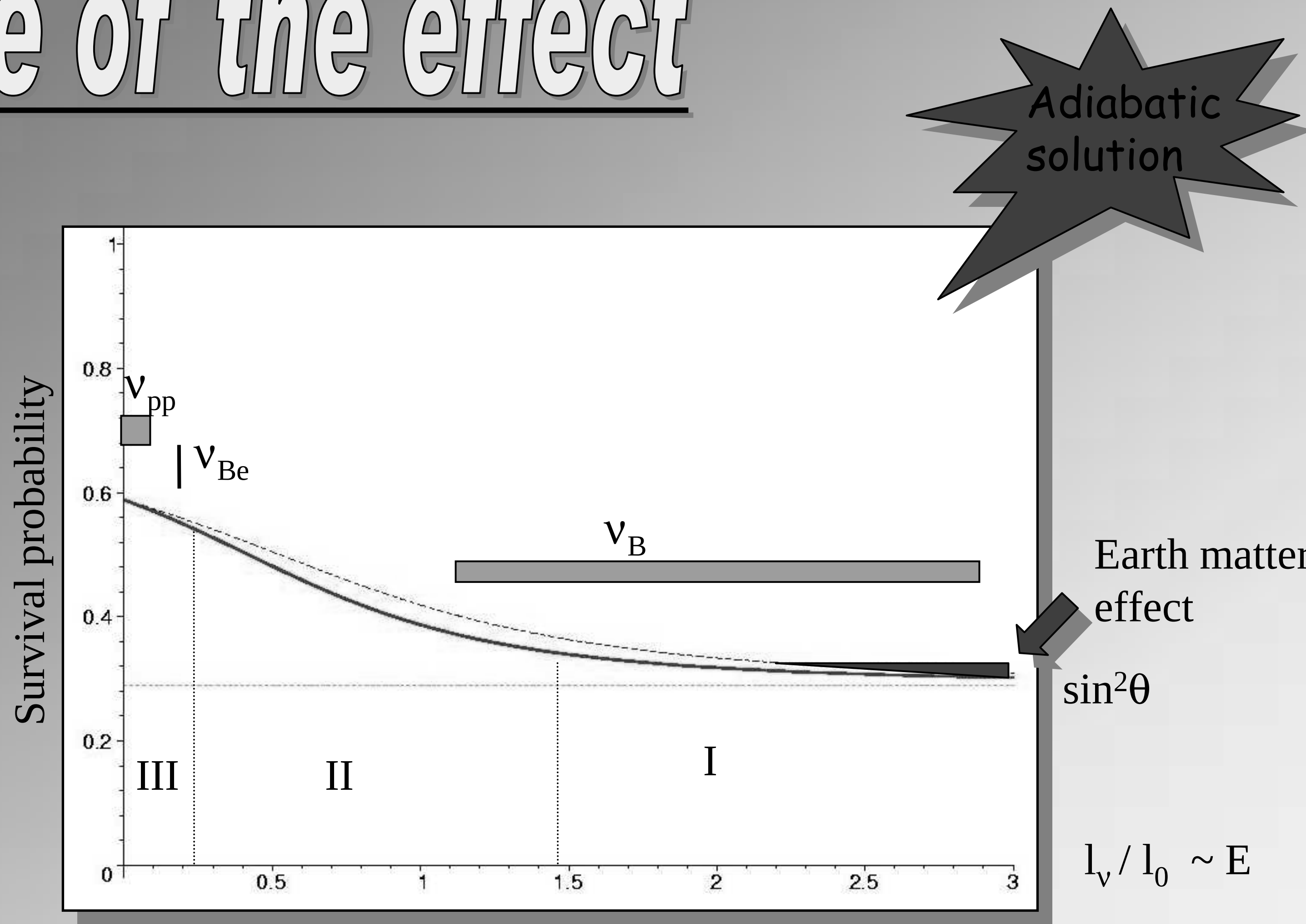


Evolution of the eigenstate ν_{2m}
Flavor of neutrino state follows density change

Inside the Earth. Regeneration



Profile of the effect



Oscillations with small matter effect

Conversion + oscillations

Conversion with small oscillation effect

Non-oscillatory transition

How does it work

Pure adiabatic conversions

(Adiabatic solution)

Universality

$$y = \frac{n_R - n}{\Delta n_R}$$

n_R is the resonance density

$$\Delta n_R = \tan^2 2\theta \, n_R$$

width of the resonance layer

The average probability and depth of oscillations are the universal functions of y and y_0

$$P_{ee} = P_{ee}(y, y_0)$$

$$P_{ee}^{max} = P_{ee}^{max}(y, y_0)$$

$$P_{ee}^{min} = P_{ee}^{min}(y, y_0)$$

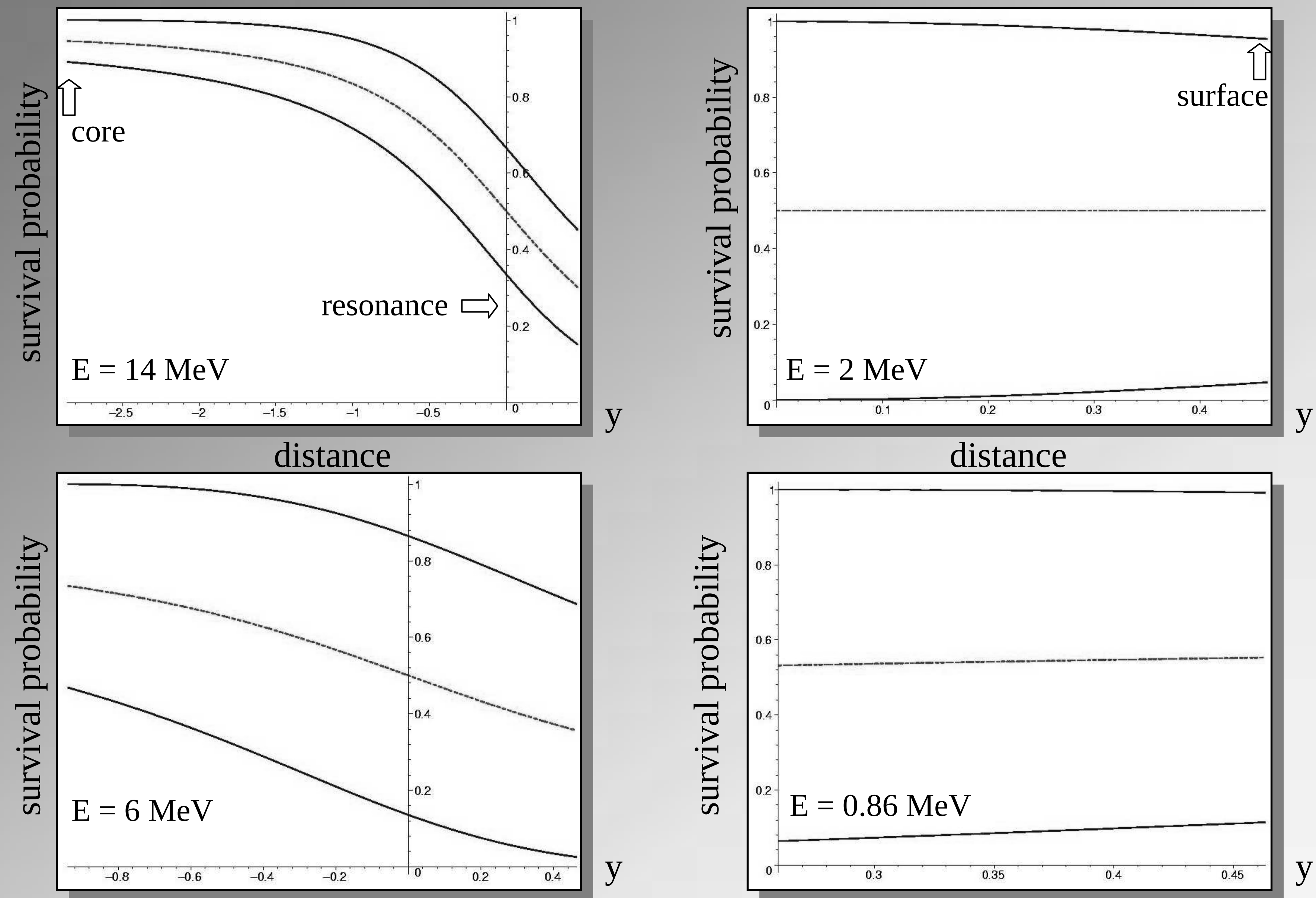
y_0 value of y the production point

- in resonance: $y = 0$
- at the exit ($n = 0$):

$$y_f = 1/\tan 2\theta$$

Conversion inside the Sun

$\tan^2\theta = 0.41$,
$\Delta m^2 = 7.3\ 10^{-5}\ eV^2$



Inside the Earth

- Averaging of oscillations, divergency of the wave packets

➡ incoherent fluxes of ν_1 and ν_2 arrive at the surface of the Earth

- ν_1 and ν_2 oscillate inside the Earth

➡ Regeneration of the ν_e flux

$l_\nu / l_0 \sim 0.03$
E = 10 MeV

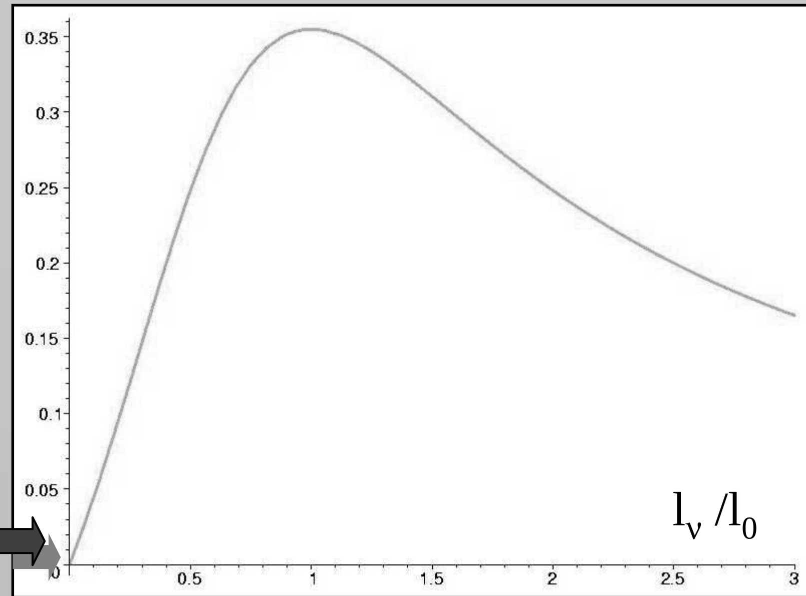
$$P \sim \sin^2\theta + f_{reg}$$

$$f_{reg} \sim 0.5 \sin^2 2\theta \; l_\nu / l_0$$

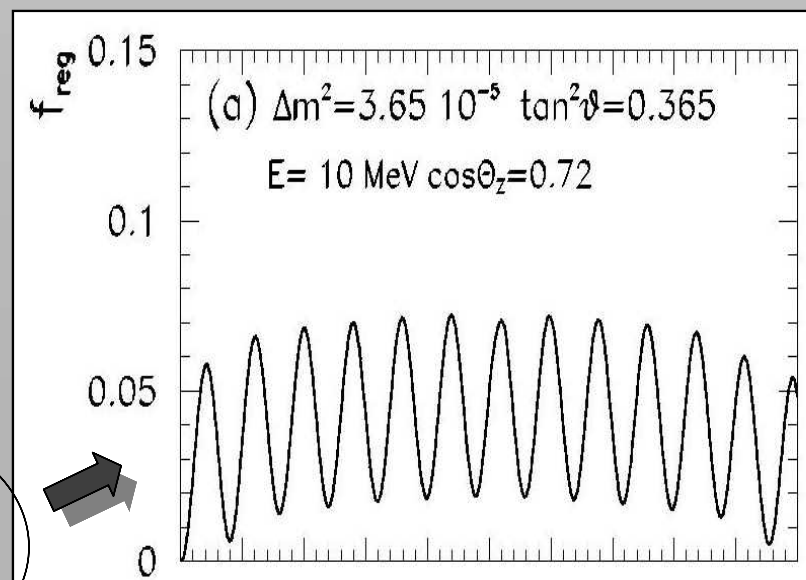
- The Day -Night asymmetry:

$$A_{ND} = f_{reg}/P \sim 3 - 5\ \%$$

f_{reg}



Oscillations + adiabatic conversion



distance

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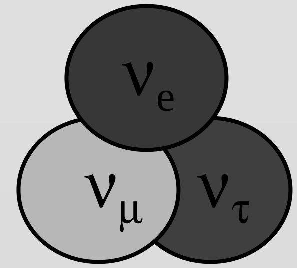
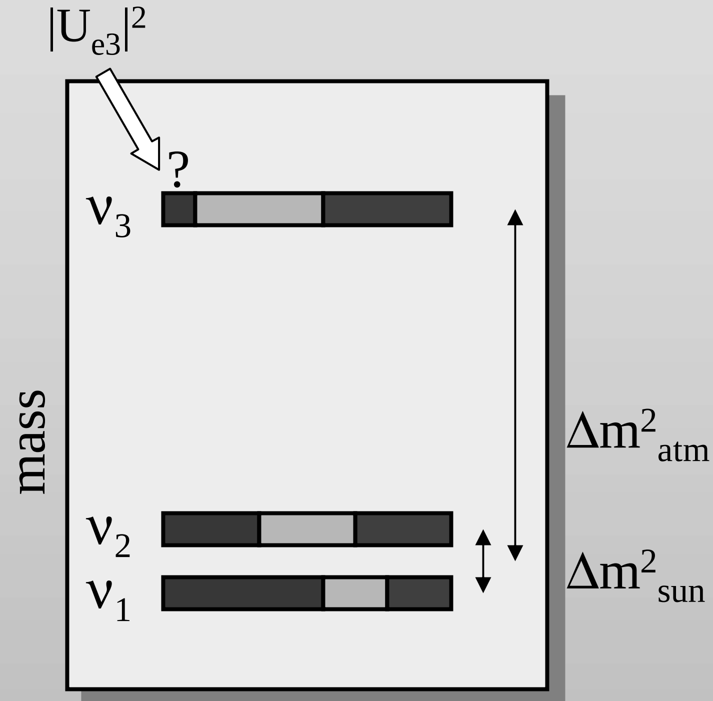
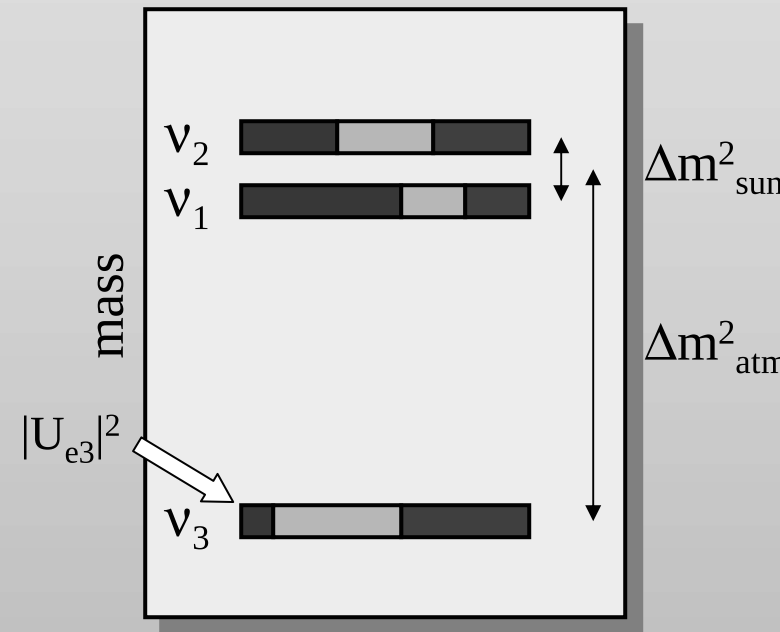
Mass spectrum and mixing





Normal mass hierarchy
(ordering)



Inverted mass hierarchy
(ordering)

- Type of mass spectrum: with Hierarchy, Ordering, Degeneracy ⇨ absolute mass scale
- Type of the mass hierarchy: Normal, Inverted
- U_{e3} = ?

Is the Solar Neutrino Problem Solved?

LMA: precise determination of parameters

Consistency checks

Bounds on physics beyond LMA

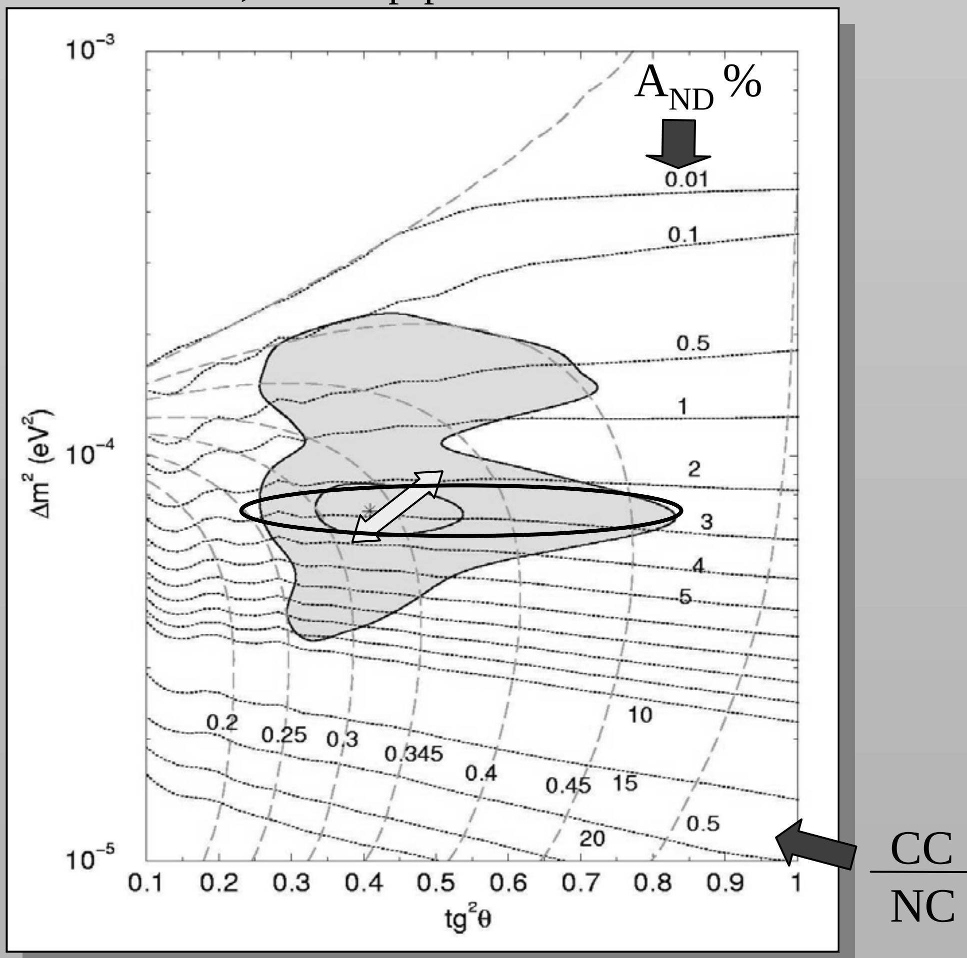
- Physics of conversion
- Implications for phenomenology (LBL, $\beta\beta_{0\nu}$, absolute mass scale determination...)
- Theory: deviations from maximal mixing

Solar neutrinos vs KamLAND

Is LMA MSW sufficient?

Delta m^2 and 1-2 mixing

P.de Holanda, A.S. hep-ph/0212270



Lines of constant CC/NC ratio and Day-Night asymmetry at SNO

Two stages

- Identification of the unique region:

  2ν analysis, sub-leading effects (13 -mixing) can be neglected

- Precision measurements:

  Possible sub-leading effects should be included. Generic 3ν analysis should be performed. Problem of degeneracy of parameters appears

LMA: Consistency Checks

Over determine solution, cross checks

in the b.f. point

- Day -Night Asymmetries: A_{ND}(SNO) = 2 - 5 % , A_{DN}(SK) = 2 - 3 %
- Spectrum distortion: Turn up at low energies: 5 - 10 %
- Rate at the intermediate energies BOREXINO/KamLAND: R = (0.6 - 0.7)R_{SSM}
- Seasonal variations: Small (unobservable) effect: $A_{WS} < 0.5\%$
- Low energy experiments

Implications

- further confirmation of LMA
- precise determination of the neutrino parameters
- searches for physics ``beyond the LMA''

Beyond LMA MSW

Physics of sub-leading effects

LMA MSW + ...

Signatures

Implications

Magnetic moment, magnetic fields inside the Sun

+ SFP

- Searches for $\bar{\nu}_e$ flux
- Time variations

Beyond single Δm^2 context

+ nu-sterile

- CC/NC
- Additional distortion of spectrum

+ NSI

(non-standard neutrino interaction)

- Additional contribution to the matter effect

+ VEP

(violation of equivalence principle)

LMA + SFP

Spin-flavor precession
(resonance, non-resonance)

- ``Post-KamLAND'' study in the context of single

$$\Delta m^2 = \Delta m^2_{LMA}$$

E. Akhmedov, J. Pulido
hep-ph/0209192

- The effect (neutrino spin flip) is in the central regions of the Sun (radiative zone)

$B > 10$ MG

- Signature: Appearance of the antineutrino $\bar{\nu}_e$ flux

$$\frac{F(\nu_e)}{F(\nu_e)} = 1.5\% \left(\frac{\mu_\nu}{10^{-12}\,\mu_B}\right)^2 \left(\frac{B}{100\ \text{MG}}\right)^2$$

(for the boron neutrinos)

At the present SK bound

- Magnetic moment: (natural* value)

$$\mu_\nu \sim \frac{e}{\Lambda^2}\, m_\nu$$

(unless Voloshin's cancellation, or polarization suppression occurs)

For the cut energy $\Lambda = 100$ GeV and $m_\nu = 1$ eV: $\mu_\nu \sim 10^{-16}\,\mu_B$ unobservable?

- Beyond single Δm^2 : if for second $\Delta m^2 \ll \Delta m^2_{LMA}$ effect can be much larger

Solar Neutrinos versus KamLAND

Parameters from the 2ν analysis:

Solar neutrinos		KamLAND
Δm^2 $\tan^2\theta$	=	Δm^2 $\tan^2\theta$

The equality is satisfied within 1σ

Gives hint that CPT is OK

Further checks of the equality

Possible deviations

(mismatch of parameters if the fit is done in terms of 2ν mixing):

CPT-violation

Physics Beyond the LMA

If some effect influences KamLAND signal it should also show up in the solar neutrinos

Inverse is not correct:

Some effect can influence solar neutrinos but not KamLAND result

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Solar neutrinos have much higher sensitivity to Physics Beyond the LMA

- $\Delta m^2 - \theta$ region of sensitivity is much larger for solar neutrinos than for KamLAND

  Additional small Δm^2 or/and θ can strongly influence the solar neutrinos but not KamLAND

- Magnetic moment: the Earth magnetic field is too small

- Non-standard interactions (NSI) of neutrinos do not change the KL signal since the matter effect is small

Even in the CPT conserving case one can find

$$\left. \boxed{\Delta m^2, \theta} \right|_{solar} \neq \left. \boxed{\Delta m^2, \theta} \right|_{KL}$$

Testing the theory of conversion

Solar neutrinos

- Adiabatic conversion (MSW)
- Matter effect dominates
  (at least in the HE part)
- Non-oscillatory transition
  the oscillation phase
  is irrelevant

Adiabatic conversion formula

KamLAND

- Vacuum oscillations
- Matter effect is very small
- Oscillation phase is crucial
  for observed effect

Vacuum oscillation formula

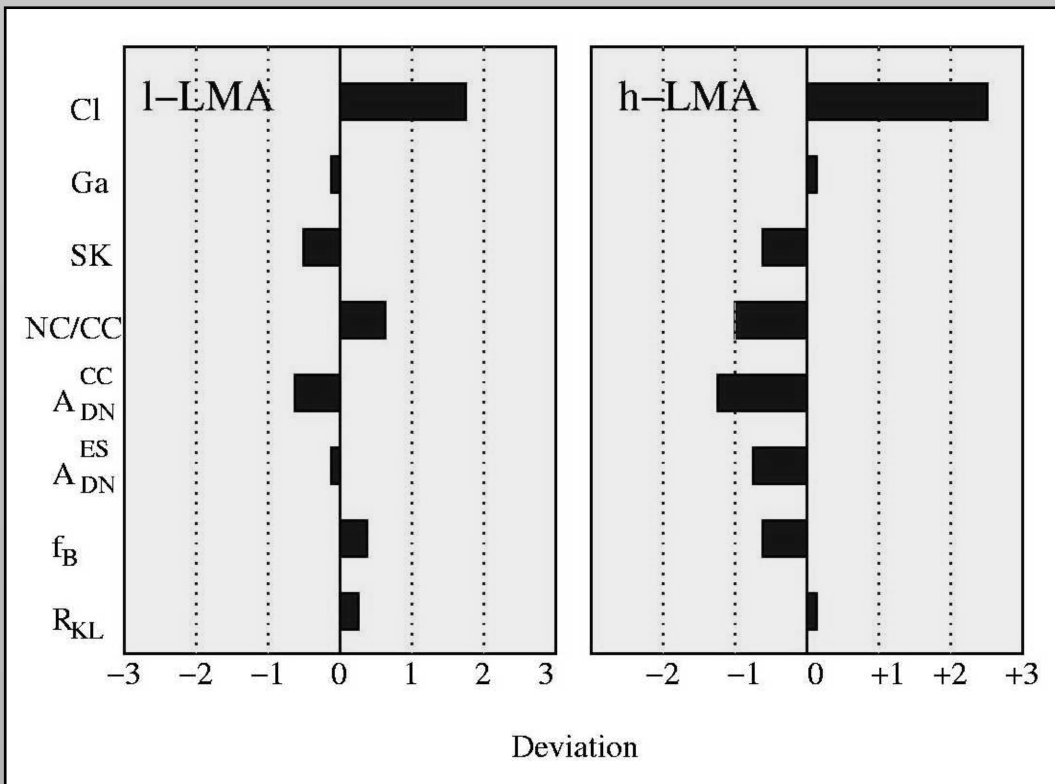
→ Δm^2 , θ ←

Coincidence of these parameters determined from the solar neutrino data and from KamLAND results testifies for the correctness of the theory (phase of oscillations, matter potential, etc..)

See also F.L. Fogli et al., hep-ph/0211414

Homestake Anomaly?

Pull-off diagrams for the best fit points
of the l- and h- LMA regions



(2 - 2.5) σ pull

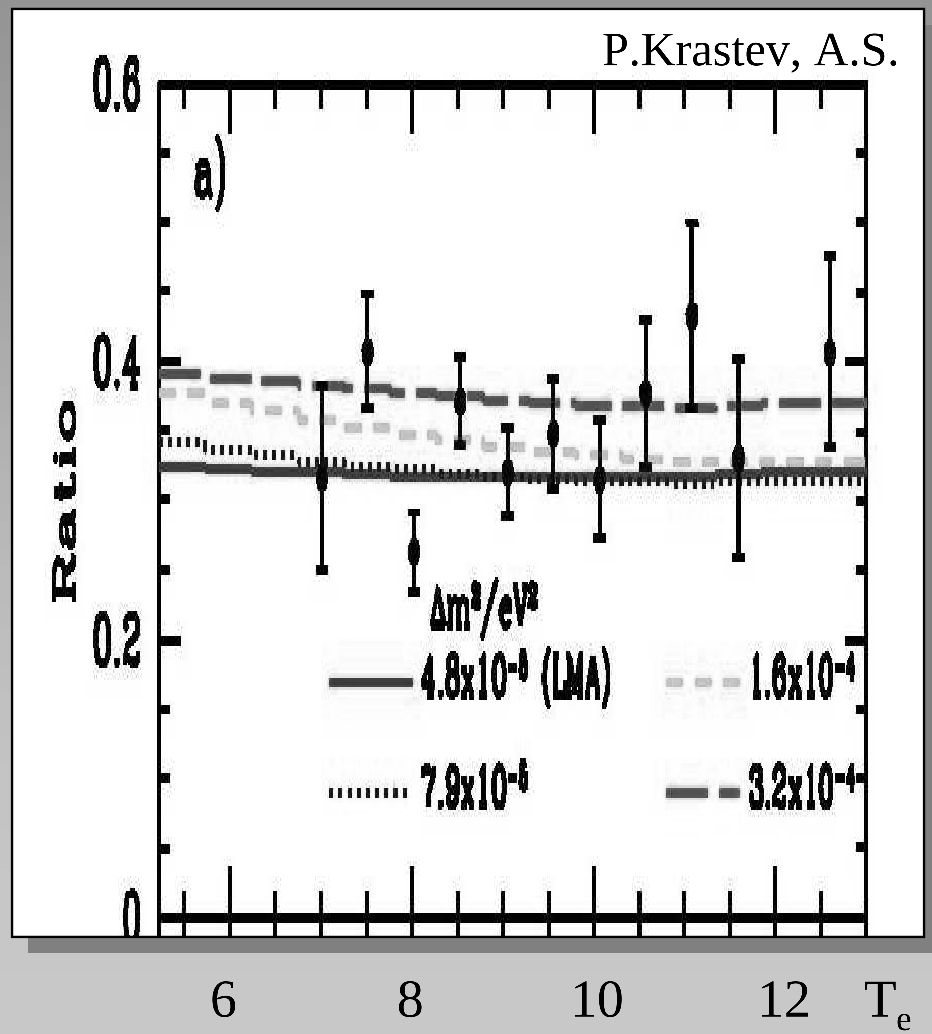
- Statistical fluctuation ?
- Systematics? Related to time variations of rate?
- Neutrino properties: conversion driven by second Δm^2

⇨ Additional deep in the suppression pit at E ~ 1 MeV?

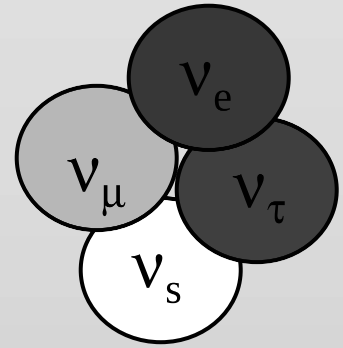
Q_{Ar}(LMA) > Q_{Ar}(Homestake)

Spectrum distortion at SNO

Turn up of the spectrum
at low energies is expected



Sterile Neutrino?



ν_s mixes mainly with the lightest active neutrino:

$$\nu_0 = \cos\alpha\, \nu_s + \sin\alpha\, (\cos\theta\, \nu_e - \sin\theta\, \nu_a)$$
$$\nu_1 = -\sin\alpha\, \nu_s + \cos\alpha\, (\cos\theta\, \nu_e - \sin\theta\, \nu_a)$$
$$\nu_2 = \sin\theta\, \nu_e + \cos\theta\, \nu_a$$

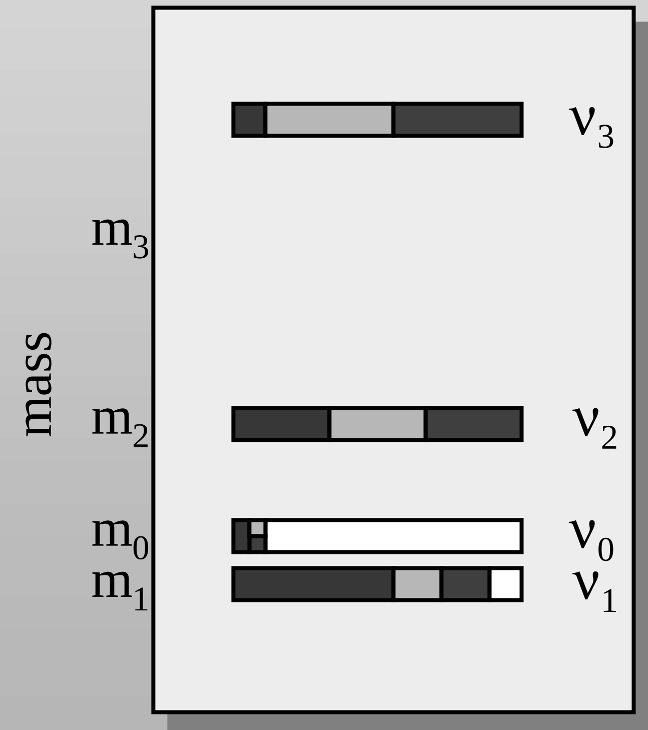
$$\nu_a \sim (\nu_\mu + \nu_\tau)/\sqrt{2}$$

θ is the solar mixing angle

Δm^2_{12} and θ have the LMA values

$$\sin^2 2\alpha = 10^{-4} - 10^{-2}$$
$$\Delta m^2_{01} = (4 - 10)\, 10^{-6}\ \mathrm{eV}^2$$

in the SMA region



Neutrino mass and flavor spectrum

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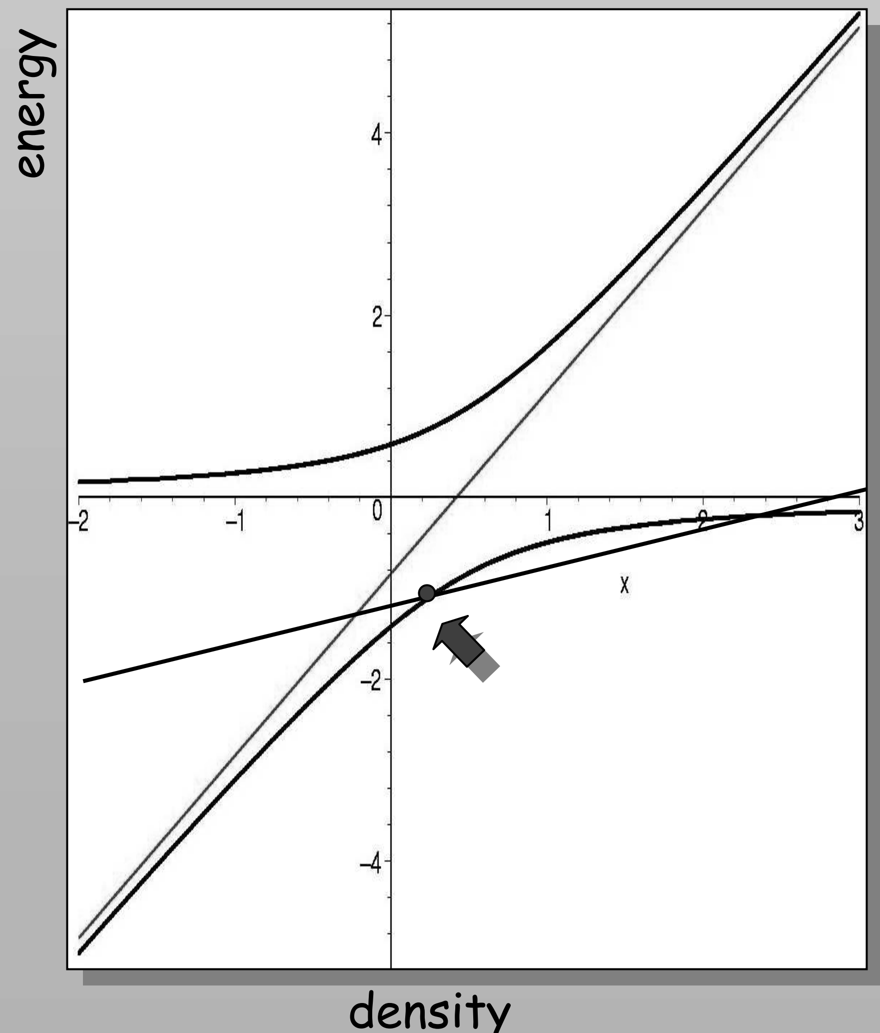
Conversion probabilities



$$P_{ee} = \sin^2\theta_m^0 \sin^2\theta + \cos^2\theta_m^0 \cos^2\theta (\cos^2 \alpha_m^0 - P_2 \cos2\alpha_m^0)$$

$$P_{es} = \cos^2\theta_m^0 (\sin^2\alpha_m^0 + P_2 \cos2\alpha_m^0)$$

Here P_2 is the jump probability in active-sterile resonance

θ_m^0 and α_m^0 are the mixing angles in matter in the production point

For production above a-s resonance:

$$P_{ee} = \sin^2\theta_m^0 \sin^2\theta + \cos^2\theta_m^0 \cos^2\theta \ P_2$$

$$P_{es} = \cos^2\theta_m^0 (1 - P_2)$$

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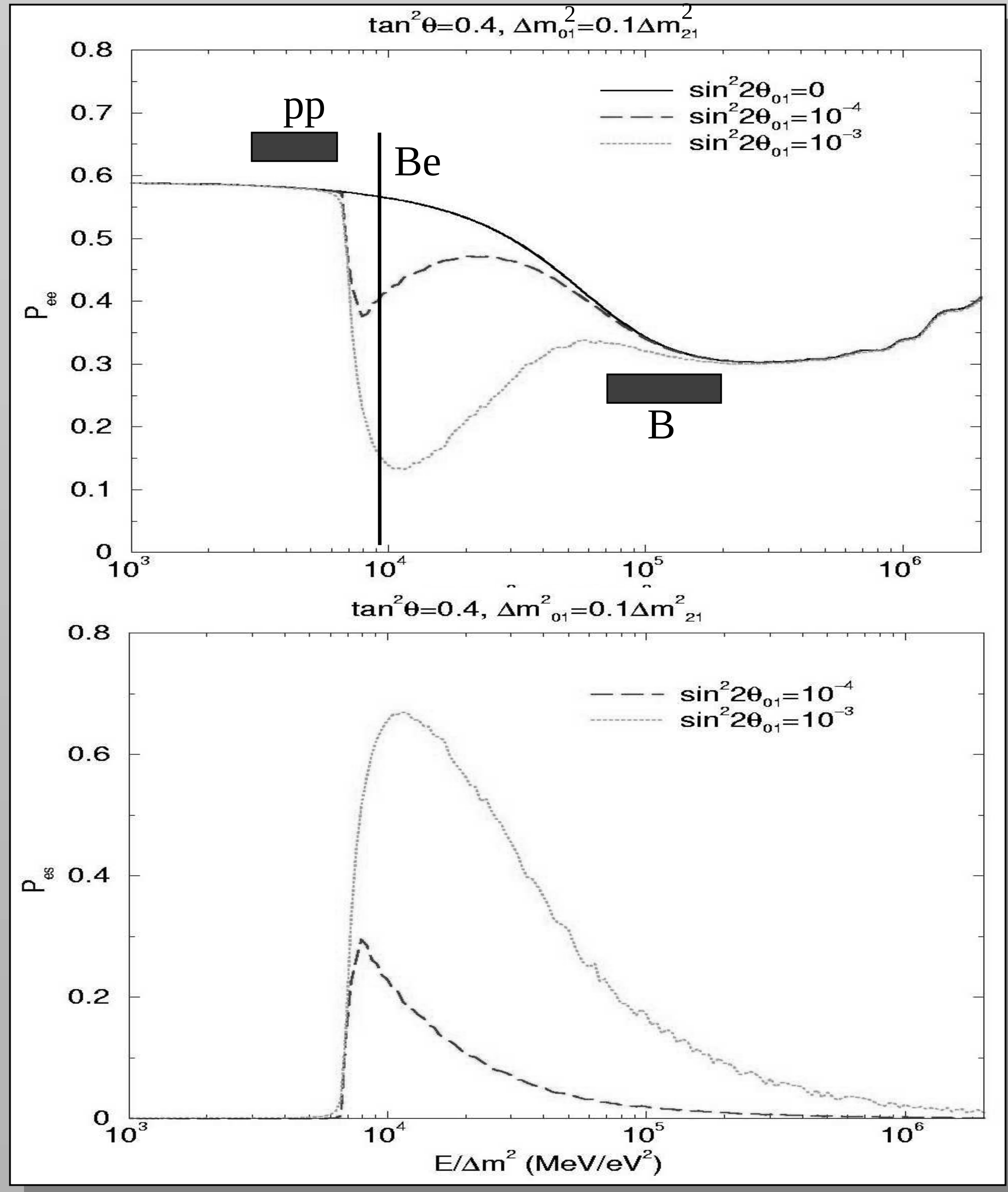
Modification of the energy profile

- Suppression of the Be- N- O- pep- neutrino fluxes
- Q_{Ar} Q_{Ge} ⇩
- It can be no significant influence on the turn up

P_{ee}

P_{es}



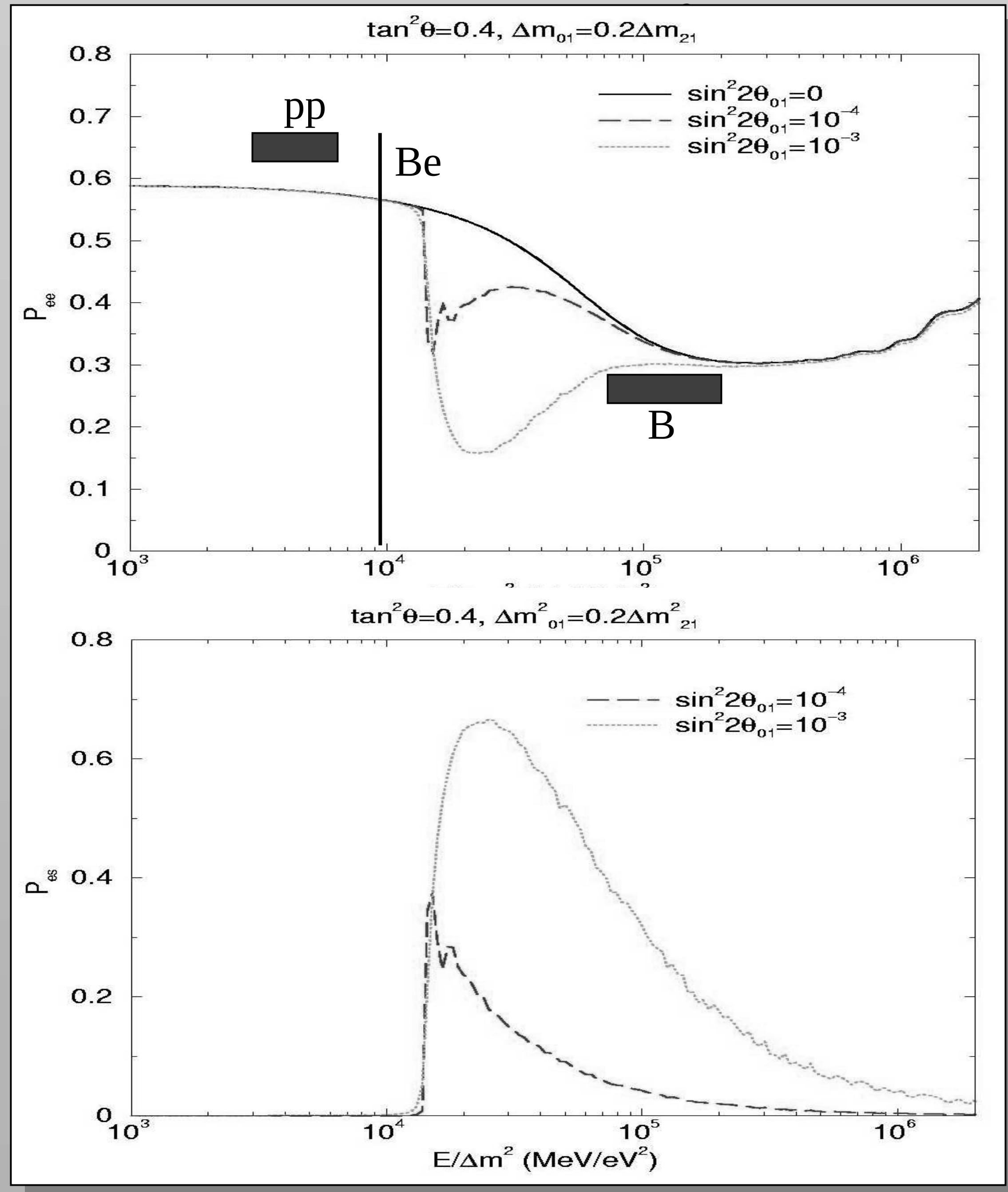
P. de Holanda, and A.S.

Modification of the energy profile

- Be neutrino flux is unsuppressed
- N, O, pep fluxes are suppressed
- Q_{Ar} ⇩
- Diminishing or elimination of the turn up

P_{ee}

P_{es}



P. de Holanda, and A.S.

Relations and Results

The transformation is mainly to the sterile component

- Maximal suppression in the dip: $P_{ee} = \sin^4\theta \sim 0.1$
- Decrease of the Ar- production rate: $\Delta Q_{ar} = -0.4$ SNU → $\Delta P_{ee} = 0.3$, $P_{ee}(Be) \sim 0.3$
- Decrease of the Ge-production rate: $\Delta Q_{Ge} = -10$ SNU
- Can be compensated by increase of the survival probability for the pp-neutrinos

  $P_{ee}(pp) \sim 1 - 0.5\sin^2 2\theta$

  Decrease of θ

  $\Delta P_{ee}(pp) \sim -0.5\, \Delta P_{ee}(Be)$
- Decrease of the survival probability for boron neutrinos

  $P_{ee}(B) \sim \sin^2\theta$

  $\Delta P_{ee}(pp) \sim -\Delta P_{ee}(B)$
- $P_{ee}(B)$ is fixed by CC/NC ratio:

$$\frac{CC}{NC} = \frac{P_{ee}}{1 - \eta_s (1 - P_{ee})}$$

where η_s is sterile fraction to which ν_e transforms

For E > 5 MeV: $\eta_s < 0.2$ does not allow to compensate the decrease of P_{ee}

$\Delta\eta_s = -(4 - 5)\, \Delta P_{ee}$

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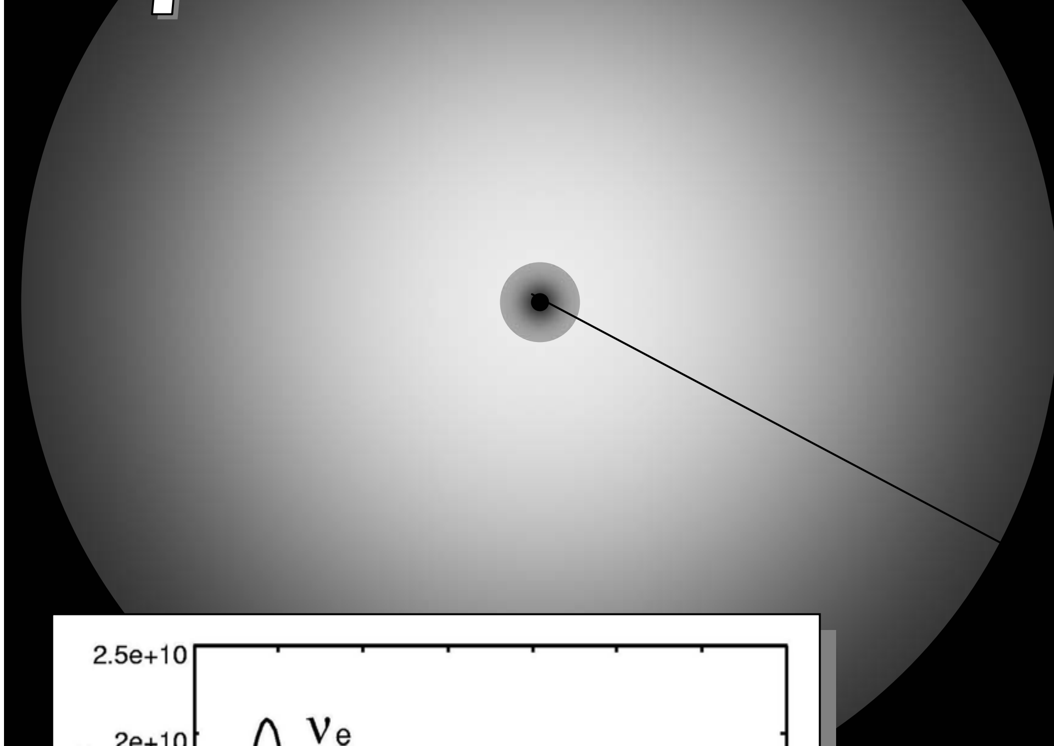
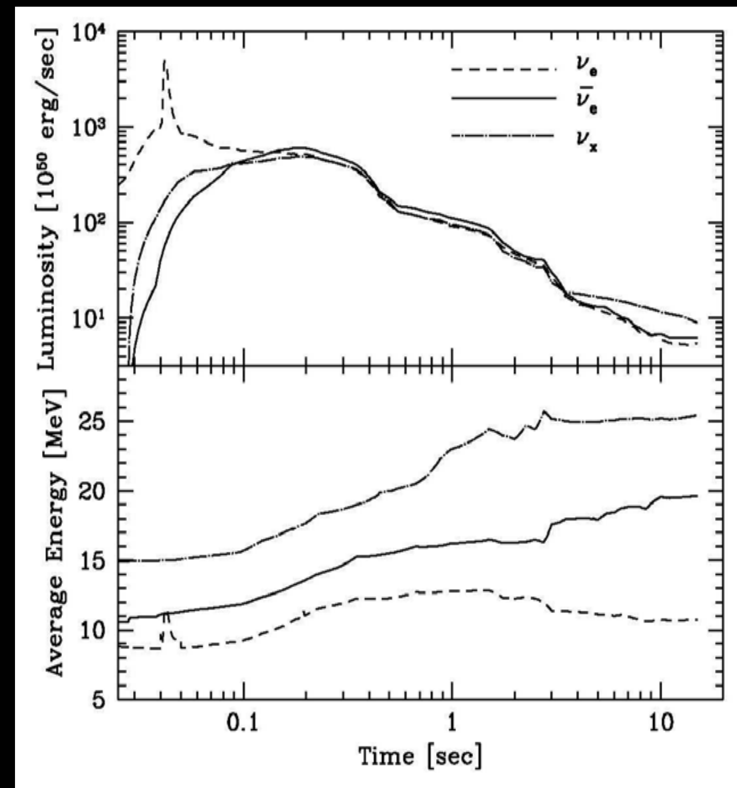
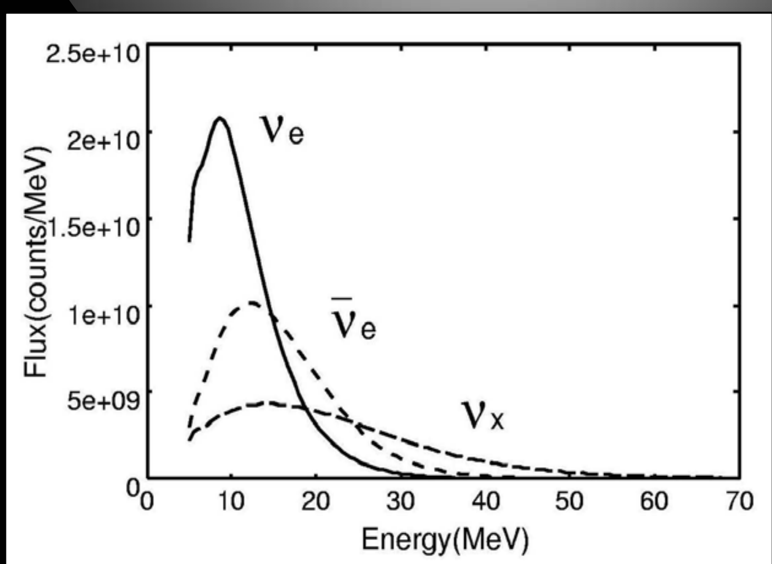
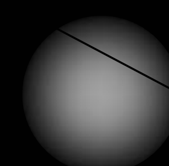
Supernova neutrinos









Neutrinos from SN1987A after KamLAND

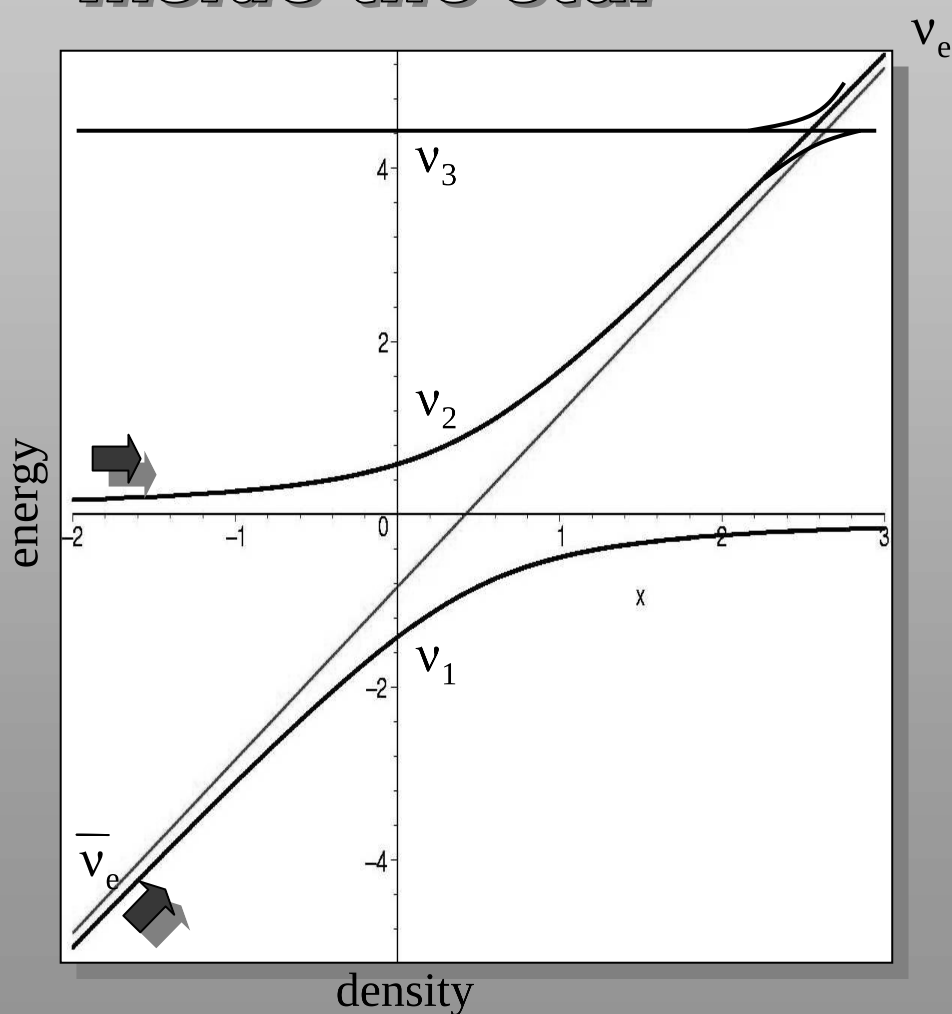
- Certainly, neutrino signal from SN1987A was affected by conversion inside the star and probably oscillations in the matter of the Earth

- Effects of neutrino conversion must be taken into account in the analysis of neutrino data:
  - determination of parameters of the original neutrino fluxes,
  - comparison of signals in different detectors

- The observable conversion effect depends also on the difference of original spectra of the electron and muon/tau antineutrinos

Conversion of SN (anti)neutrinos

Inside the star



Level crossing scheme for normal hierarchy

adiabatic transitions:

$\bar{\nu}_e \to \bar{\nu}_1$

$\bar{\nu}_\mu / \bar{\nu}_\tau \to \bar{\nu}_2$

$|\langle \bar{\nu}_e | \bar{\nu}_1 \rangle|^2 = \cos^2\theta \qquad |\langle \bar{\nu}_e | \bar{\nu}_2 \rangle|^2 = \sin^2\theta$

Electron antineutrino flux at the detector:

$$\bar{F}_e = \cos^2\theta \, \bar{F}_e^0 + \sin^2\theta \, \bar{F}_x^0$$

where $\bar{F}_e^0$, $\bar{F}_x^0$ are the original fluxes of $\bar{\nu}_e$ and $\bar{\nu}_\mu$

$$\bar{F}_e = \bar{F}_e^0 + \sin^2\theta \, \Delta\bar{F}^0$$

$$\Delta\bar{F}^0 = \bar{F}_x^0 - \bar{F}_e^0$$

Permutation factor

In general:

$$\bar{F}_e = (1 - p)\, \bar{F}_e^0 + p\, \bar{F}_x^0$$

or

$$\bar{F}_e = \bar{F}_e^0 + p\, \Delta F^0$$

$$\Delta F^0 = \bar{F}_x^0 - \bar{F}_e^0$$

As a consequence of equality $\bar{F}_\mu^0 = \bar{F}_\tau^0$ ⇒ $p = (1 - \bar{P}_{ee})$

Total survival probability $\bar{\nu}_e \to \bar{\nu}_e$ from a production point to a detector

Inside the Earth

$\bar{\nu}_1$ and $\bar{\nu}_2$ oscillate

$\bar{P}_{1e}$ is the probability of $\bar{\nu}_1 \to \bar{\nu}_e$ transition in the matter of the Earth

Total survival probability

$\nu_e \to \nu_1$ Inside the star

$\nu_1 \to \nu_e$ Inside the Earth

⇒ $P_{ee} = P_{1e}$

$p = (1 - \bar{P}_{1e})$

Without Earth matter effect

$P_{1e} = \cos^2\theta$ ⇒ $p = \sin^2\theta$

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SN87A and the Earth matter effect

- $F(\bar{\nu}_e) = F^0(\bar{\nu}_e) + p\,\Delta F^0$

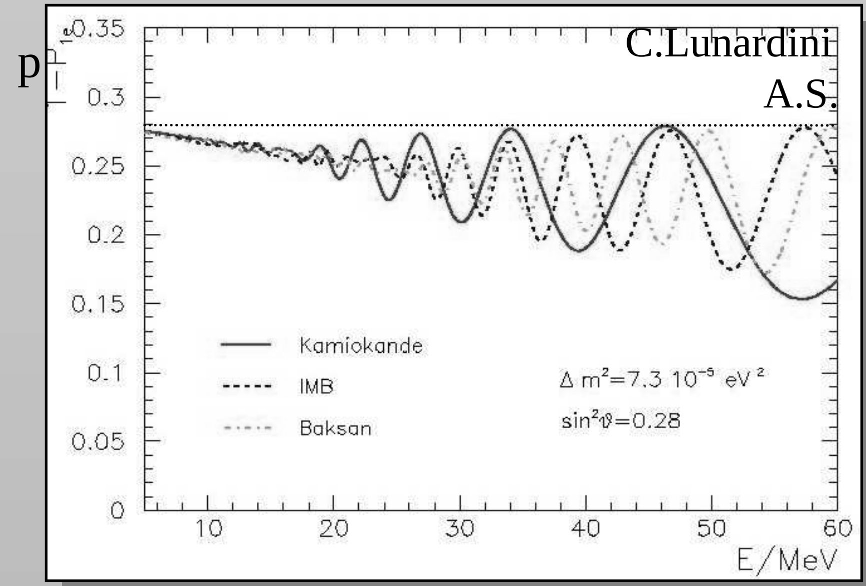
  $p = (1 - P_{1e})$ is the permutation factor
  P_{1e} is the probability of $\bar{\nu}_1 \to \bar{\nu}_e$ transition inside the Earth
  $\Delta F^0 = F^0(\bar{\nu}_\mu) - F^0(\bar{\nu}_e)$

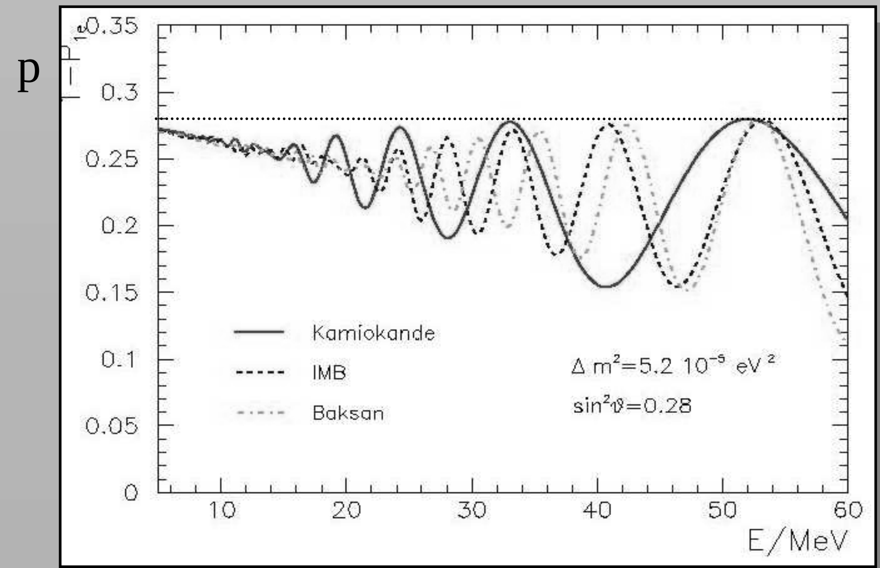
- p depends on distance traveled by neutrinos inside the earth to a given detector:

$$d = \begin{cases} 4363\text{ km} & \text{Kamioka} \\ 8535\text{ km} & \text{IMB} \\ 10449\text{ km} & \text{Baksan} \end{cases}$$

- Can partially explain the difference of energy distributions of events detected by Kamiokande and IMB: at E ~ 40 MeV the signal is suppressed at Kamikande and enhanced at IMB

C.Lunardini
A.S.



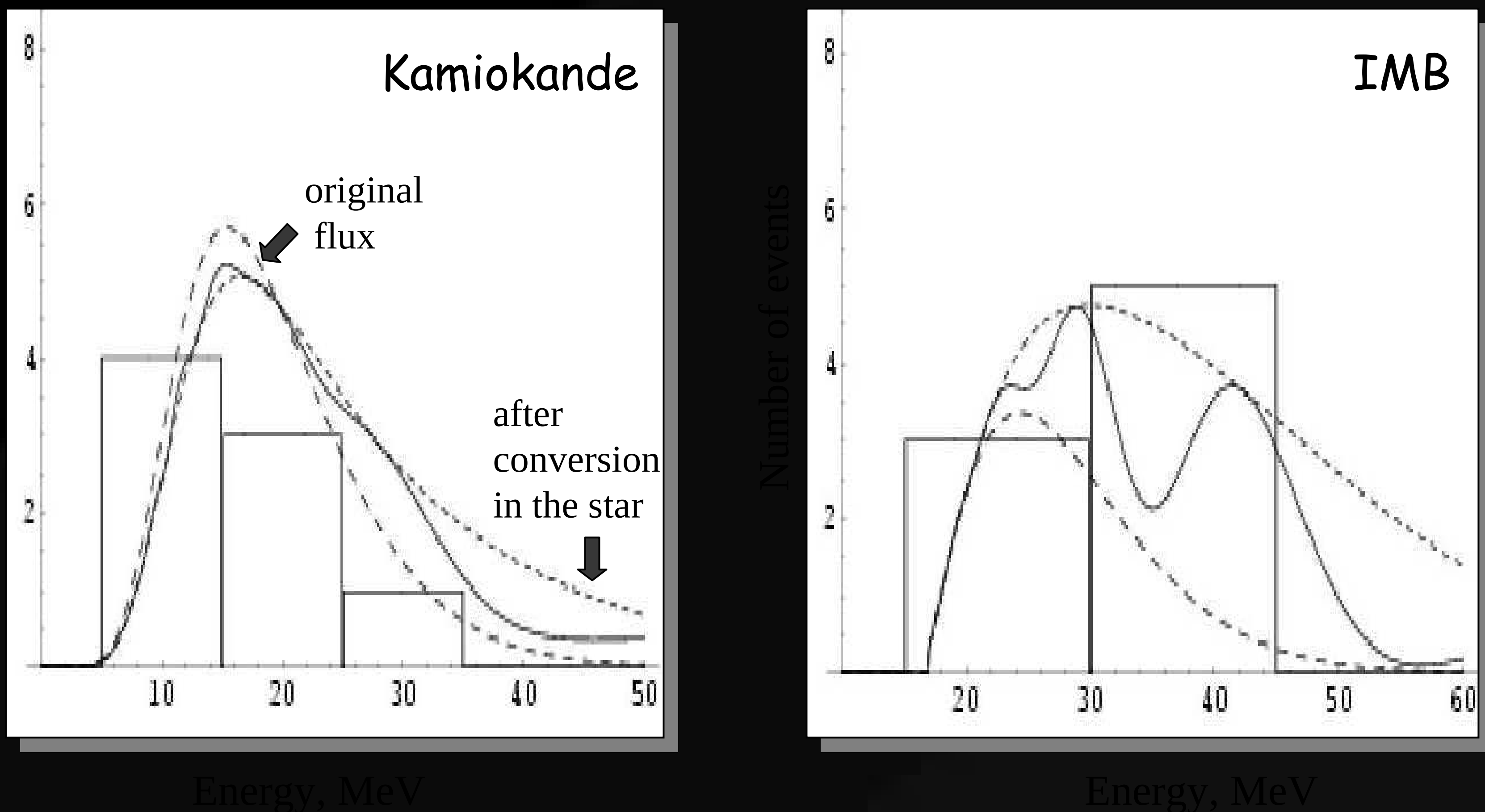


Spectra of events

$\cos 2\theta = 0.5$

$\Delta m^2 = 2.75\ 10^{-5}\ eV^2$

$T(\nu_e) = 3.5$ MeV, $T(\nu_\mu) = 7$ MeV

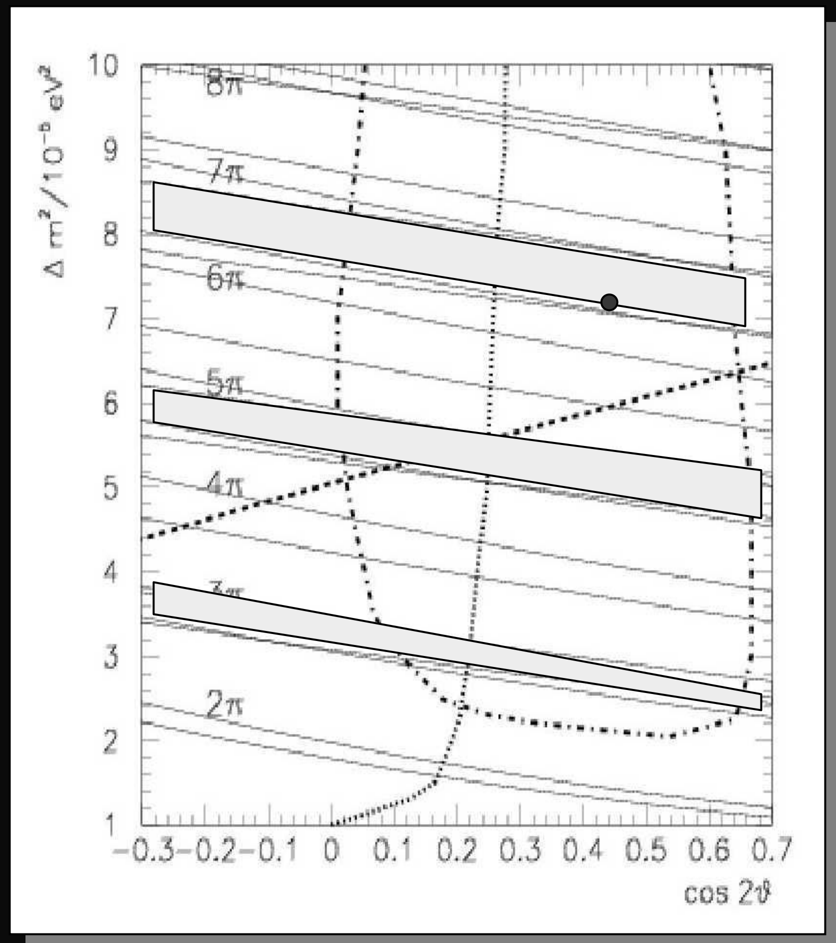


Reconciling Kamiokande and IMB

Bands of equal oscillation phases:

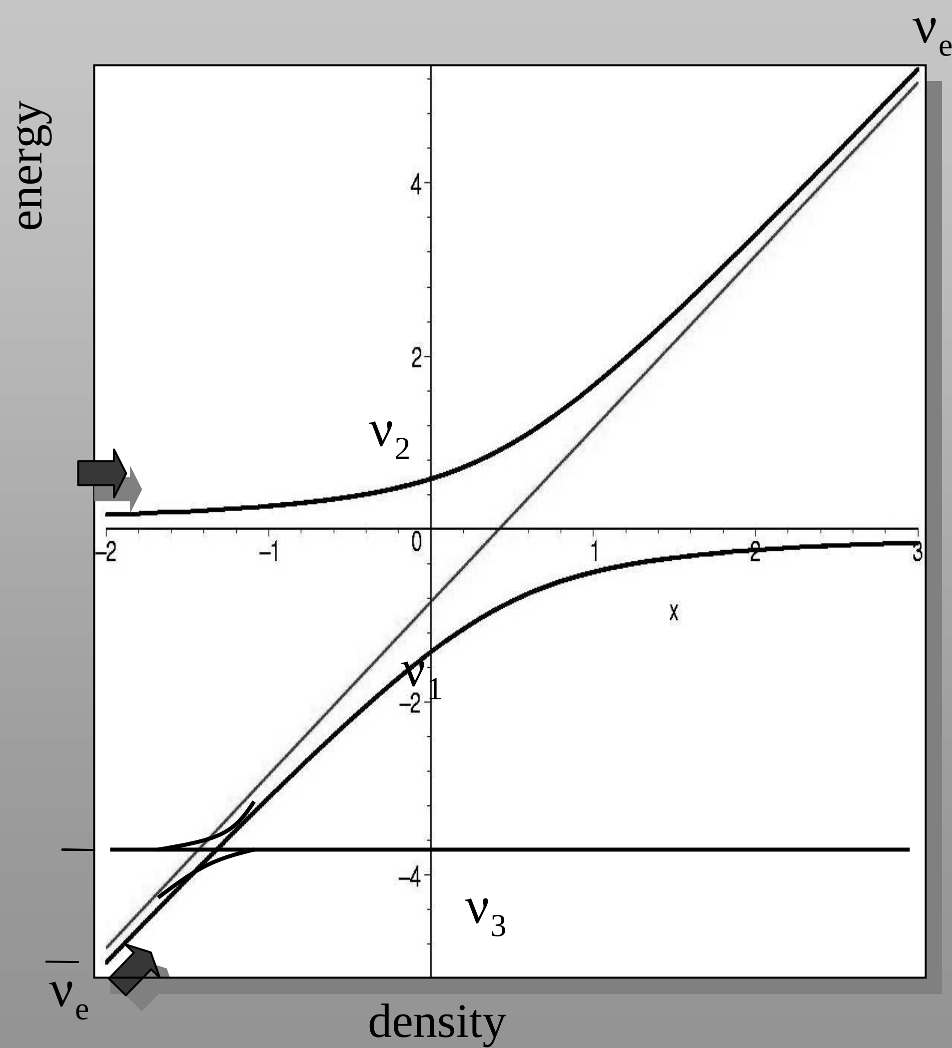
$\Phi_{IMB}(40 MeV) \sim k\pi$

$\Phi_{K}(40 MeV) \sim (1/2 + k)\pi$



C. Lunardini, A.S. PRD 63 073009

Inverted mass hierarchy



Level crossing scheme for normal hierarchy

adiabatic transitions:

$\bar{\nu}_e \;\to\; \bar{\nu}_3$
$\bar{\nu}_\mu / \bar{\nu}_\tau \;\to\; \bar{\nu}_1 / \nu_2$

$|\langle \bar{\nu}_e | \bar{\nu}_3 \rangle|^2 = \sin^2\theta_{13}$

If $\sin^2\theta_{13} > 10^{-3}$ ➡ adiabaticity

Electron antineutrino flux at the detector:

$\bar{F}_e \sim \bar{F}_x^0$ hard

No Earth matter effect in antineutrino channel

Disfavored?

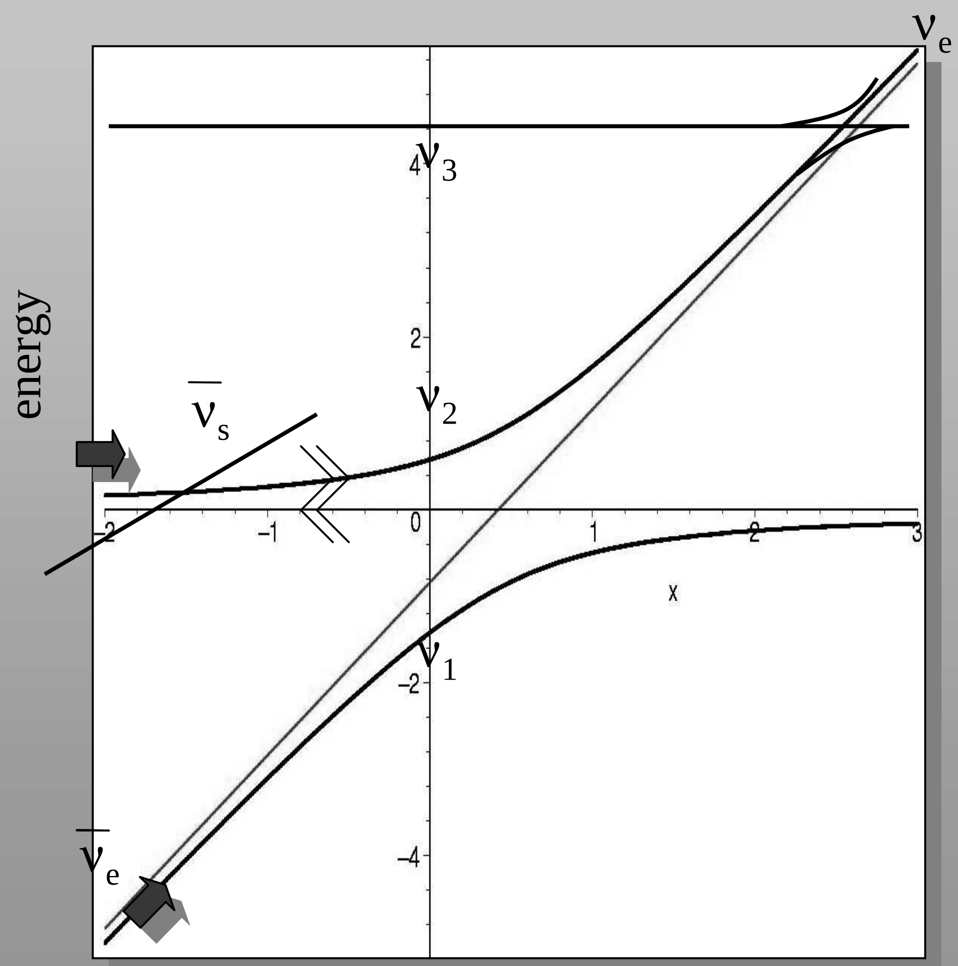
Electron neutrinos:

$F_e = \sin^2\theta \, F_e^0 + \cos^2\theta \, F_x^0$

Strong permutation, composite spectrum

Sterile Neutrino?

3 + 1 scheme



density

Level crossing scheme for normal hierarchy

adiabatic transitions:

$\bar{\nu}_e \to \bar{\nu}_1$
$\bar{\nu}_\mu / \bar{\nu}_\tau \to \bar{\nu}_s$

$|\langle \bar{\nu}_e | \bar{\nu}_1 \rangle|^2 = \cos^2\theta \qquad |\langle \bar{\nu}_e | \bar{\nu}_2 \rangle|^2 = \sin^2\theta$

Electron antineutrino flux at the detector:

$$\bar{F}_e = \cos^2\theta \, \bar{F}_e^0$$

No hard component: only overall suppression of the flux

No Earth matter effect
no $\bar{\nu}_2$

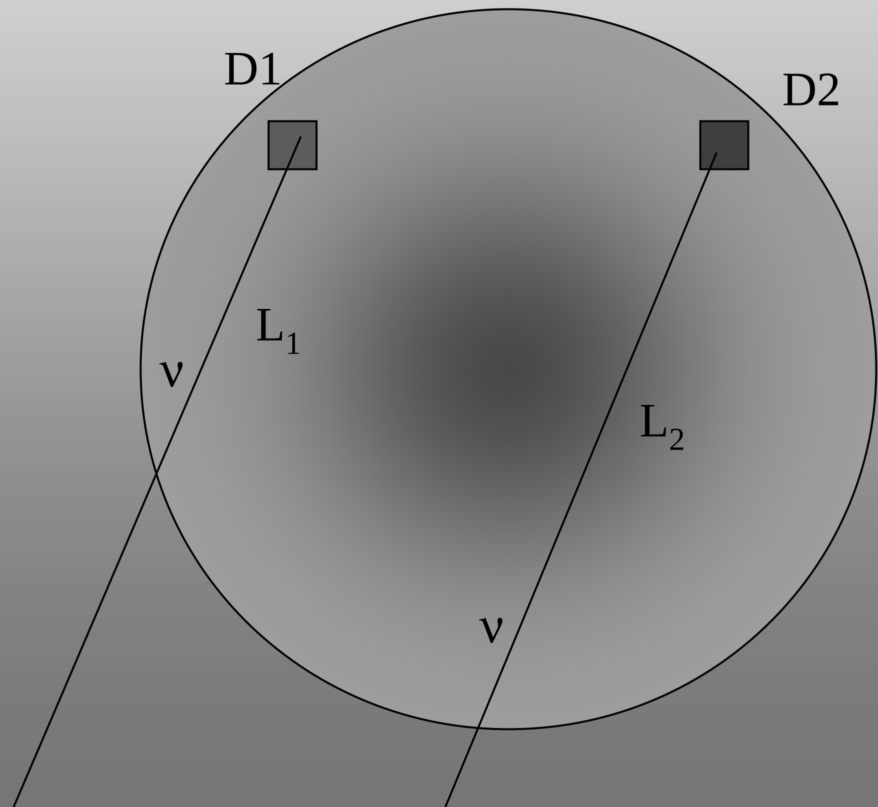
$$\Delta F^0 = \bar{F}_x^0 - \bar{F}_e^0$$

LBL experiments with SN neutrinos

Beam uncertainties can be controlled if

- Two well separated detectors are used
- Properties of medium are know

➡ Comparison of signals from the two detectors: oscillation effects between them and also test properties of the original flux



This is realized for oscillations of SN neutrinos inside the Earth:

Fluxes arriving at the surface of the earth are the same for both detectors

e.g.

If $\sin^2\theta_{13} > 10^{-4}$ an appearance of the Earth matter effect in $\bar{\nu}_e$ or (ν_e) signal will testify for normal (inverted) mass hierarchy of neutrinos

Analysing SN data

Earth matter effect

If no effect in the neutrino channel is observed

- inverted hierarchy is excluded independently of value of s_{13}

  normal hierarchy with $s_{13} > 10^{-4}$

- sterile neutrino with mixing a la 3+1

- small difference of the original ν_e– and $\nu_{\mu/\tau}$– fluxes

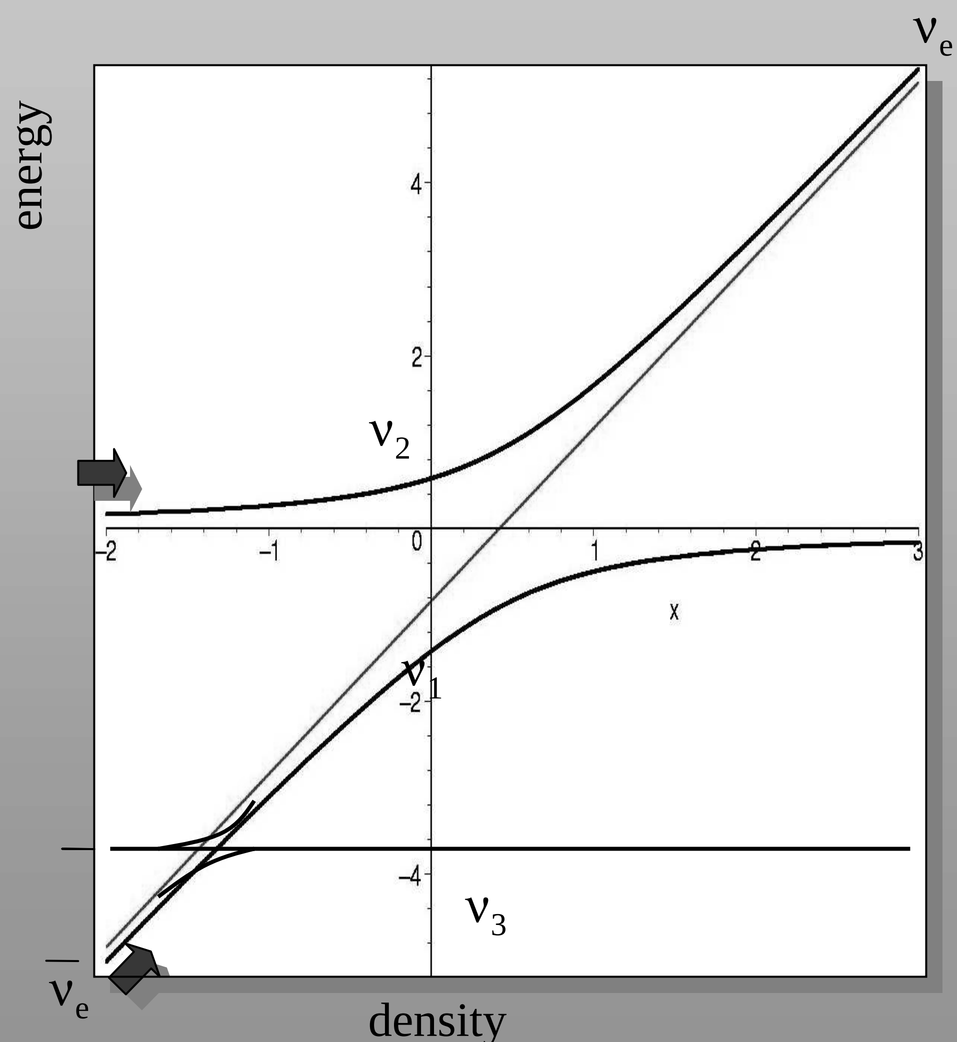
If in addition,

the effect is observed in the antineutrino channel

(alone it does not exclude inverted hierarchy if $s_{13} < 10^{-3}$)

- further confirmation of normal hierarchy
- the third possibility can be excluded since ν_e and $\nu_{\mu/\tau}$ fluxes differ stronger the antineutrino fluxes

Inverted mass hierarchy



Level crossing scheme for normal hierarchy

Earth matter effect in the neutrino channel

Probing mass hierarchy and 1-3 mixing

Extreme cases	A. Normal hierarchy large 1-3 mixing	B. Inverted hierarchy large 1-3 mixing	C. Very small 1-3 mixing
$\bar{\nu}_e$ -spectrum	composite, weakly ($\sin^2\theta \sim 1/4$) mixed	unmixed, hard	composite, weakly ($\sin^2\theta \sim 1/4$) mixed
ν_e -spectrum	unmixed, hard	composite, strongly ($\cos^2\theta \sim 3/4$) permuted	composite, strongly ($\cos^2\theta \sim 3/4$) permuted
Earth matter effect	in antineutrino channel	in neutrino channel	both in neutrino and antineutrino channels

Large 1-3 mixing: $\sin^2\theta_{13} > 10^{-4}$

A Yu Smirnov

Observables

the observed spectra of ν_e and $\bar{\nu}_e$- events

- Ratio of the neutrino and antineutrino events in the tails

$$R\,(E_L, E_L) = \frac{N_e(E > E_L)}{N_{\bar{e}}(E > \bar{E}_L)}$$

- Ratio of the total number of neutrino and antineutrino events

$$R_{tot} = \frac{N_{tot}}{\bar{N}_{tot}}$$

- Ratio of the average energies

$$r_E = \frac{<E>}{<\bar{E}>}$$

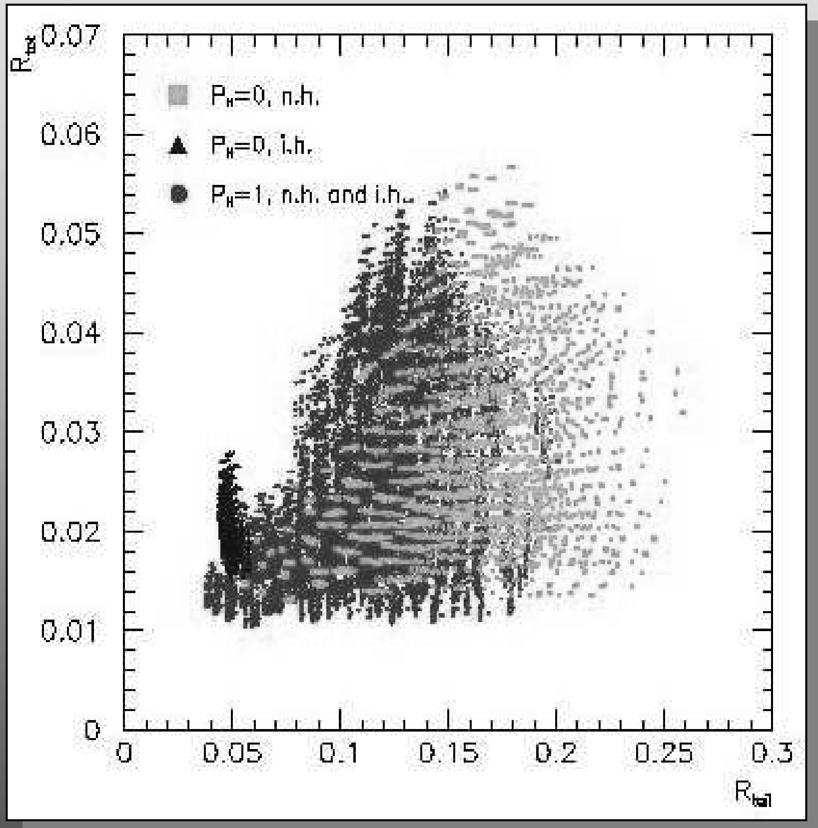
- Ratio of the width of the spectra:

$$r_\Gamma = \frac{<\Gamma>}{<\bar{\Gamma}>}$$

Scatter Plots

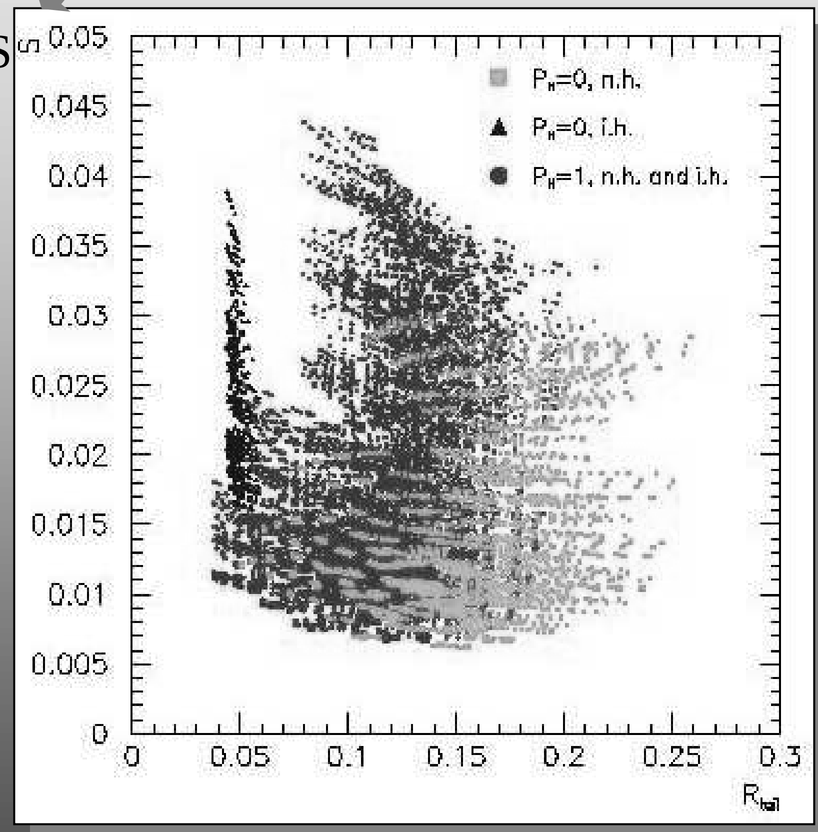
Ratio of the low energy events

R_{tot}



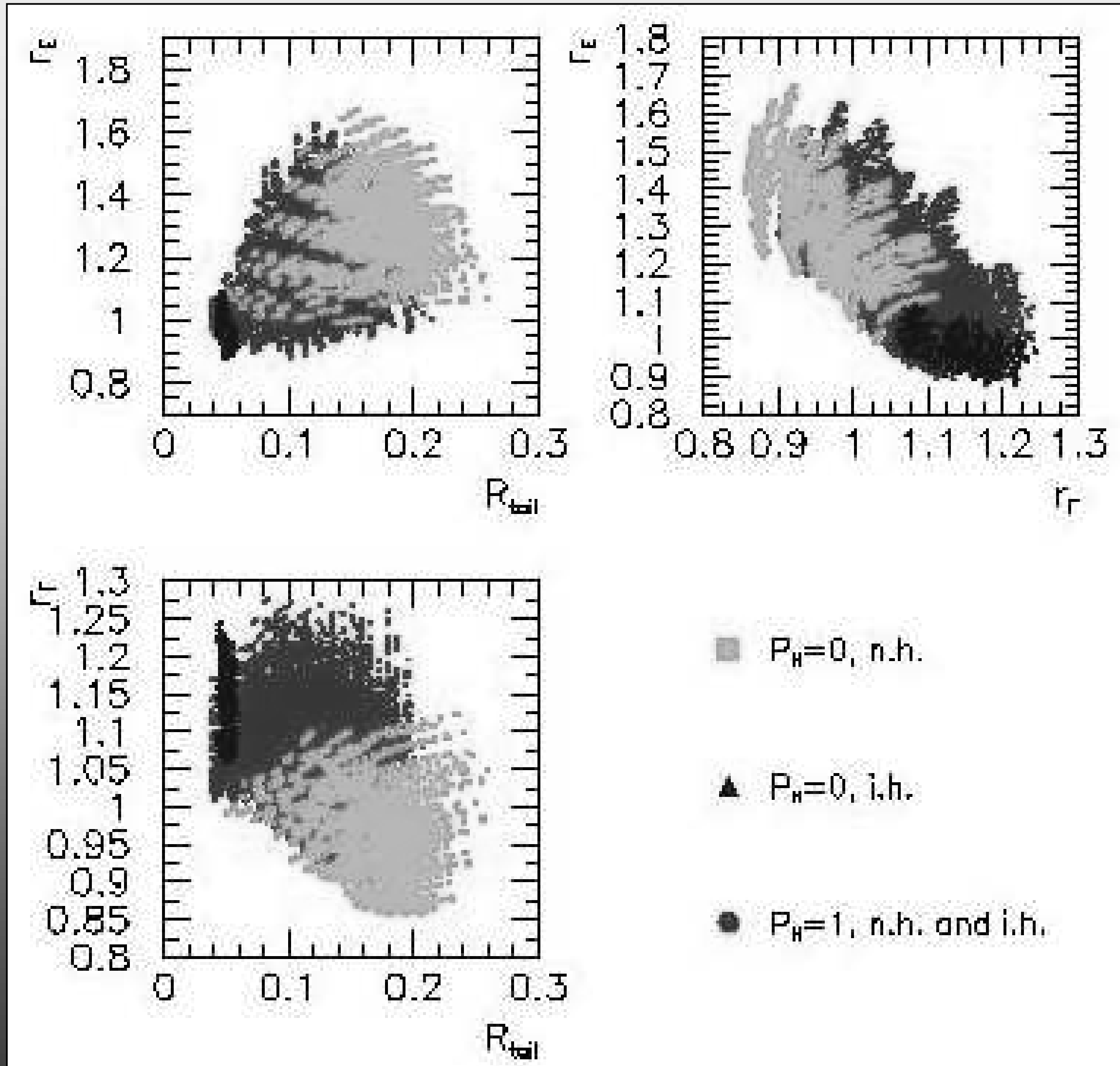
R_{tail}

S



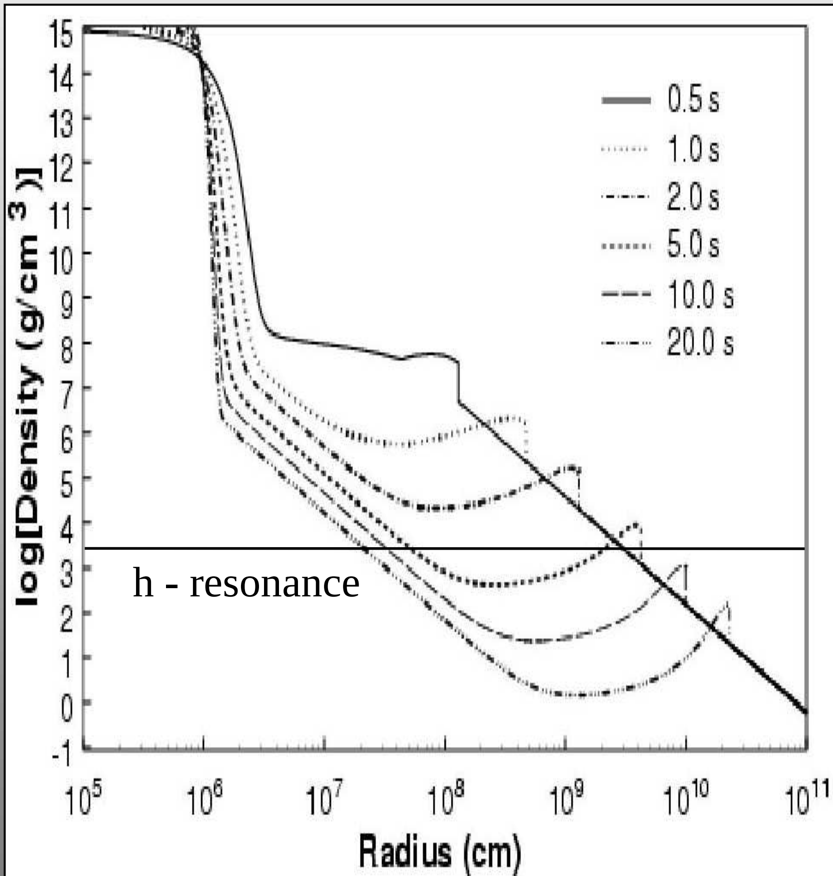
R_{tail}

Scatter plots



Shock Wave Effect

R.C. Schirato, G.M. Fuller, astro-ph/0205390



Density profile with shock wave propagation at various times post-bounce

The shock wave can reach the region relevant for the neutrino conversion

$\rho \sim 10^4$ g/cc

During 3 - 5 s from the beginning of the burst

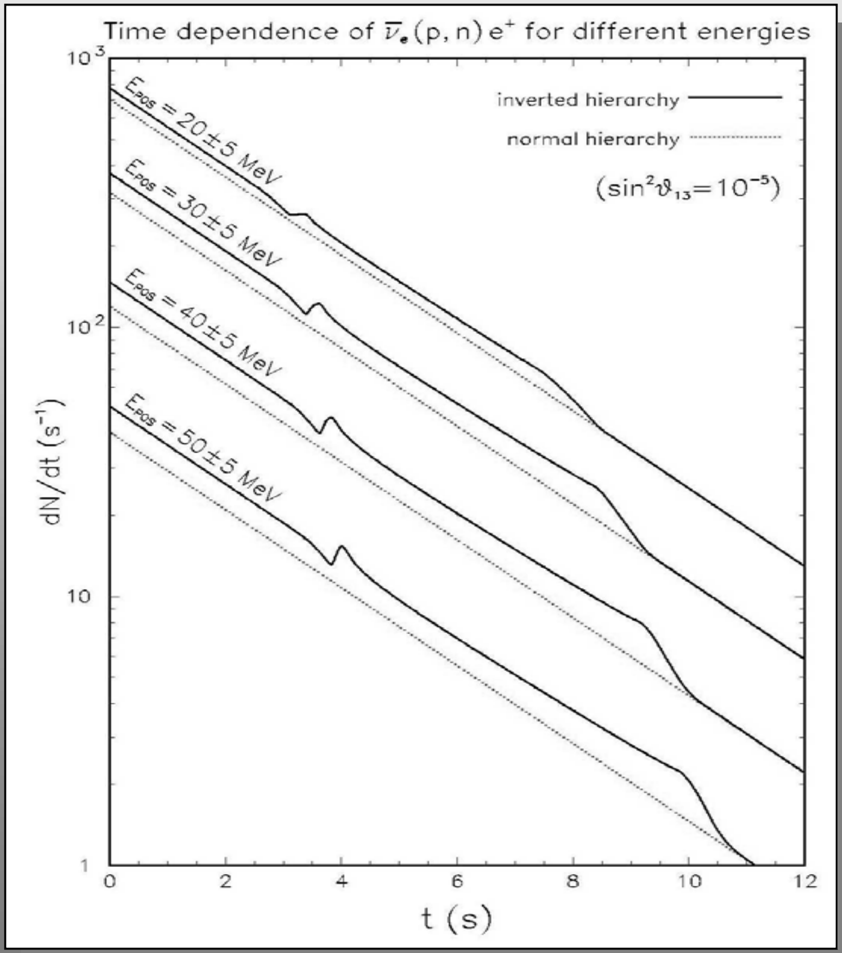
Influences neutrino conversion if $\sin^2\theta_{13} > 10^{-5}$

The effects are in the neutrino (antineutrino) for normal (inverted) hierarchy:

- change the number of events
  R.C. Schirato, G.M. Fuller, astro-ph/0205390
- ``wave of softening of spectrum''
  K. Takahashi et al, astro-ph/0212195
- delayed Earth matter effect
  C.Lunardini, A.S., hep-ph/0302033

Shock wave effect

G. L. Fogli et. al, hep-ph/0304056



Effect depends on properties of the shock wave profile and value of 1-3 mixing

- Large 1-3 mixing: $\sin^2\theta > 10^{-3}$ violation of the adiabaticity by a shock front
- Small 1-3 mixing: $\sin^2\theta < 10^{-5}$ partial restoration of the adiabaticity in the region below the front

Monitoring shock wave with neutrinos

G. Fuller

Studying effects of the shock wave
on the properties of neutrino burst
one can get (in principle) information on

- time of propagation
- velocity of propagation
- shock wave revival time
- density gradient in the front
- size of the front

Can shed some light on
mechanism of explosion

Summary: Solar Neutrinos

- KamLAND (+ CPT): confirmation of the large mixing MSW solution; other solutions are excluded as dominant mechanisms
- Determination of Δm_{12}^2 , θ_{12} : next important step in reconstruction of the neutrino mass spectrum
- Future:
  - consistency checks, observations of signatures of LMA: day-night asymmetry, turn up of the spectrum at low energies
  - precise determination of the oscillation parameters
  - Searches for physics beyond the LMA solution
    bounds on sub-dominant mechanisms
    KamLAND vs. Solar neutrinos
- Low energy part of the spectrum: not well known experimentally
  ``new'' sterile neutrinos: dip in the survival probability
  BOREXINO, KamLAND

Summary: supernova neutrinos

- SN1987A:
  - Interpretation of the neutrino signals from SN1987A must include effects of neutrino conversion both in the star and in the matter of the Earth
  - The earth matter effect can (at least partially) explain difference of the energy spectra observed by Kamioka II and IMB
  - Results favor normal mass hierarchy (earth matter effect in the antineutrino channel)

- Future detection of the SN neutrino bursts

  - lower bound on 1-3 mixing
  - identification of the mass hierarchy
  - searches for the sterile neutrinos

  Earth matter effect and mass hierarchy
  ν_e detectors and negative results

- Monitoring shock wave with neutrinos

Adiabatic conversion

$\nu_{1m} \not\leftrightarrow \nu_{2m}$