Solar Neutrino and Neutrino Physics in Brazil

Pedro Cunha de Holanda

DRCC - IFGW

UNICAMP

Florence, 2012

A little bit of history

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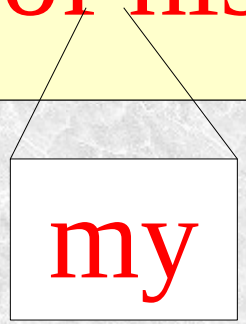

A little bit of history

➔ Pontecorvo: Solar Neutrinos, maybe we can detect them, maybe the flux will agree with solar model predictions, and if they don't agree, maybe the neutrinos are oscillating.

➔ Davis: First solar neutrino detection at Homestake.

➔ Ok, but oscillation is not a good mechanism, because it only works for large mixing angles.

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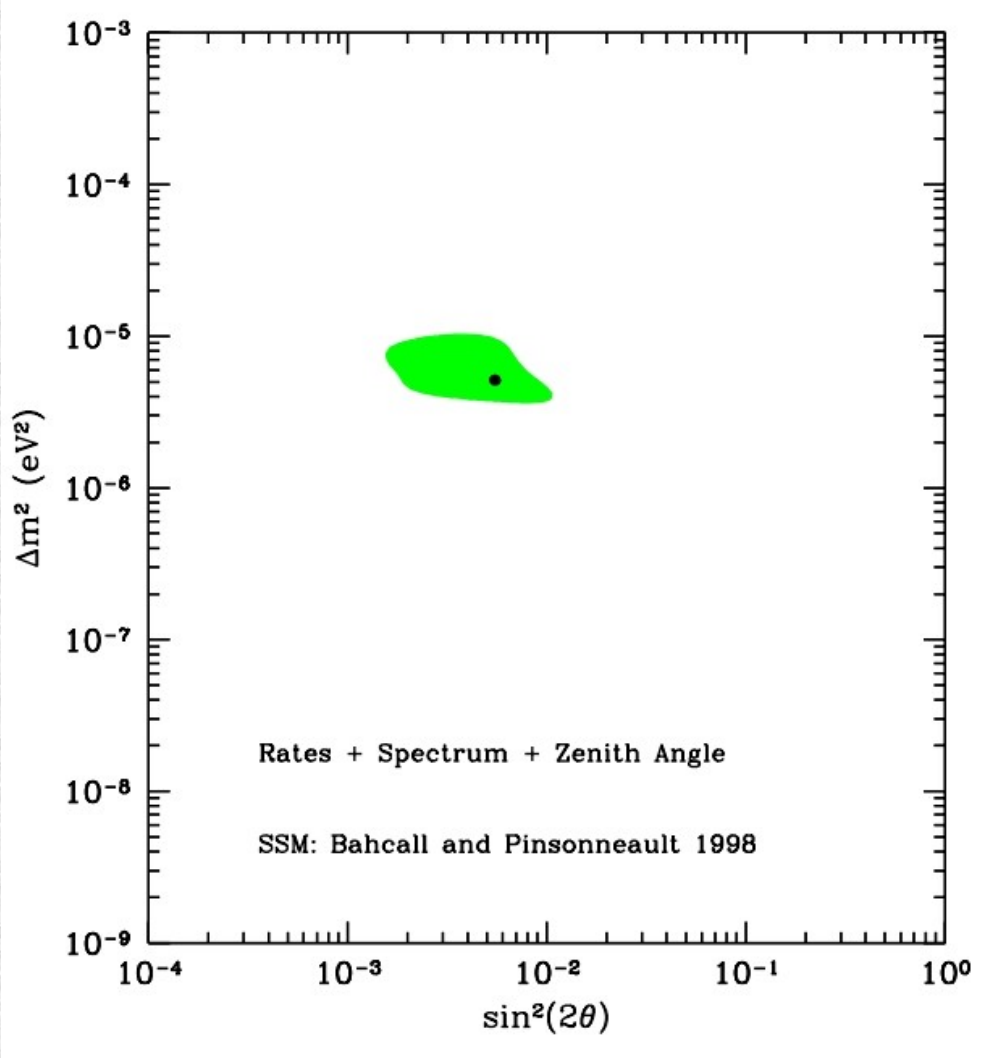
➔ Ok, but oscillation is not a good mechanism, because it only works for large mixing angles. ***But there are matter effects!***

➔ No good, matter effects are diagonal in evolution matrix, and then decrease oscillation signal. ***MSW mechanism enhance conversion even for very small mixing angles!***

A little bit of history



Bahcall, Krastev and Smirnov, Phys.Rev.D58(1998)096016.

Year: 1998

Data:

- ***Homestake*, total rate**

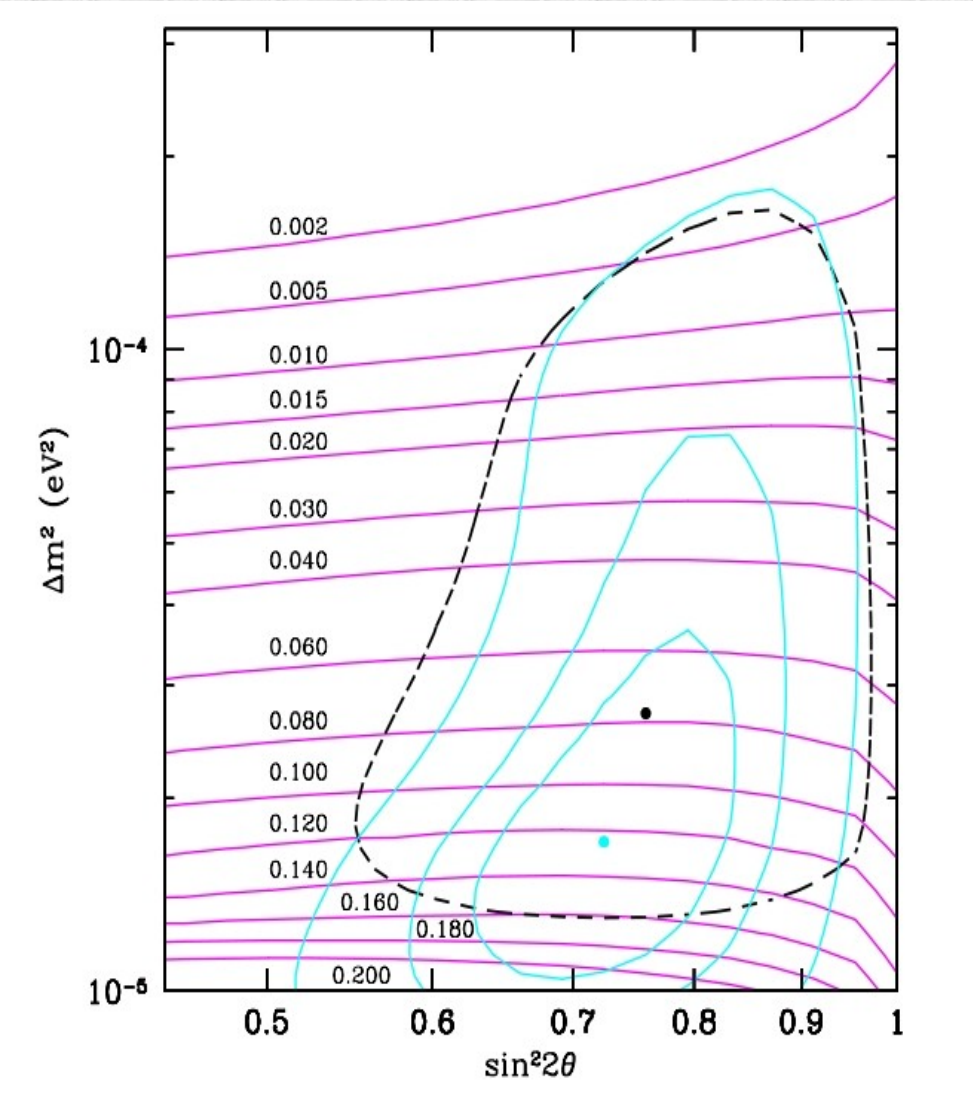
- ***Gallex* and *Sage*, total rate**

- ***Super-Kamiokande I (504 days)*, rates, day-night assymetry, spectrum.**

Solutions:

- **SMA**
- ***oscillation in vacuum***

A little bit of history



Bahcall, Krastev and Smirnov, Phys.Rev.D60(1999)093001.

Year: 1999

Data:

- ***Homestake*, total rate**

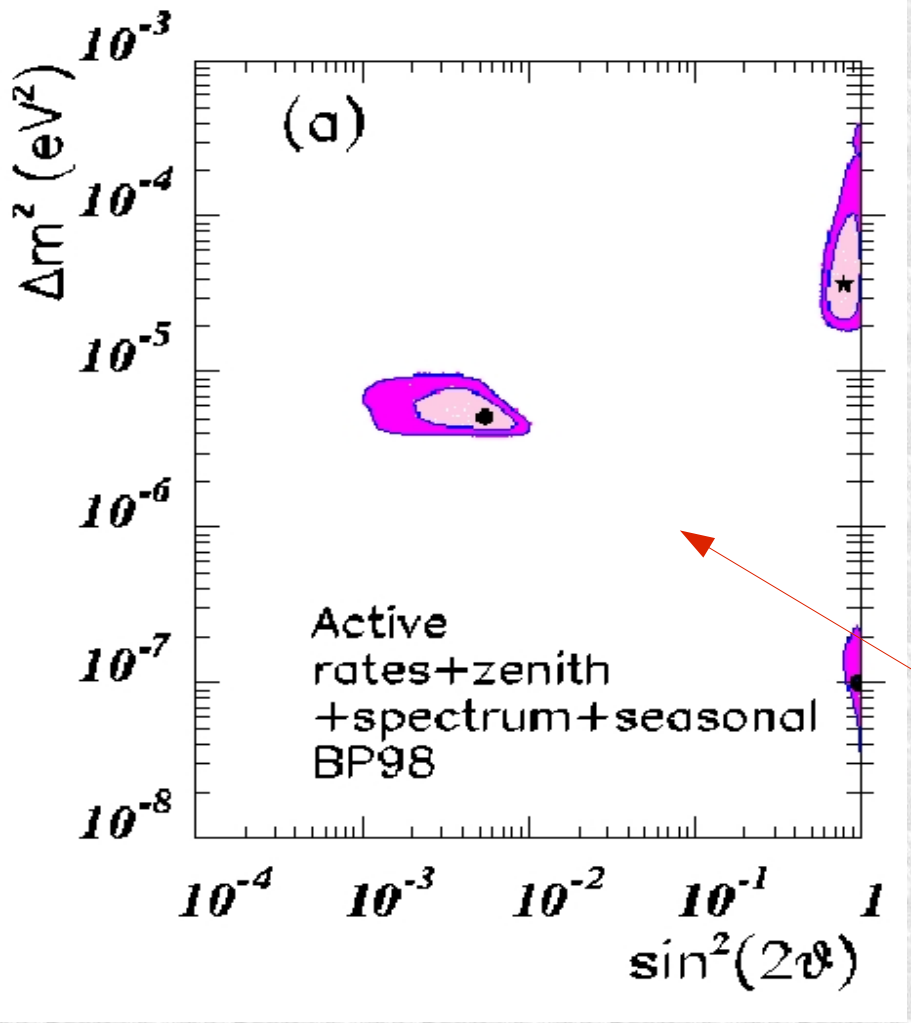
- ***Gallex* and *Sage*, total rate**

- ***Super-Kamiokande I (708 days)*, rates, day-night assymetry, spectrum information.**

Solutions:

- **LMA?**

A little bit of history



Year: 2000

Data:

- ***Homestake*, total rate**

- ***Gallex* and *Sage*, total rate**

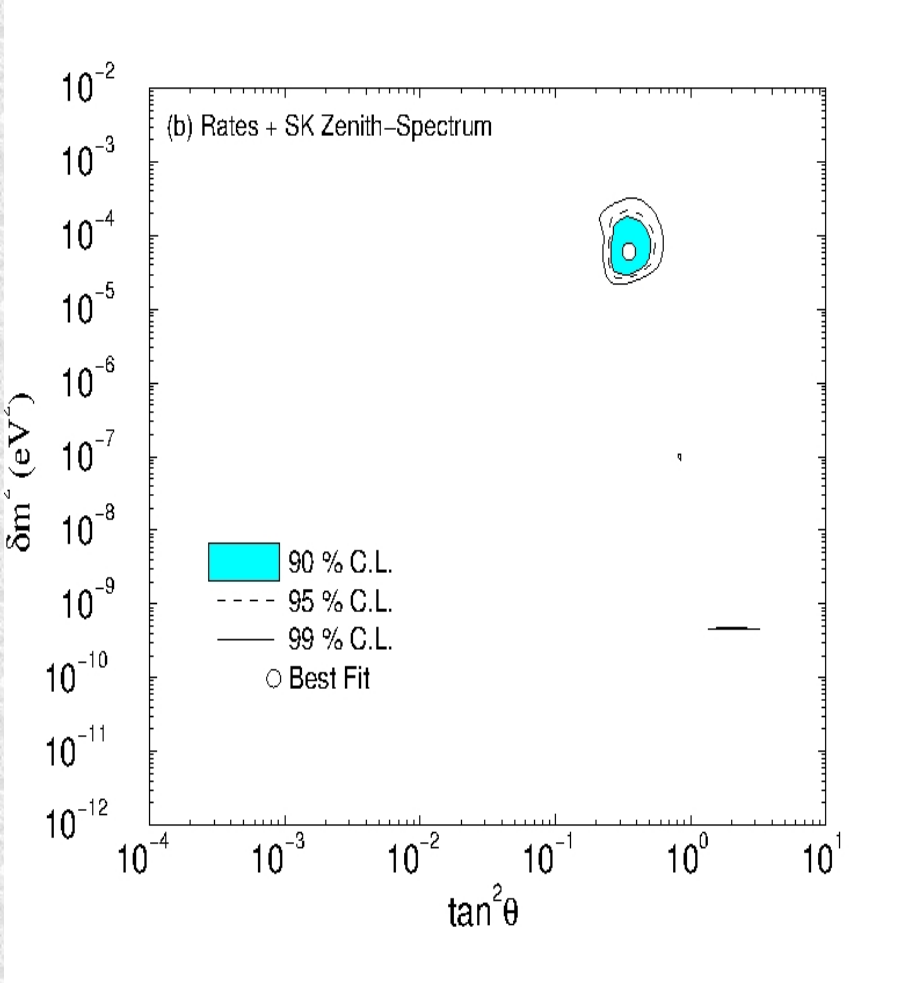
- ***Super-Kamiokande I (825 days)*, rates, zenith angle distribution, spectrum and seasonal variation.**

Solutions:

- **SMA, LOW, LMA**
- ***oscillation in vacuum***
- ***RSFP***
- ***NSNI***
- ***VEP***

M. C. Gonzalez-Garcia, PCH, C. Peña-Garay and J.W.F. Valle
Nucl.Phys.B573(2000), 3-26.

A little bit of history



Year: 2002

Data:

- ***Homestake*, total rate**

- ***Gallex*, *GNO* and *Sage*, total rate**

- ***Super-Kamiokande*, rates, zenith angle distribution, spectrum and seasonal variation.**

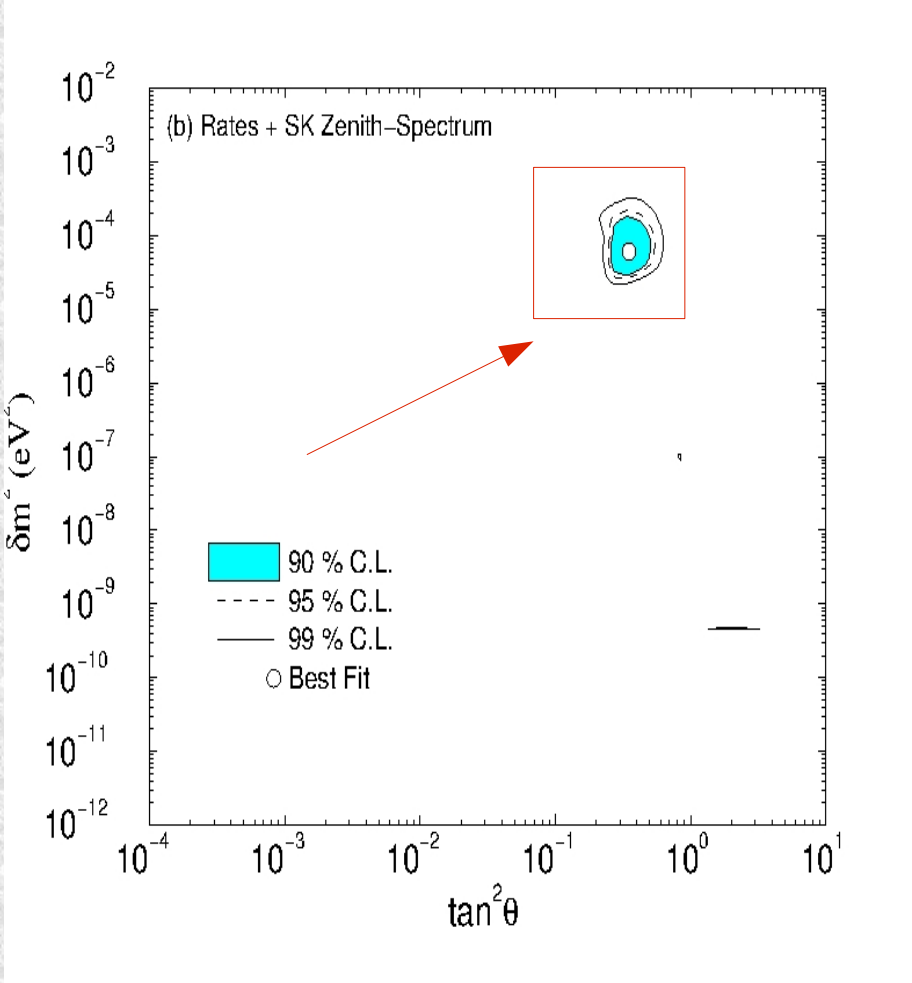
- ***SNO*, charged current**

Solutions:

- ***LOW*, *LMA***
- ***oscillation in vacuum***
- ***RSFP***
- ***NSNI***
- ***VEP***

A.M. Gago, M.M. Guzzo, PCH, H. Nunokawa, O.L.G. Peres, V. Pleitez, R. Zukanovich Funchal, Phys.Rev.D65 (2001), 073012..

A little bit of history



Year: 2002

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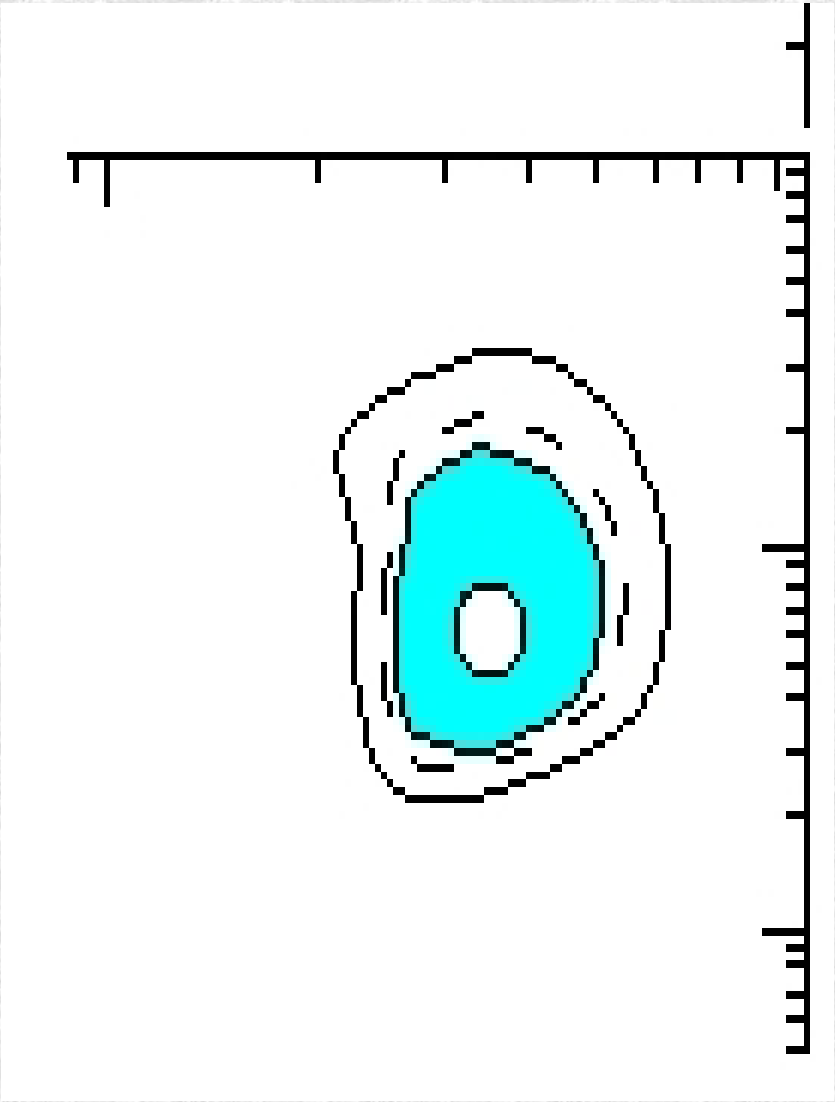


Year: 2002

Data:

- ***Homestake, total rate***

- ***Gallex, GNO and Sage, total rate***

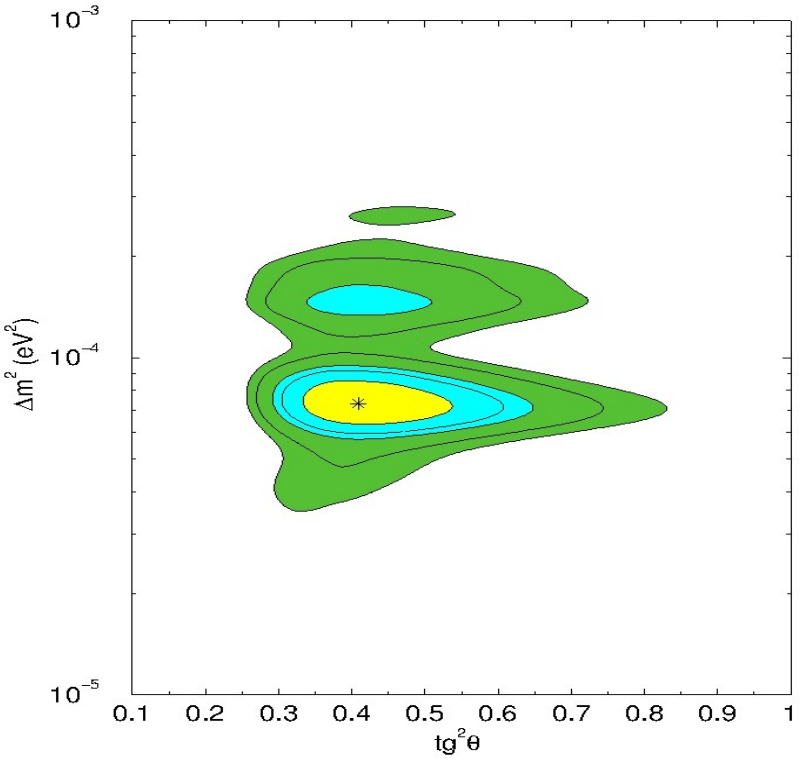
- ***Super-Kamiokande, rates, zenith angle distribution, spectrum and seasonal variation.***

- ***SNO, charged current***

Solutions:

- ***LOW, LMA***
- ***oscillation in vacuum***
- ***RSFP***
- ***NSNI***
- ***VEP***

A little bit of history



PCH, A. Yu. Smirnov, JCAP 02 (2003) 001.

Year: 2003

Data:

- ***Homestake*, total rate**

- ***Gallex*, *GNO* and *Sage*, total rate**

- ***Super-Kamiokande*, rates, zenith angle distribution, spectrum and seasonal variation.**

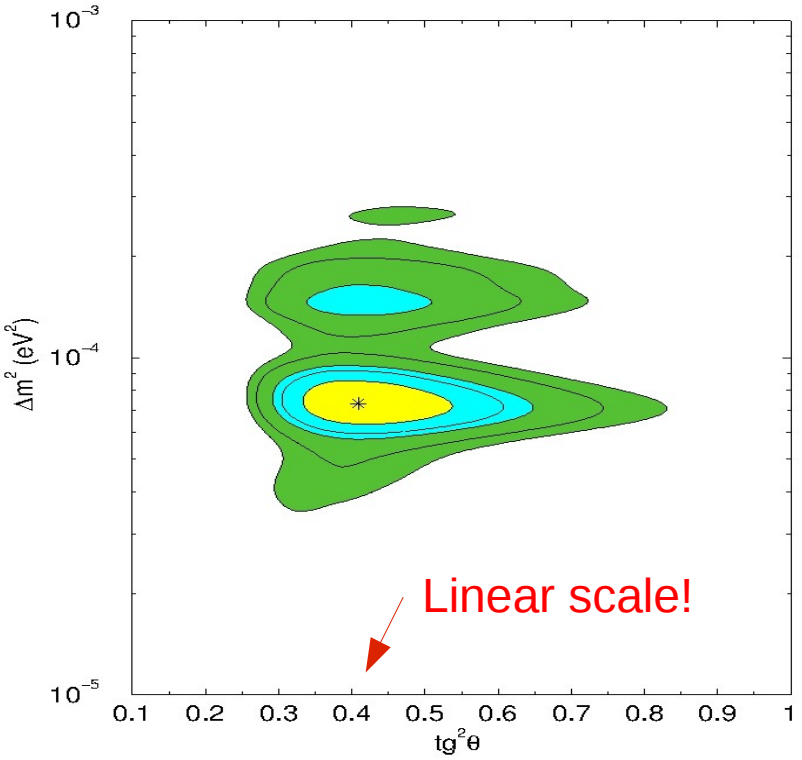
- ***SNO*, charged current day-night spectrum**

- ***KamLAND*, spectrum**

Solutions:

- ***LMA***

A little bit of history



PCH, A. Yu. Smirnov, JCAP 02 (2003) 001.

Year: 2003

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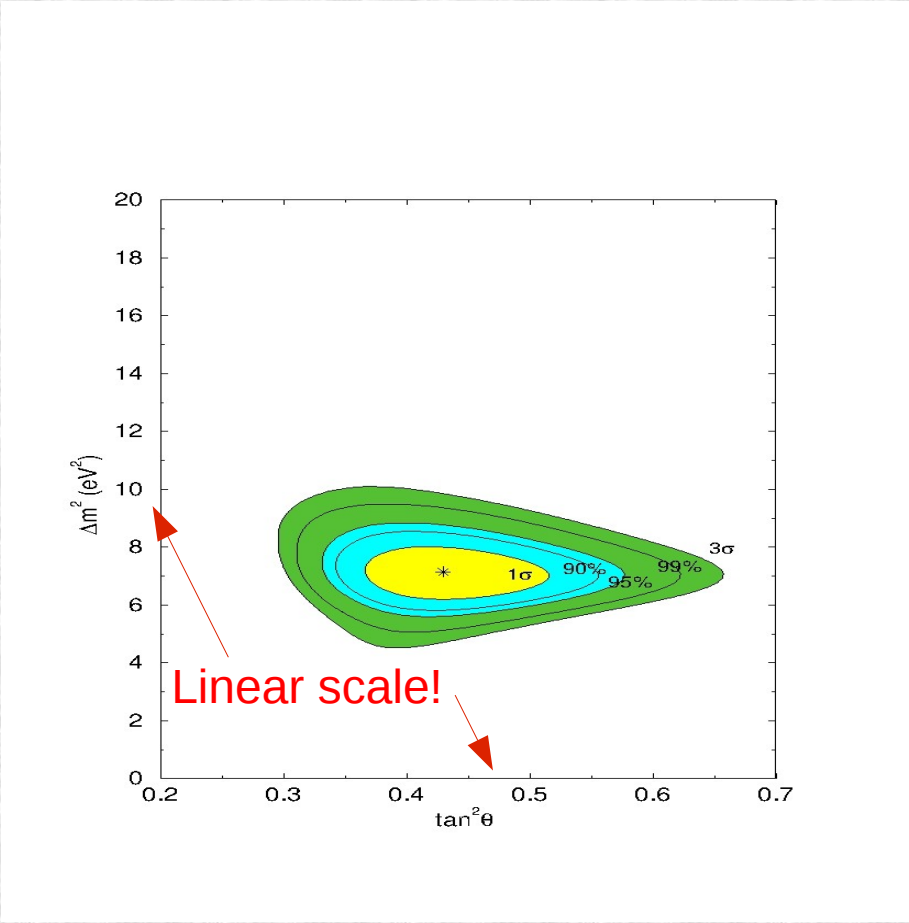


PCH, A. Yu. Smirnov, Astropart.Phys.21 (2004) 287..

Year: 2004

Data:

- ***Homestake**, total rate*

- ***Gallex**, **GNO** and **Sage**, total rate*

- ***Super-Kamiokande**, rates, zenith angle distribution, spectrum and seasonal variation.*

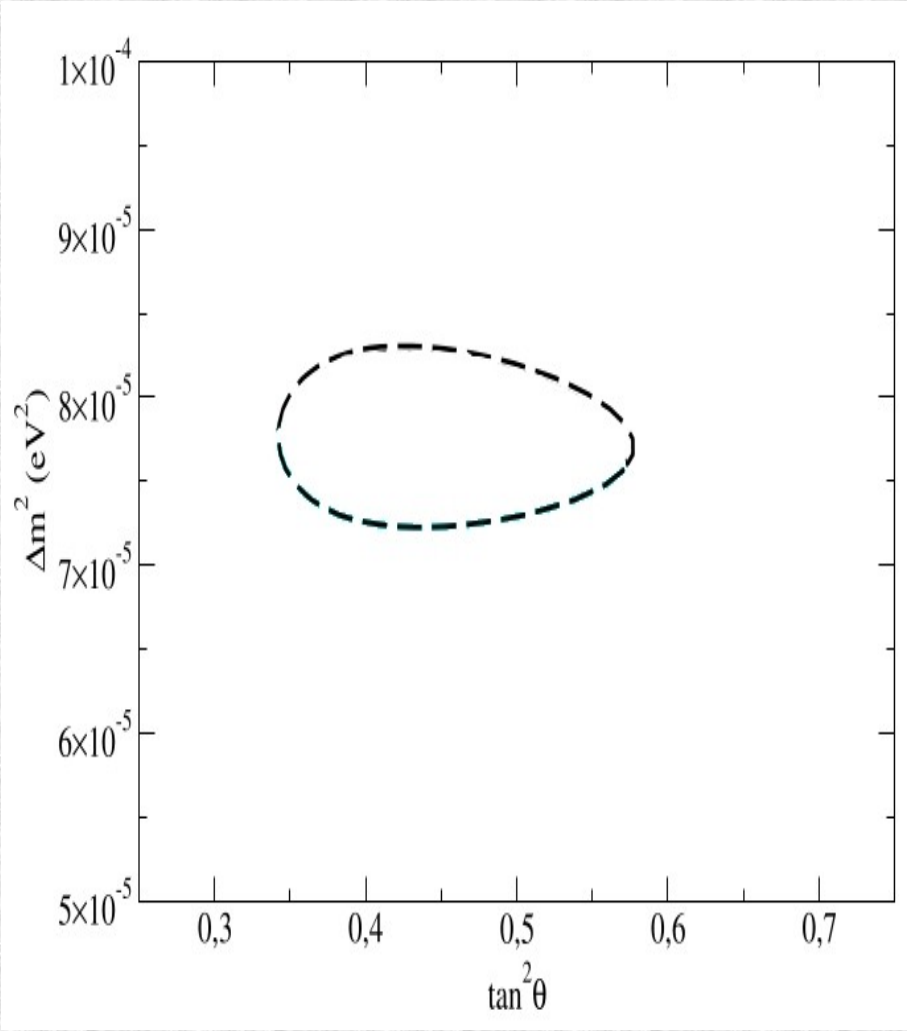
- ***SNO**, charged current day-night spectrum, NC and ES rates.*

- ***KamLAND**, spectrum*

Solutions:

- ***LMA***

A little bit of history



G.A.Valdiviesso, M.M. Guzzo, PCH, Phys.Lett. B (2011) 240.

Year: 2011

Data:

- ***Homestake*, total rate**

- ***Gallex*, *GNO* and *Sage*, total rate**

- ***Super-Kamiokande*, rates, zenith angle distribution, spectrum and seasonal variation.**

- ***SNO*, CC, NC and ES day-night spectrum, all fases**

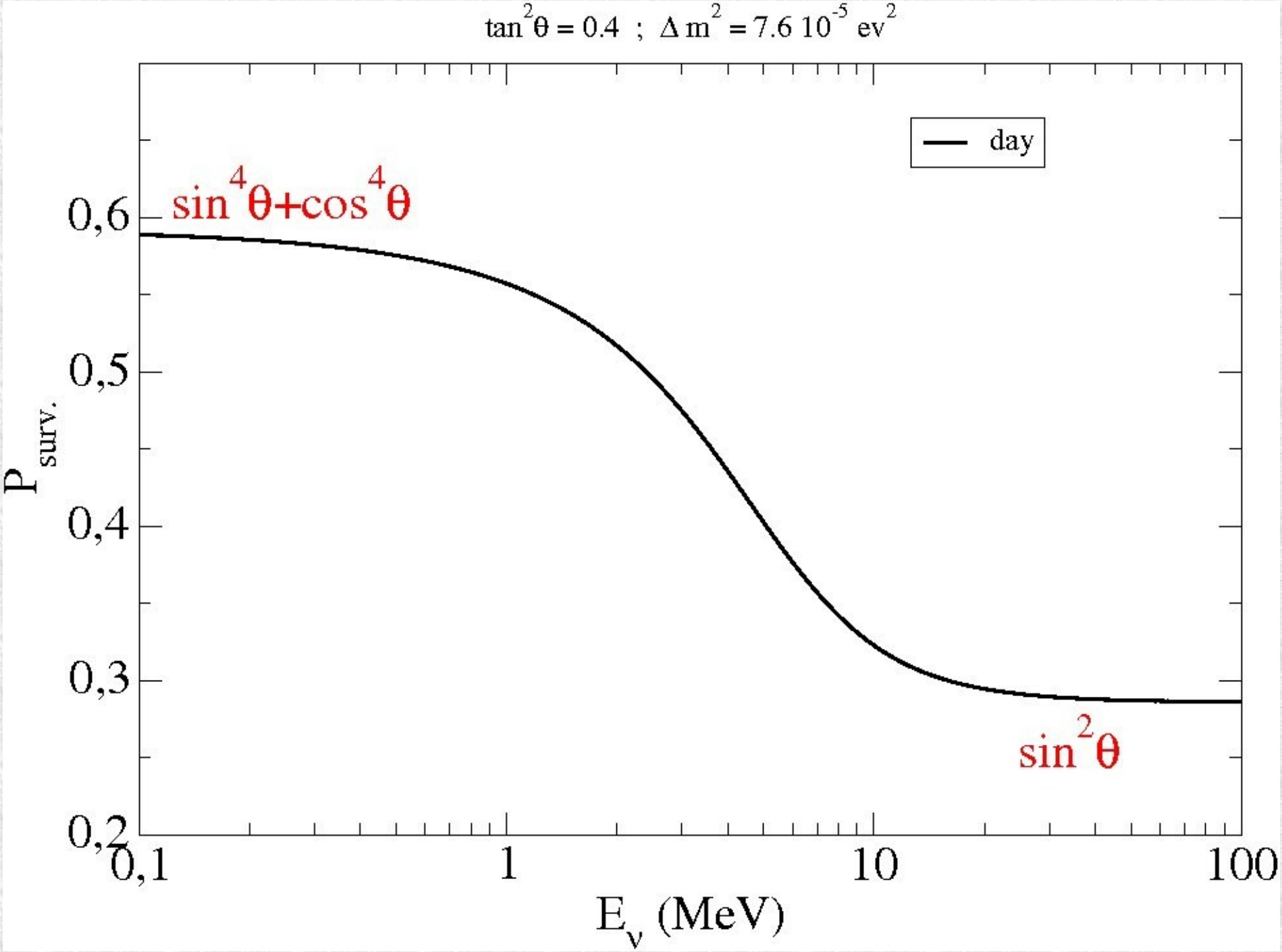
- ***Borexino*.**

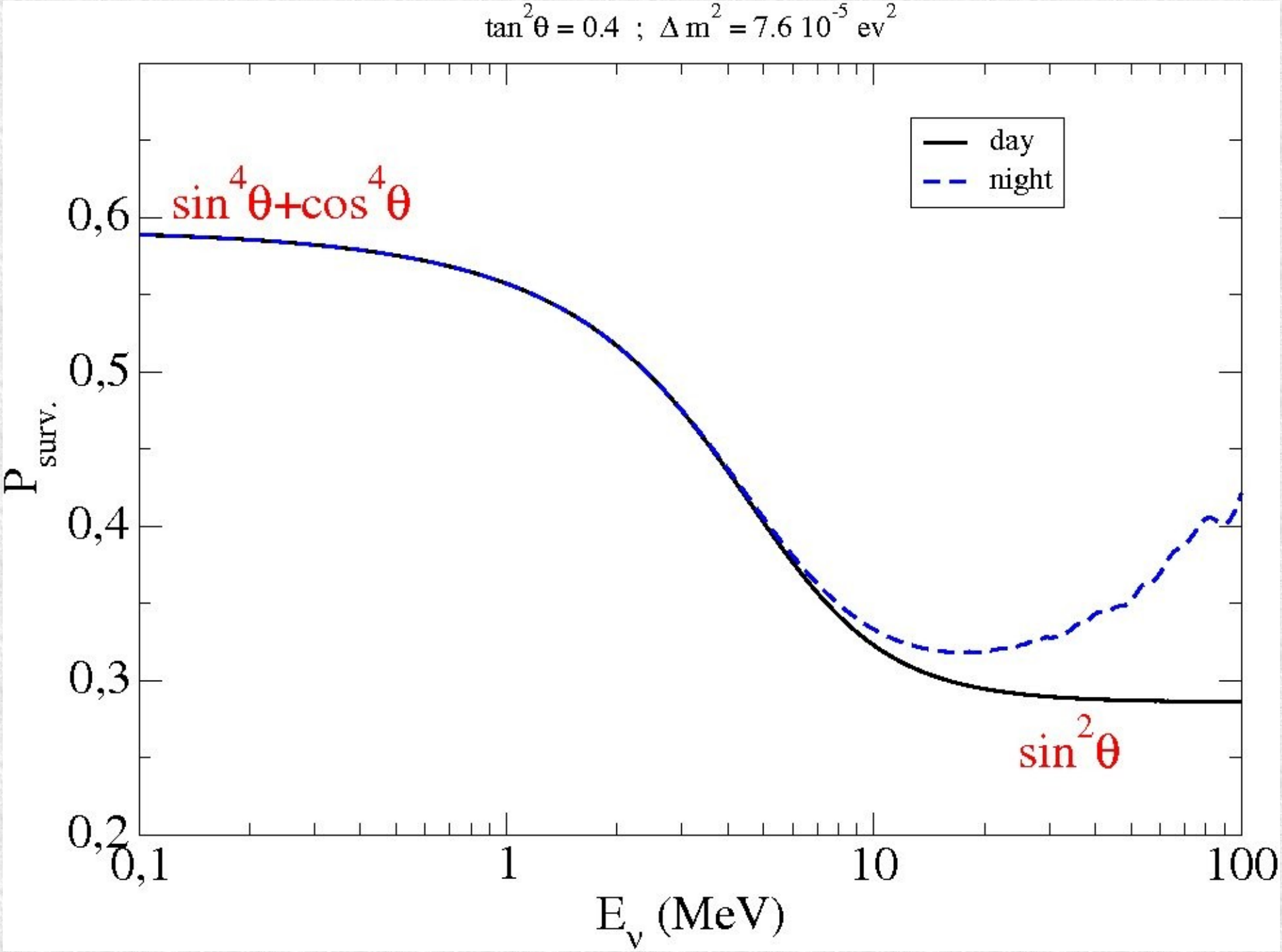
- ***KamLAND*, spectrum**

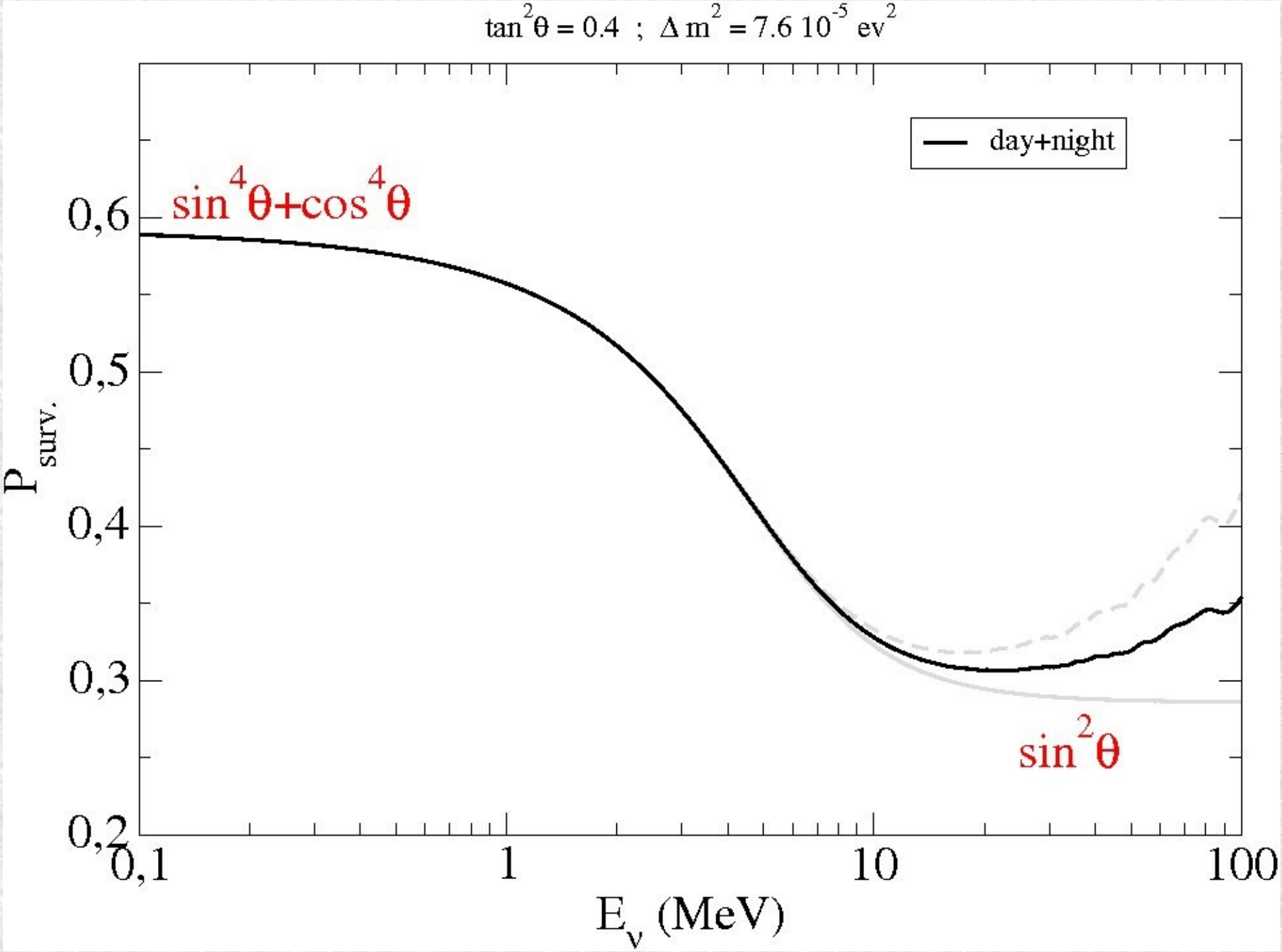
Solutions:

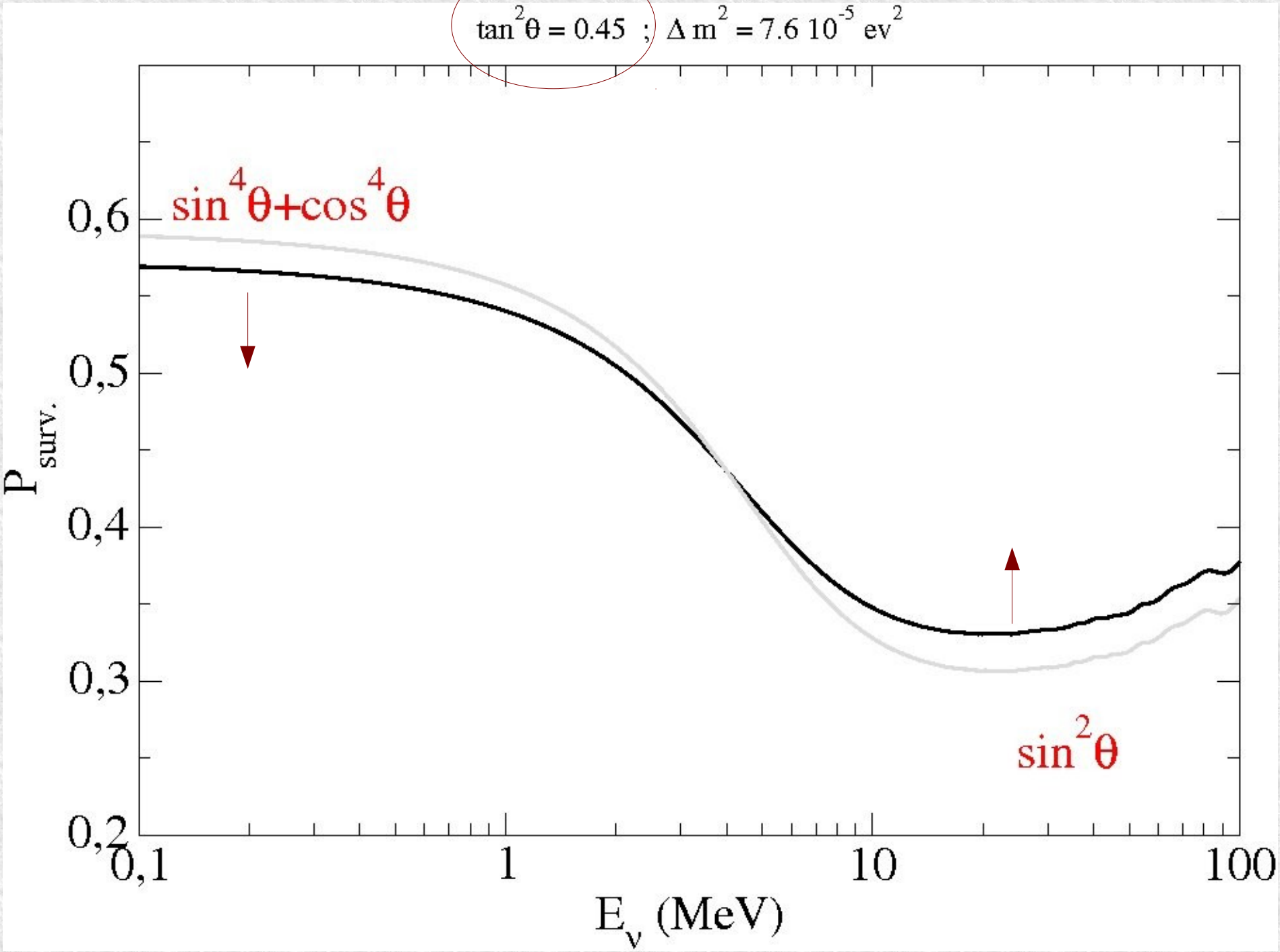
- ***LMA***

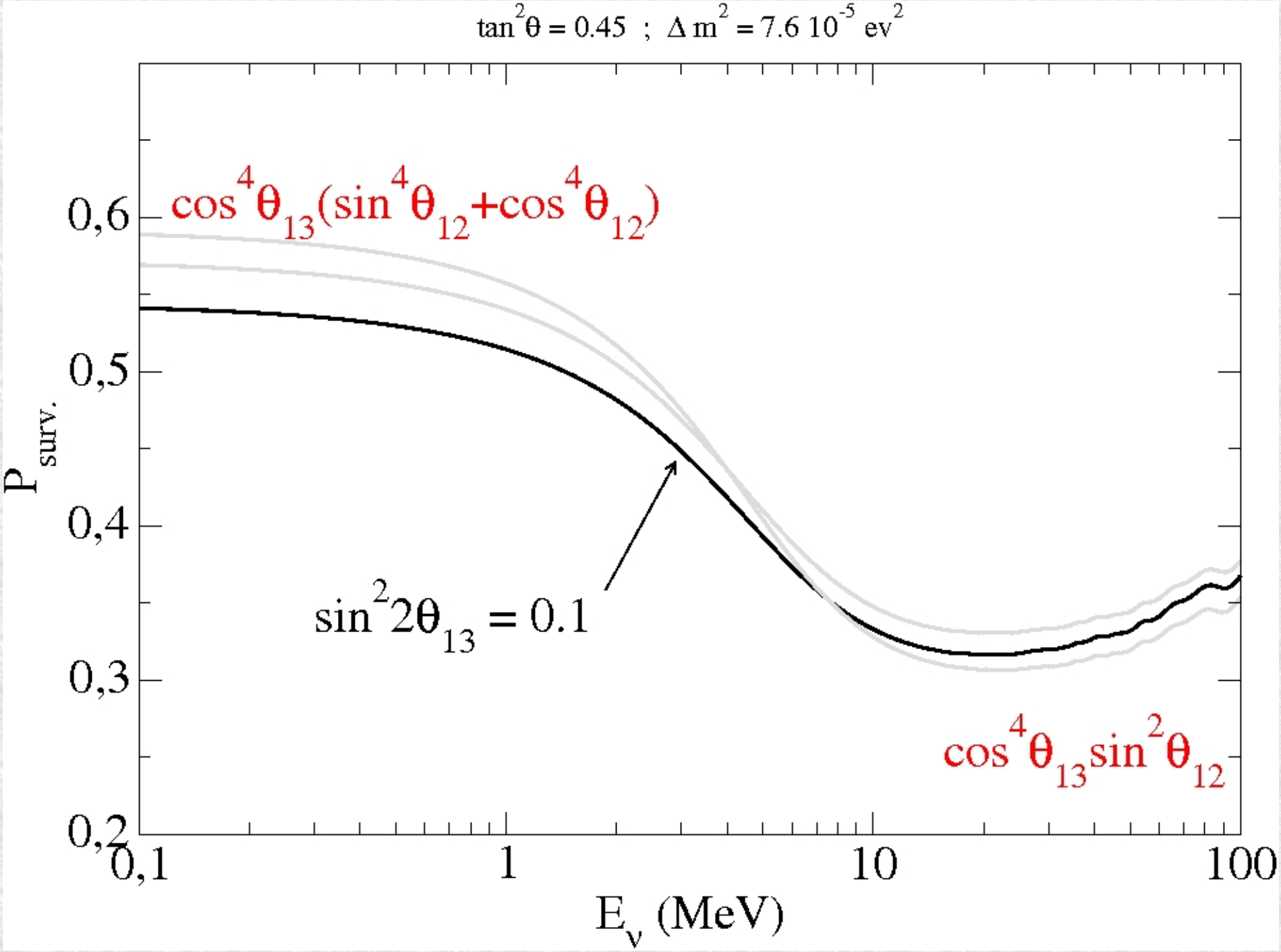
MSW-LMA: robust solution


tan²θ = 0.4 ; Δm² = 7.6 10⁻⁵ ev²
day
sin⁴θ+cos⁴θ
sin²θ
P surv.
0,6
0,5
0,4
0,3
0,2
0,1
1
10
100
E_ν (MeV)


tan²θ = 0.4 ; Δm² = 7.6 10⁻⁵ ev²
day
night
sin⁴θ+cos⁴θ
sin²θ
P surv.
0,6
0,5
0,4
0,3
0,2
0,1
1
10
100
E_ν (MeV)

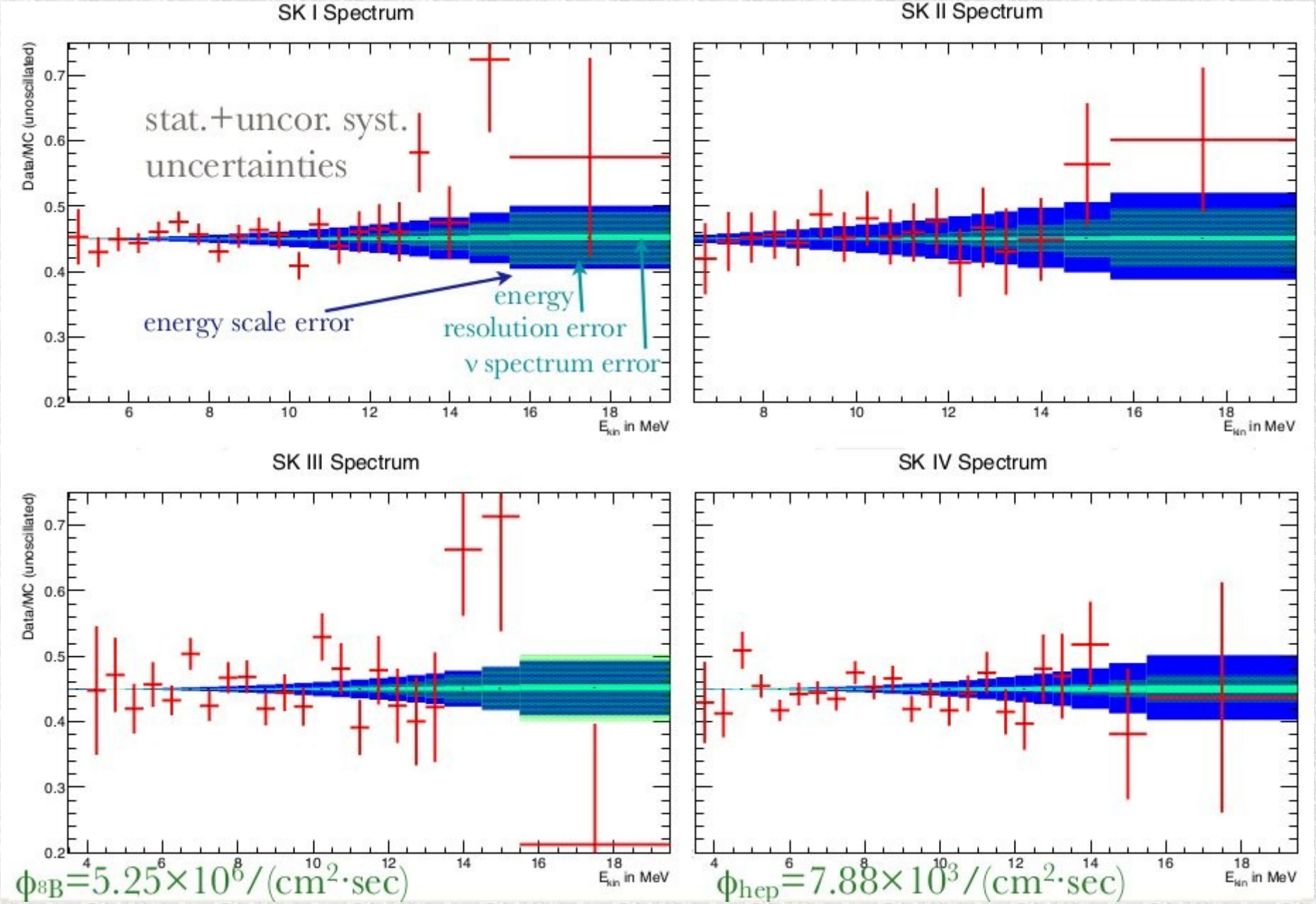

tan²θ = 0.4 ; Δm² = 7.6 10⁻⁵ ev²
day+night
sin⁴θ+cos⁴θ
sin²θ
P surv.
0,6
0,5
0,4
0,3
0,2
0,1
1
10
100
E_ν (MeV)


tan²θ = 0.45 ; Δm² = 7.6 10⁻⁵ ev²
sin⁴θ+cos⁴θ
sin²θ
P surv.
0,6
0,5
0,4
0,3
0,2
0,1
1
10
100
E_ν (MeV)


$\tan^2\theta = 0.45$; $\Delta m^2 = 7.6\ 10^{-5}$ ev^2
$\cos^4\theta_{13}(\sin^4\theta_{12}+\cos^4\theta_{12})$
$\sin^2 2\theta_{13} = 0.1$
$\cos^4\theta_{13}\sin^2\theta_{12}$
$P_{surv.}$
0,6
0,5
0,4
0,3
0,2
0,1
1
10
100
E_ν (MeV)

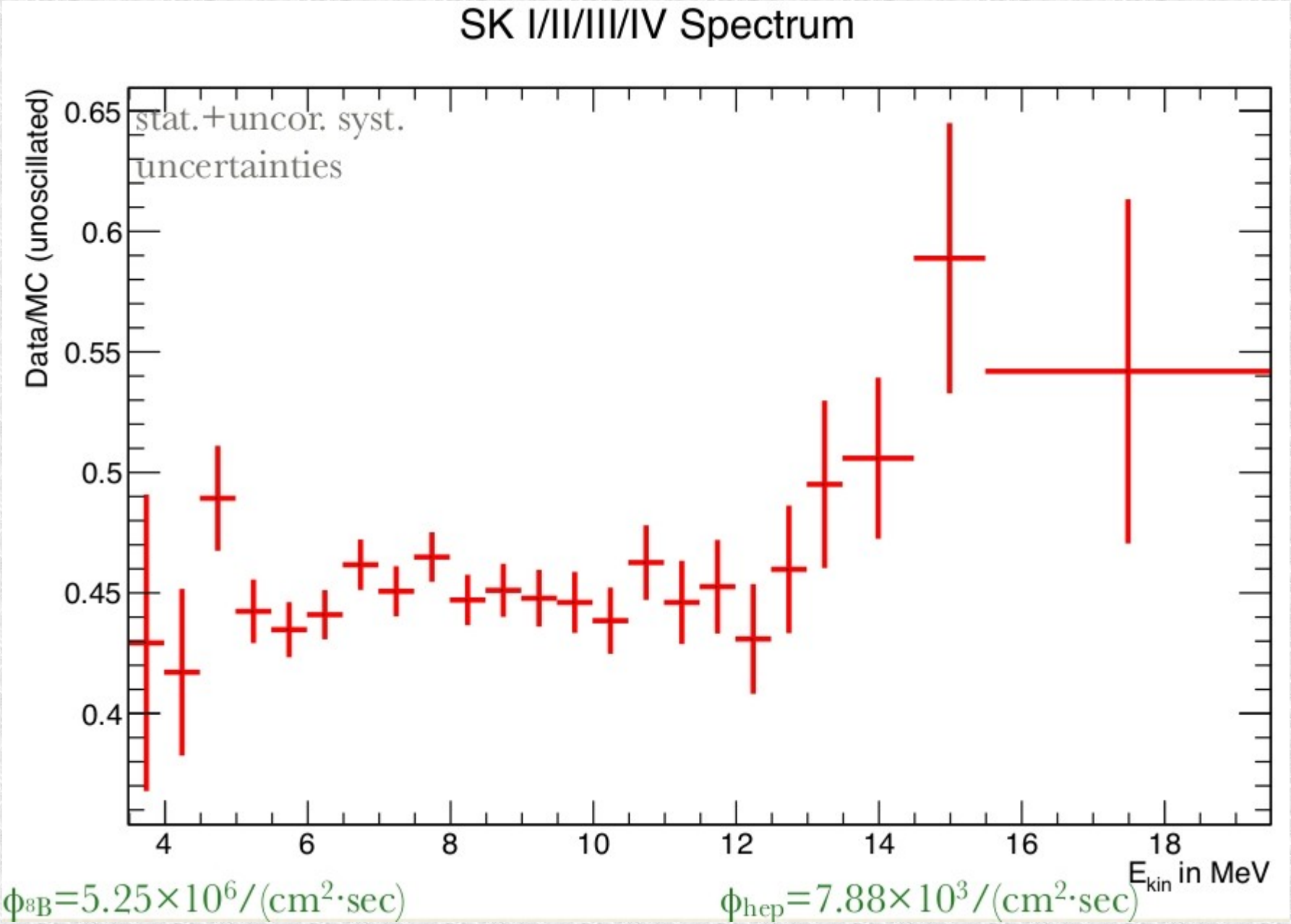
Solar neutrino experiments
- latest data -

Super-Kamiokande IV



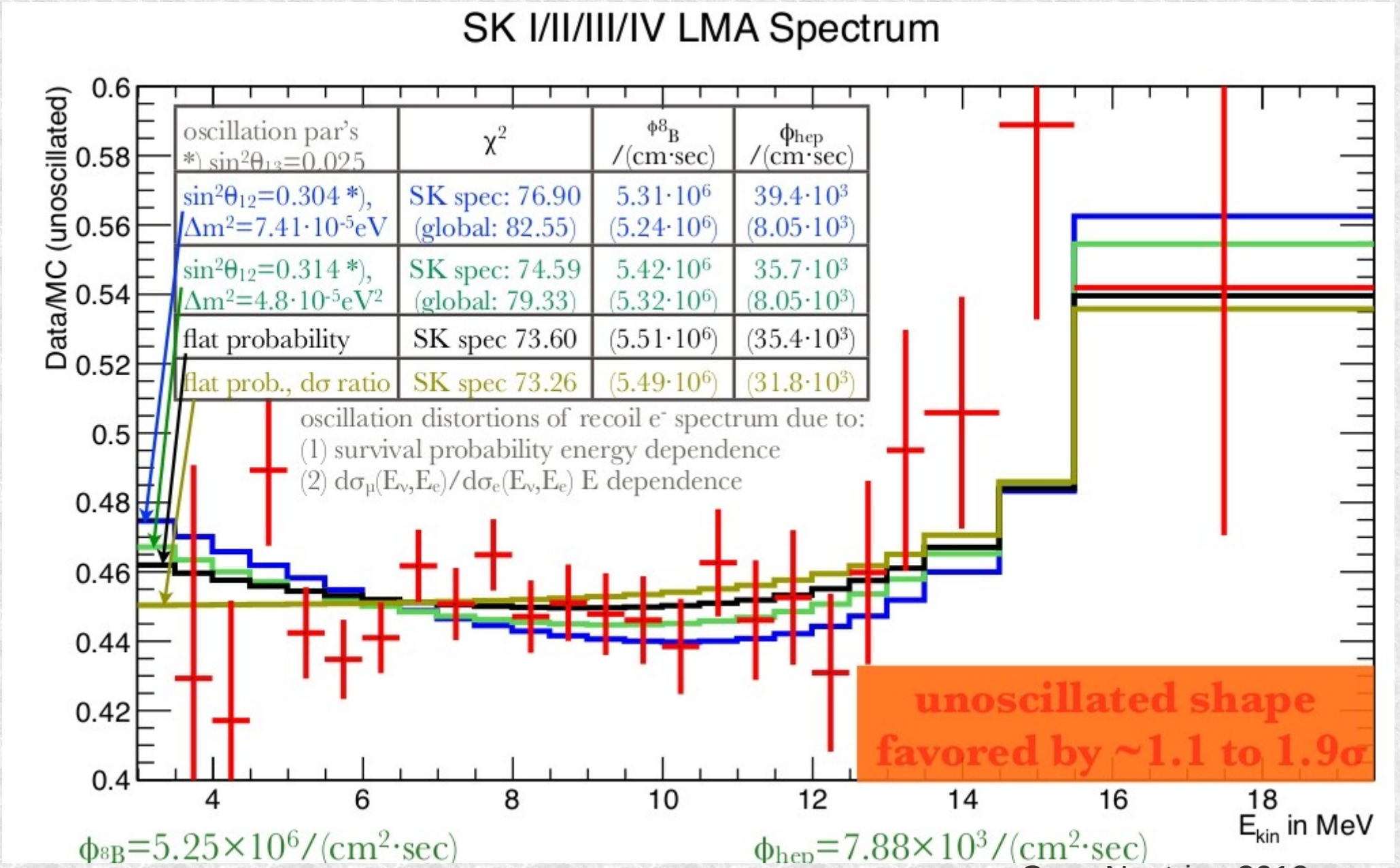
Smy, Neutrino 2012

Super-Kamiokande IV



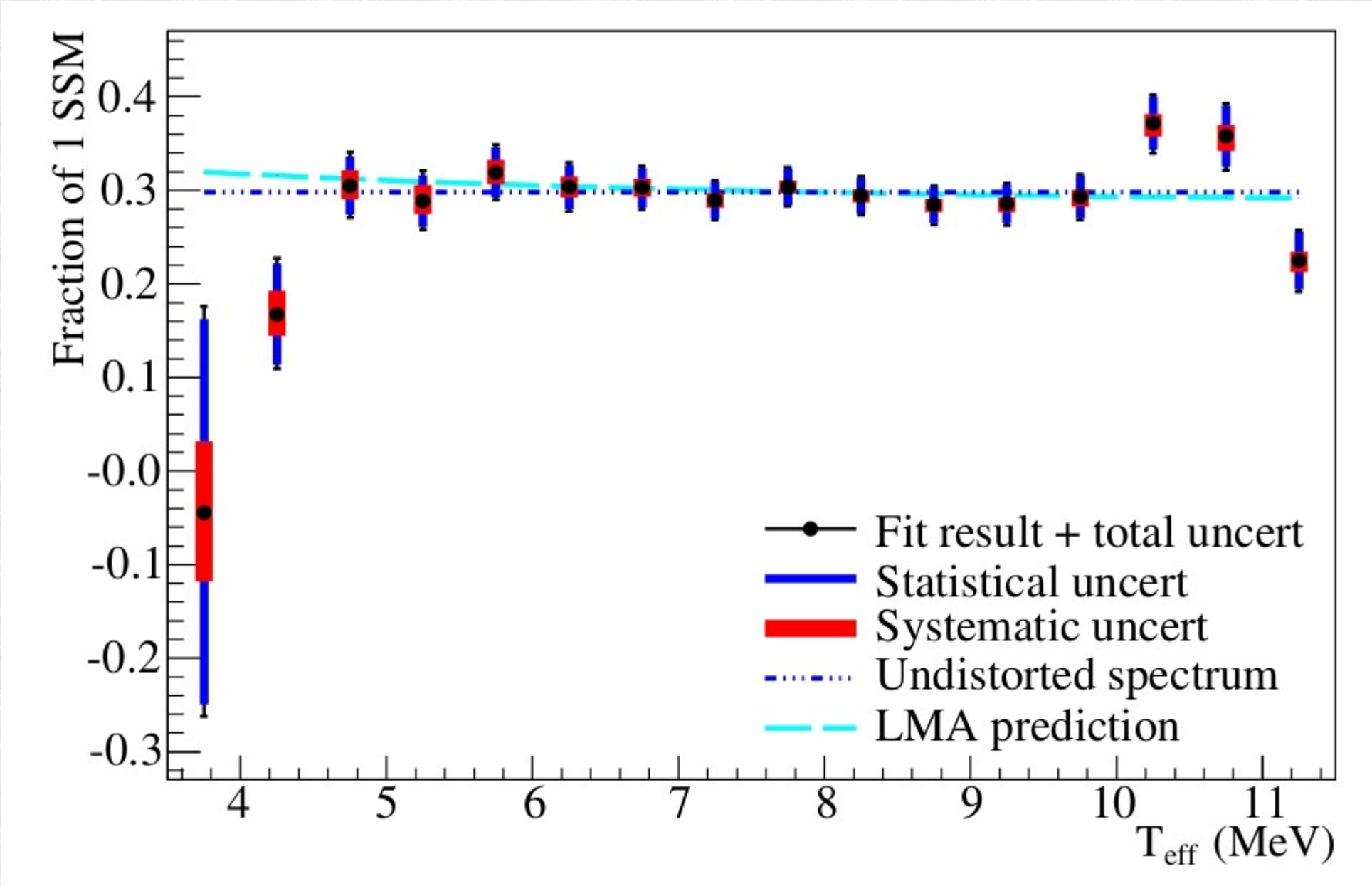
Smy, Neutrino 2012

Super-Kamiokande IV



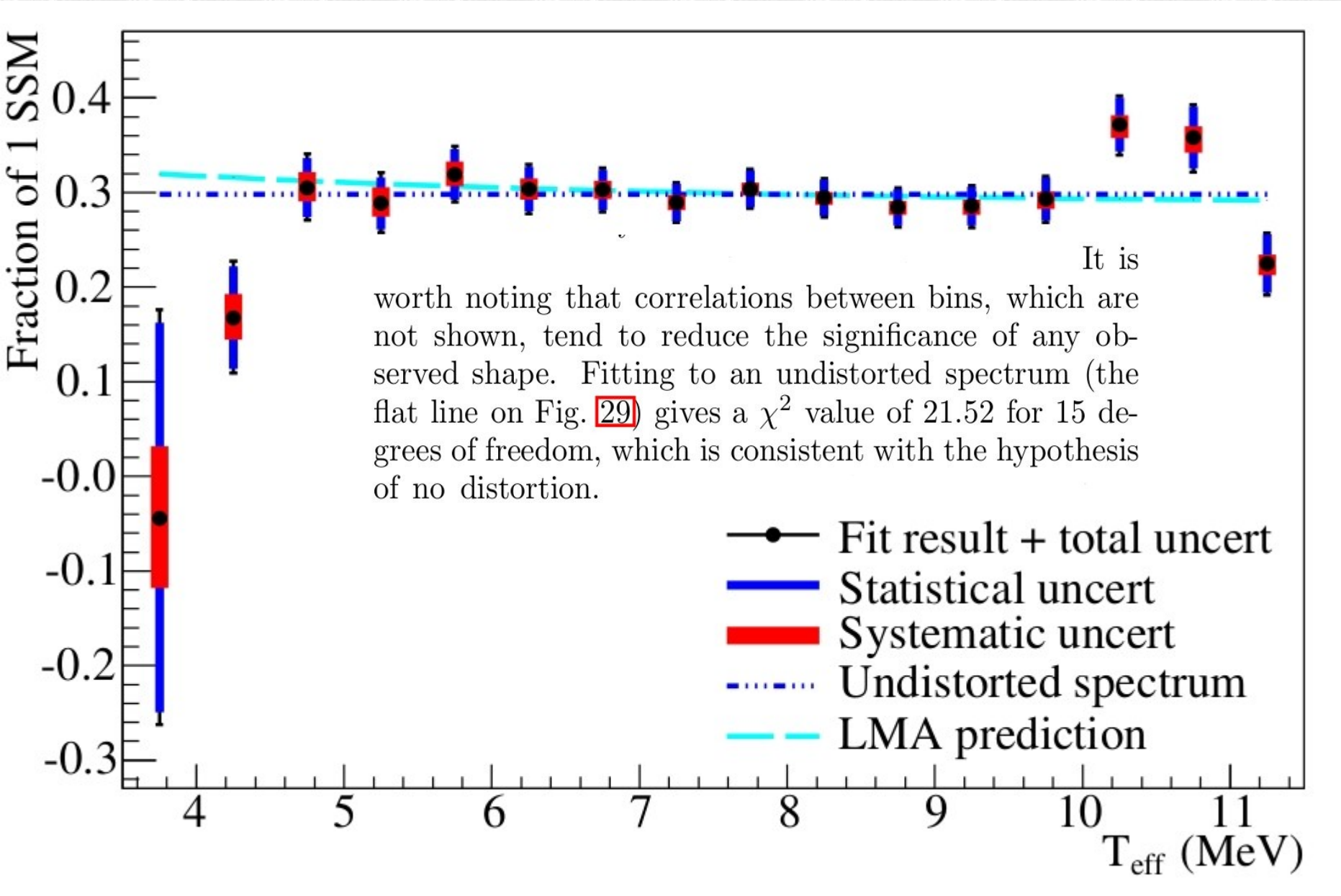
Smy, Neutrino 2012

Sudbury Neutrino Observatory, I & II



SNO Collaboration, Phys.Rev.C81:055504,2010

Sudbury Neutrino Observatory, I & II



It is worth noting that correlations between bins, which are not shown, tend to reduce the significance of any observed shape. Fitting to an undistorted spectrum (the flat line on Fig. 29) gives a χ^2 value of 21.52 for 15 degrees of freedom, which is consistent with the hypothesis of no distortion.

SNO Collaboration, Phys.Rev.C81:055504,2010

Sudbury Neutrino Observatory, I & II

➔ Test of spectral distortion following a SNO prescription through expansion of survival probability:

$$P_{ee}^{Day}(E_\nu) = c_0 + c_1(E_\nu\text{-}10\ \text{MeV}) + c_2(E_\nu\text{-}10\ \text{MeV})^2$$

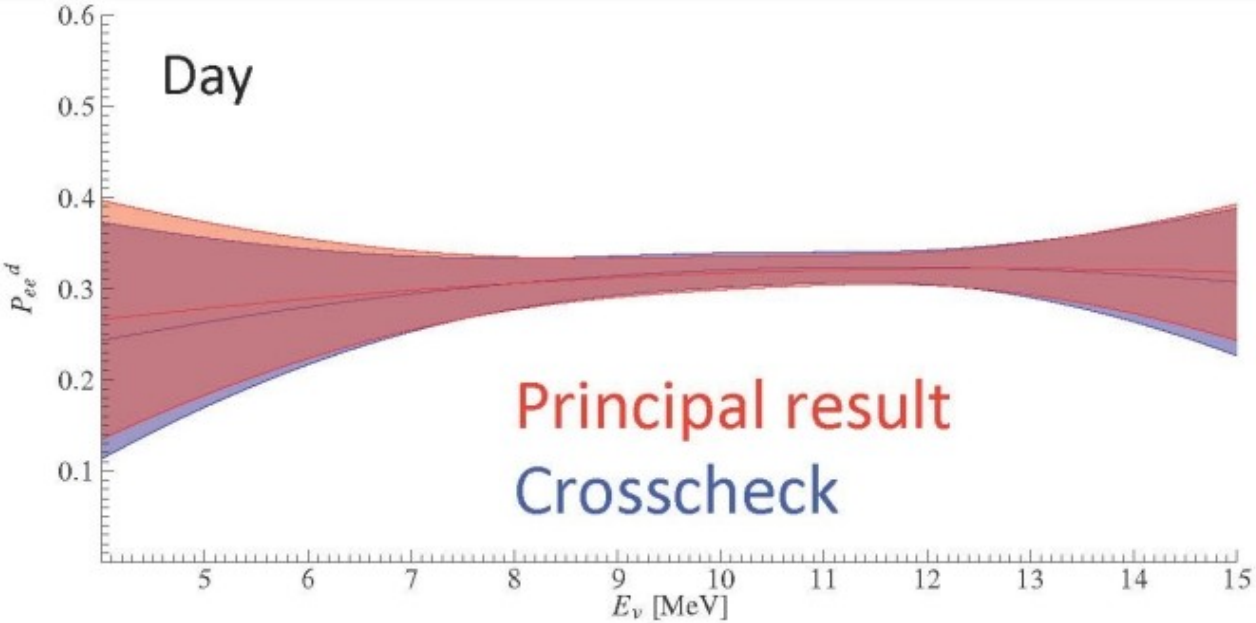
$$P_{ee}^{Asym}(E_\nu) = a_0 + a_1(E_\nu\text{-}10\ \text{MeV})$$

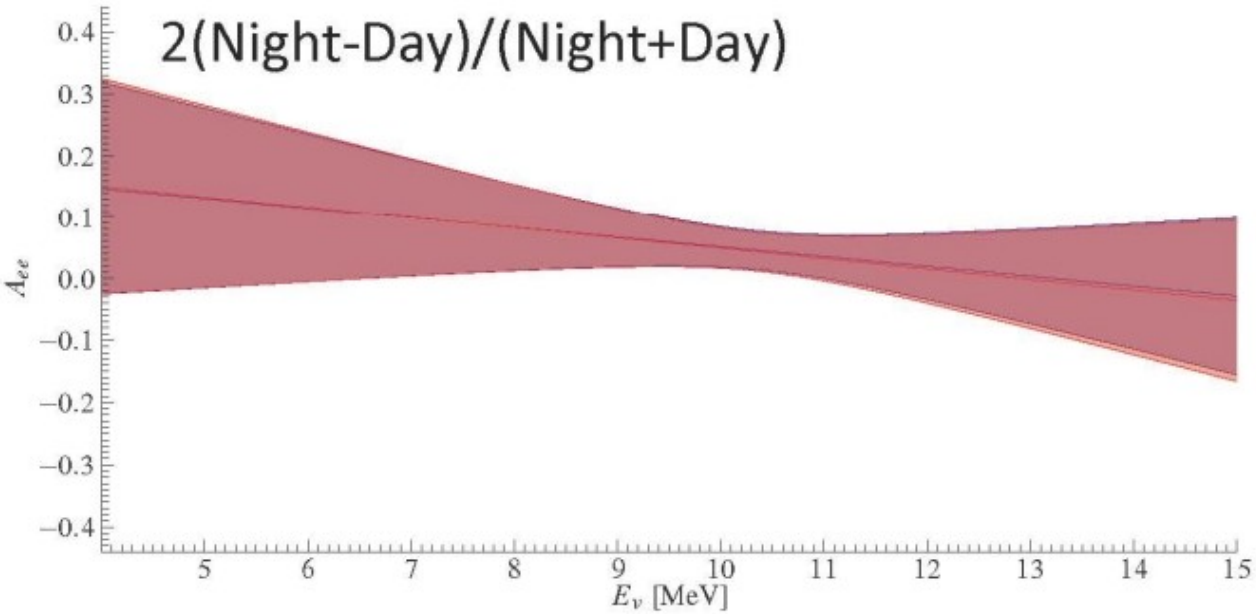
and correlations between coeficients:

	Φ_B	c_0	c_1	c_2	a_0	a_1
Φ_B	1.000	−0.723	0.302	−0.168	0.028	−0.012
c_0	−0.723	1.000	−0.299	−0.366	−0.376	0.129
c_1	0.302	−0.299	1.000	−0.206	0.219	−0.677
c_2	−0.168	−0.366	−0.206	1.000	0.008	−0.035
a_0	0.028	−0.376	0.219	0.008	1.000	−0.297
a_1	−0.012	0.129	−0.677	−0.035	−0.297	1.000

SNO Collaboration, ArXiV:1109.0763

Sudbury Neutrino Observatory, I & II





$$c_0 = 0.317 \pm 0.016 \pm 0.009$$

$$c_1 = 0.0039^{+0.0065}_{-0.0067} \pm 0.0045$$

$$c_2 = -0.0010 \pm 0.0029^{+0.0014}_{-0.0016}$$

$$a_0 = 0.046 \pm 0.031^{+0.014}_{-0.013}$$

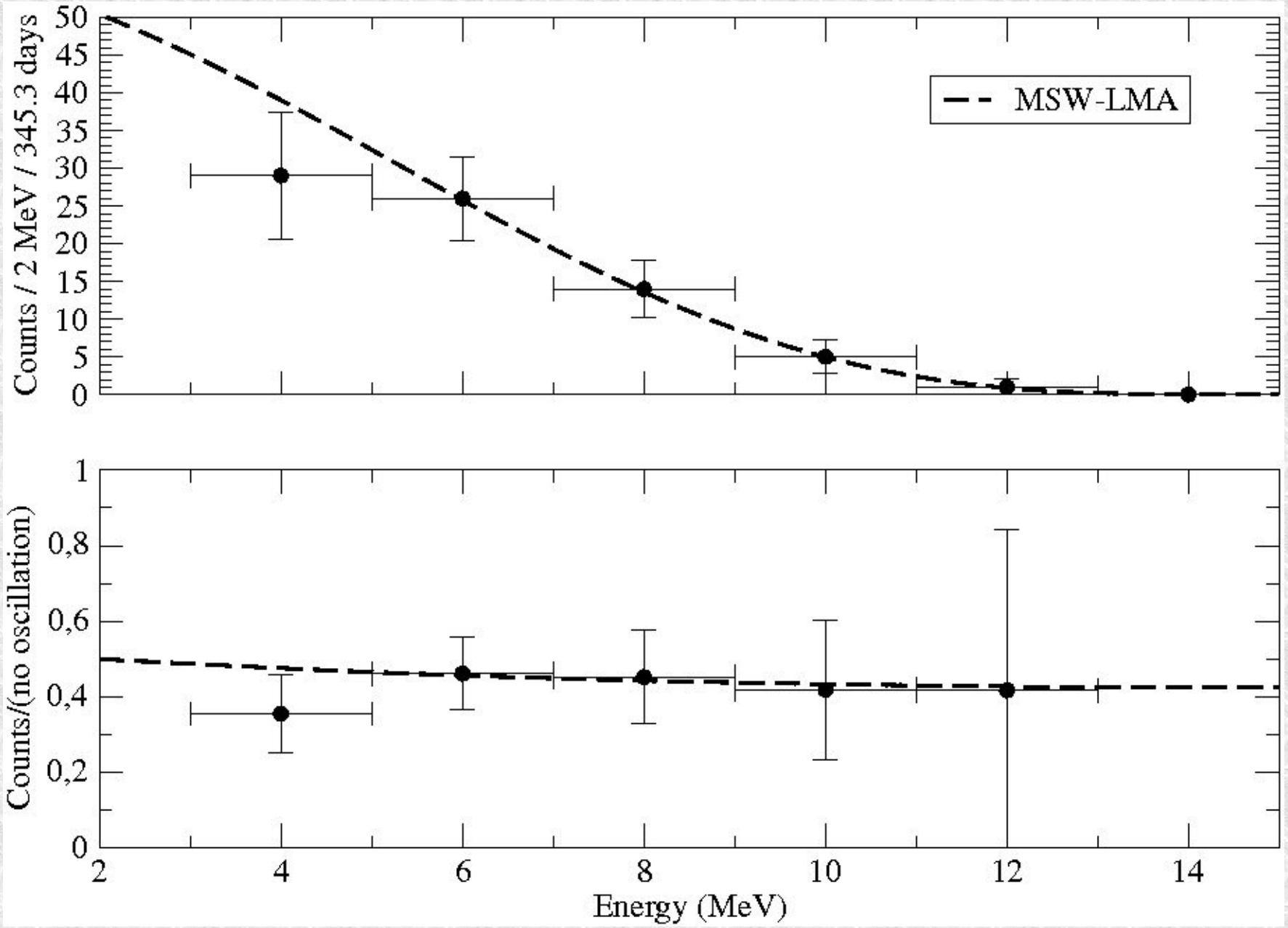
$$a_1 = -0.016 \pm 0.025^{+0.010}_{-0.011}$$

Approximately 20% improvement over previous analysis.

^{8}B Flux: 5.25 +- 3.7% x 10^{-6} $cm^{2}s^{-1}$

McDonald talk, Neutrino 2012

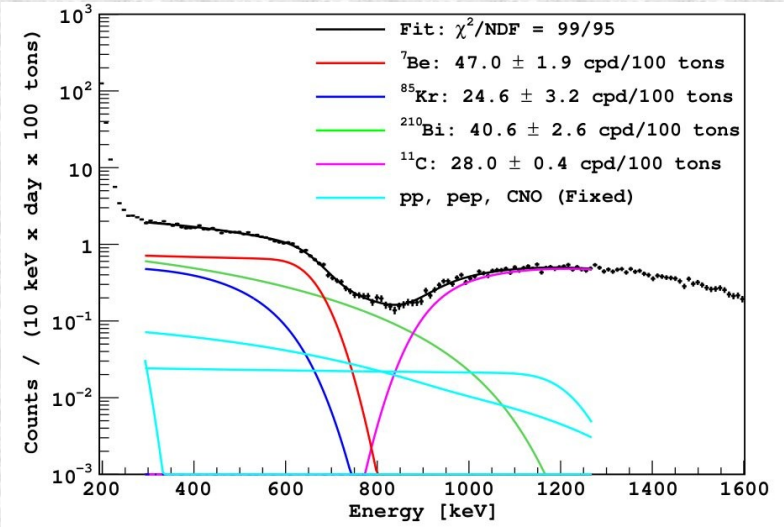
Borexino, measurement of ^{8}B flux



Borexino

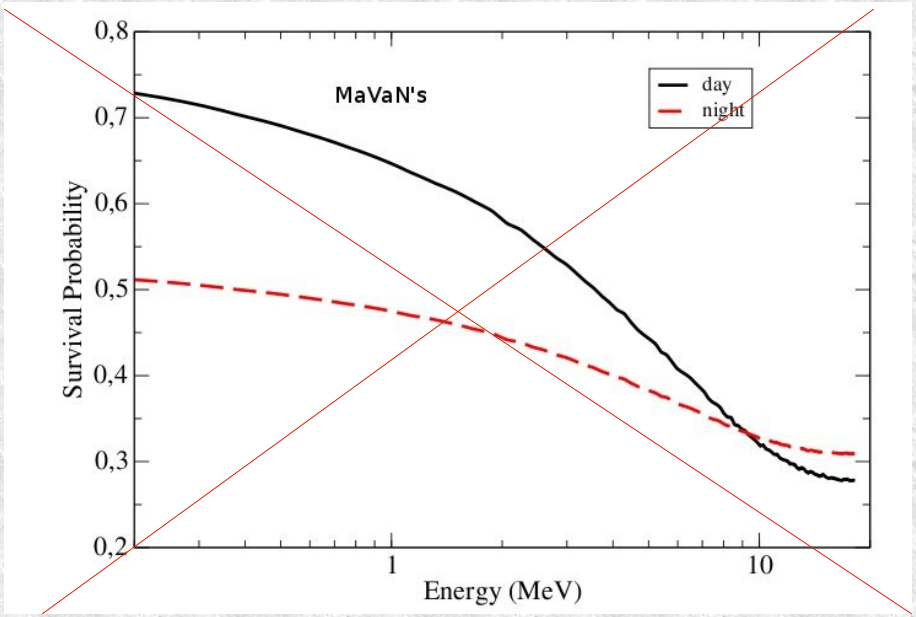
PLUS:

- Measurement of 7Be neutrino flux, and absence of day-night variation (exluding LOW solution and a particular exotic scenario)



$$\Phi(^{7}\mathrm{Be}) = (4.87 \pm 0.24) \times 10^{9}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$$

Borexino Coll. Phys.Rev.Lett.107(20011)141302

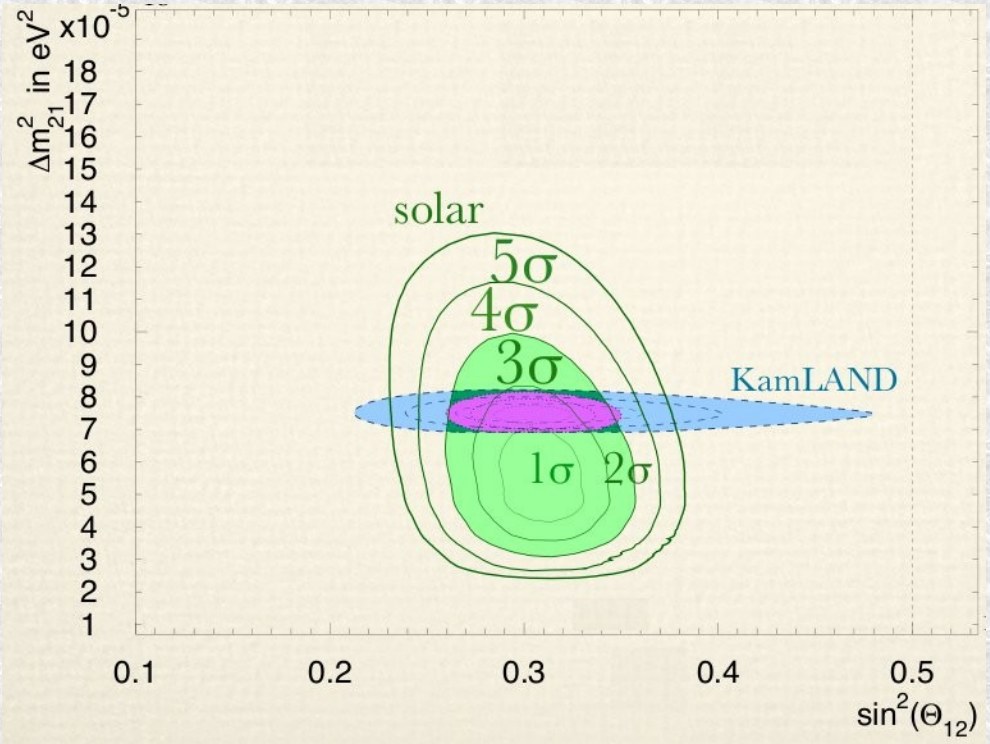


PCH, JCAP07(2009)024

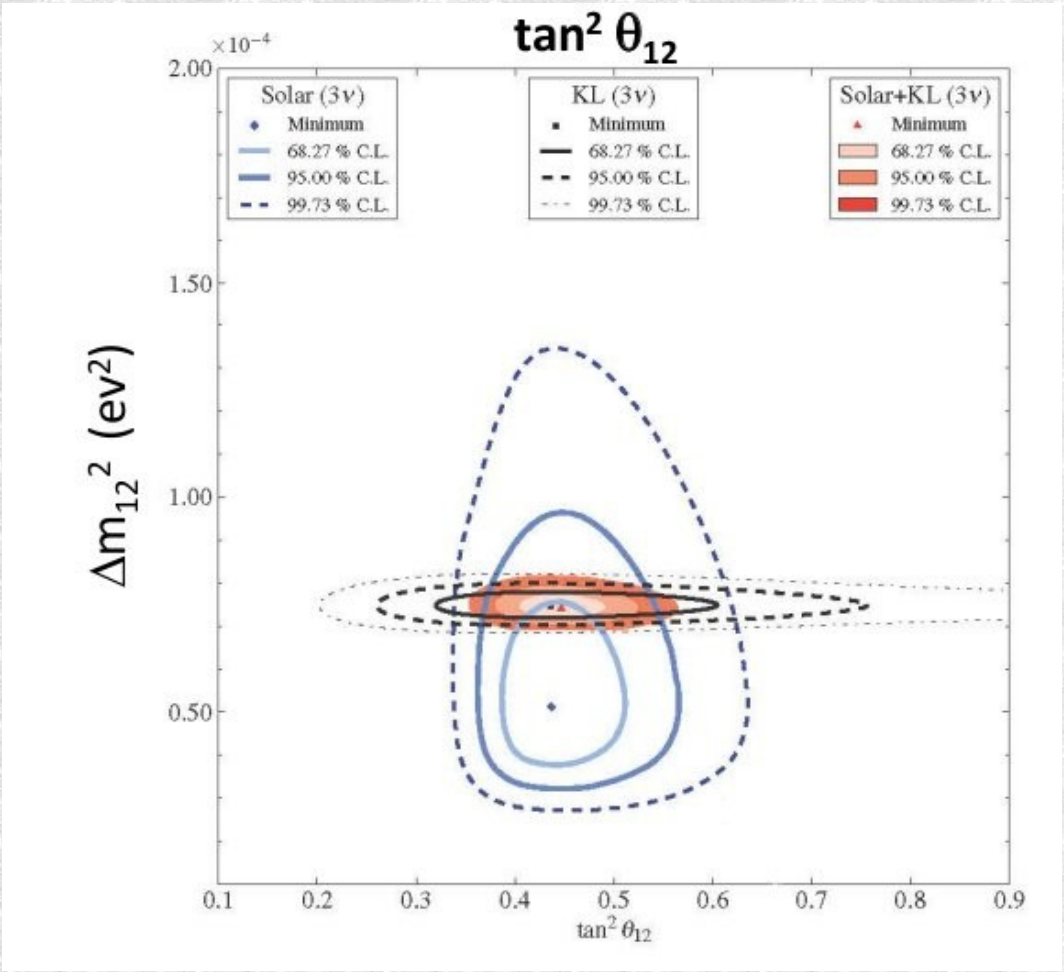
- Measurement of pep neutrinos.

- $\Phi_{pep} = 1.6 \pm 0.3\ 10^{8}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$

Putting everything together



Smy talk, Neutrino 2012



McDonald talk, Neutrino 2012

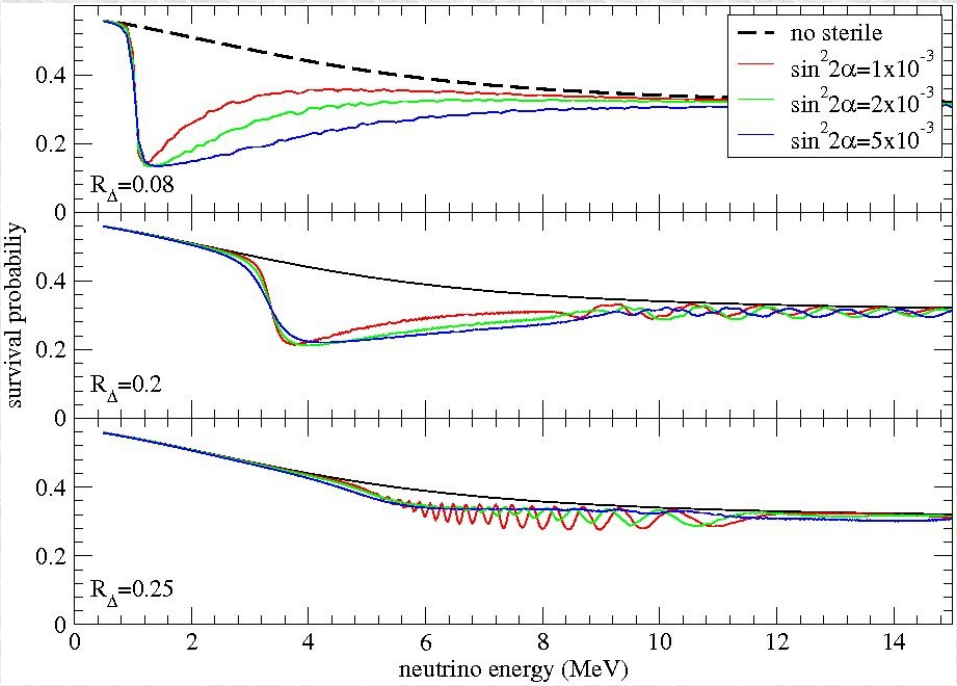
New physics related to “tension” between solar and KamLAND prefered mass scale

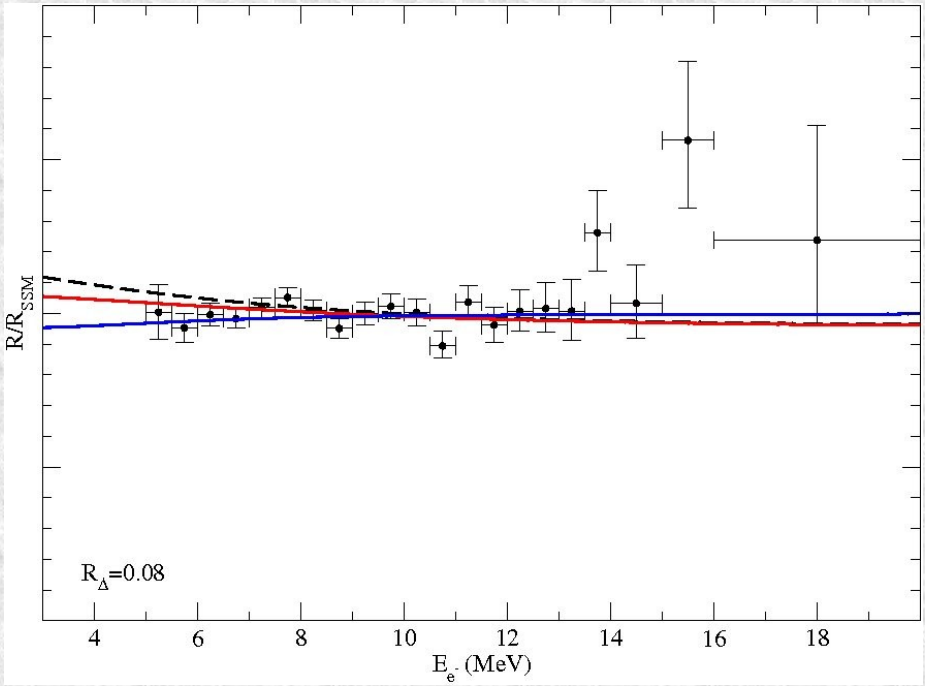
New physics related to “tension” between solar and KamLAND prefered mass scale

You're are not suppose to name it.
Once you name it, you start
getting attached to it!

New physics related to “tension” between solar and KamLAND prefered mass scale

- 4^{th} (sterile) neutrino with low mass.





PCH and A. Yu. Smirnov, Phys.Rev.D83 (2001)113011

- MaVaN's, NSNI, magnetic moment...

Smirnov and Brazil

Smirnov and Brazil

Smirnov and Brazil

- Quite a strong group of people talking about neutrino physics.

- From this group, Alexei Smirnov collaborated with Orlando Peres (Unicamp), myself (Unicamp) and Renata Zukanovich Funchal (USP).

- To put some numbers, in 15 years we can count from direct collaboration with Alexei Smirnov, 14 papers on neutrino phenomenology, involving solar, atmospheric, and reactor neutrinos.

- And hopefully, the collaboration continues!

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Thank you, Alexei!