Solar Neutrinos

on the beginning of 2017

Francesco Vissani

LNGS & GSSI

Workshop *Neutrinos: the quest for a new physics scale,* CERN, March 2017

The European Physical Journal A
All Volumes & Issues

Underground nuclear astrophysics and solar neutrinos: Impact on astrophysics, solar and neutrino physics

ISSN: 1434-6001 (Print) 1434-601X (Online)

In this topical collection (17 articles)

Editorial
Topical issue on underground nuclear astrophysics and solar neutrinos: Impact on astrophysics, solar and neutrino physics
Gianpaolo Bellini, Carlo Broggini…
» Download PDF (138KB) Article:88

Review
Solar neutrinos and neutrino physics
Michele Maltoni, Alexei Yu. Smirnov
» Get Access le:8

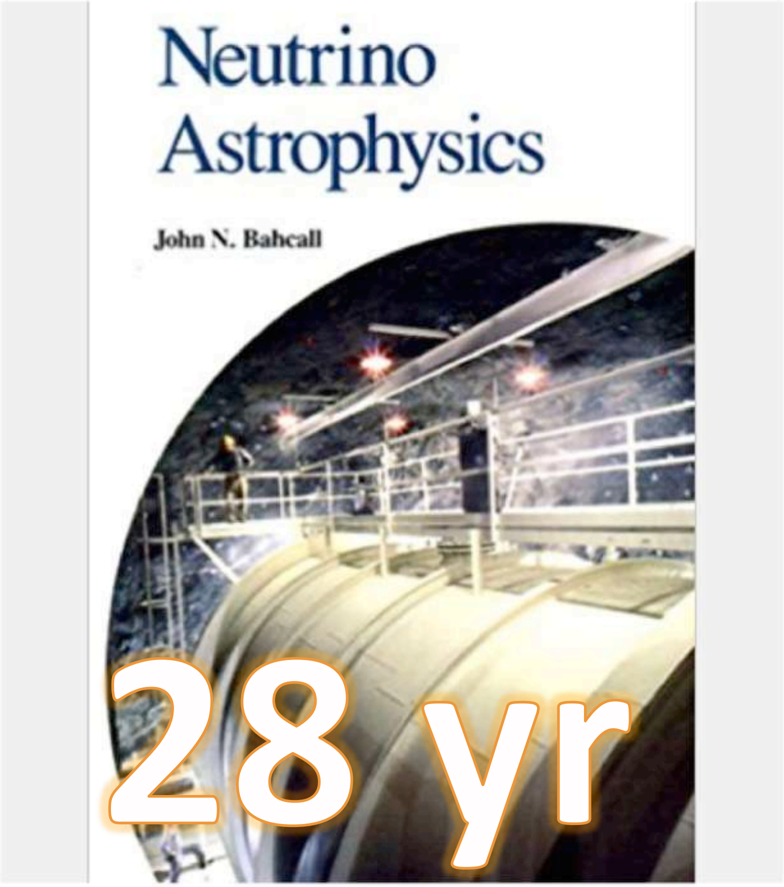
Review
α / β discrimination in Borexino
C. Galbiati, M. Misiaszek, N. Rossi
» Get Access Article:86

Review
Data ysis in s eutri iquid-scintillator detectors
G. T
Get Acc Article:85

eview
Da analy s for solar neutrinos observed by water Cherenkov d tors*
asuke Koshio
» Get Access Article:84

Review
Experimental and analysis methods in radiochemical experiments
C. M. Cattadori, L. Pandola
» Get Access Article:83

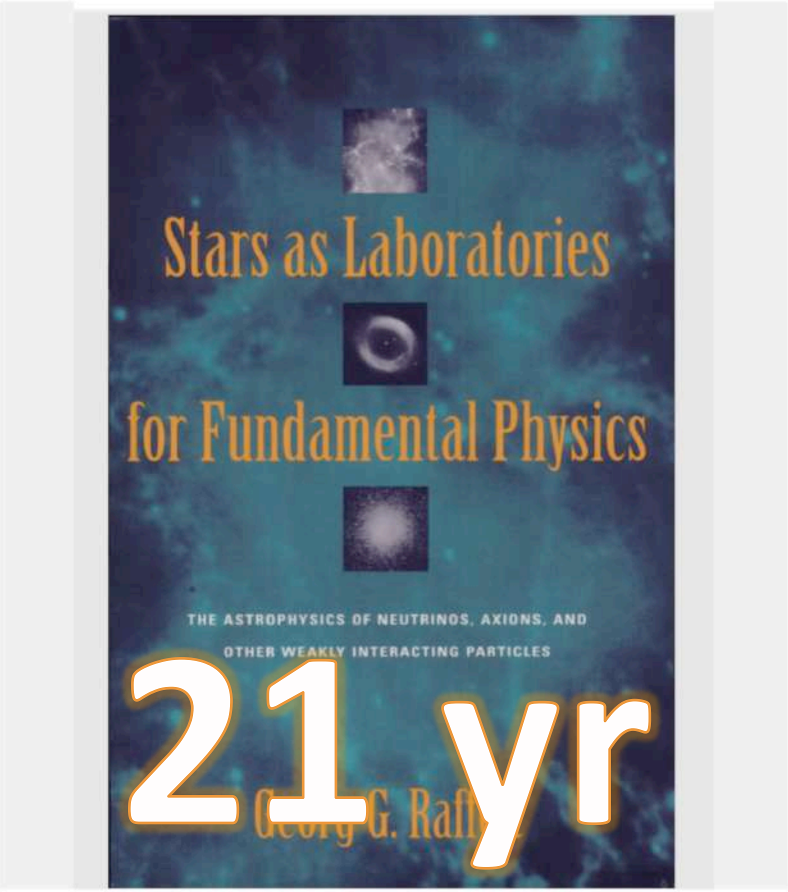
2016 APRIL 19



Neutrino Astrophysics

John N. Bahcall

28 yr



Stars as Laboratories for Fundamental Physics

THE ASTROPHYSICS OF NEUTRINOS, AXIONS, AND OTHER WEAKLY INTERACTING PARTICLES

Georg G. Raff

21 yr

SOLAR NEUTRINOS

We are especially interested in theoretical particle physics, but, we need to be aware of the links with

Nuclear physics

Astrophysics

Astronomy

Experimental physics

SOLAR NEUTRINOS

We are especially interested in theoretical particle physics, but, we need to be aware of the links with

Nuclear physics

Astrophysics

Astronomy

Experimental physics

S.S.M.

radiopurity

metallicity

E.S.

Borexino

helioseismology

THE ASTROPHYSICAL JOURNAL

A New Generation of Standard Solar Models

Núria Vinyoles[1], Aldo M. Serenelli[1], Francesco L. Villante[2,3], Sarbani Basu[4], Johannes Bergström[5], M. C. Gonzalez-Garcia[5,6,7], Michele Maltoni[8], Carlos Peña-Garay[9,10], and Ningqiang Song[7]

Published 2017 January 31 • © 2017. The American Astronomical Society. All rights reserved.
The Astrophysical Journal, Volume 835, Number 2

Abstract

We compute a new generation of standard solar models (SSMs) that includes recent updates on some important nuclear reaction rates and a more consistent treatment of the equation of state. Models also include a novel and flexible treatment of opacity uncertainties based on opacity kernels, required in light of recent theoretical and experimental works on radiative opacity. Two large sets of SSMs, each based on a different canonical set of solar abundances with high and low metallicity (Z), are computed to determine model uncertainties and correlations among different observables. We present detailed comparisons of high- and low-Z models against different ensembles of solar observables, including solar neutrinos, surface helium abundance, depth of the convective envelope, and sound speed profile. A global comparison, including all observables, yields a p-value of 2.7σ for the high-Z model and 4.7σ for the low-Z one. When the sound speed differences in the narrow region of $0.65 < r/R_\odot < 0.70$ are excluded from the analysis, results are 0.9σ and 3.0σ for high- and low-Z models respectively. These results show that high-Z models agree well with solar data but have a systematic problem right below the bottom of the convective envelope linked to steepness of molecular weight and temperature gradients, and that low-Z models lead to a much more general disagreement with solar data. We also show that, while simple parametrizations of opacity uncertainties can strongly alleviate the solar abundance problem, they are insufficient to substantially improve the agreement of SSMs with helioseismic data beyond that obtained for high-Z models due to the intrinsic correlations of theoretical predictions.

THE ASTROPHYSICAL JOURNAL

A New Generation of Standard Solar Models

Núria Vinyoles[1], Aldo M. Serenelli[1], Francesco L. Villante[2,3], Sarbani Basu[4], Johannes Bergström[5], M. C. Gonzalez-Garcia[5,6,7], Michele Maltoni[8], Carlos Peña-Garay[9,10], and Ningqiang Song[7]

Published 2017 January 31 • © 2017. The American Astronomical Society. All rights reserved.
The Astrophysical Journal, Volume 835, Number 2

171 Total downloads

Abstract

We compute a new generation of standard solar models (SSMs) that includes recent updates on some important nuclear reaction rates and a more consistent treatment of the equation of state. Models also include a novel and flexible treatment of opacity uncertainties based on opacity kernels, required in light of recent theoretical and experimental works on radiative opacity. Two large sets of SSMs, each based on a different canonical set of solar abundances with high and low metallicity (Z), are computed to determine model uncertainties and correlations among different observables. We present detailed comparisons of high- and low-Z models against different ensembles of solar observables, including solar neutrinos, surface helium abundance, depth of the convective envelope, and sound speed profile. A global comparison, including all observables, yields a p-value of 2.7σ for the high-Z model and 4.7σ for the low-Z one. When the sound speed differences in the narrow region of $0.65 < r/R_\odot < 0.70$ are excluded from the analysis, results are 0.9σ and 3.0σ for high- and low-Z models respectively. These results show that high-Z models agree well with solar data but have a systematic problem right below the bottom of the convective envelope linked to steepness of molecular weight and temperature gradients, and that low-Z models lead to a much more general disagreement with solar data. We also show that, while simple parametrizations of opacity uncertainties can strongly alleviate the solar abundance problem, they are insufficient to substantially improve the agreement of SSMs with helioseismic data beyond that obtained for high-Z models due to the intrinsic correlations of theoretical predictions.

S.S.M.

metallicity

helioseismology

THE ASTROPHYSICAL JOURNAL

A New Generation of dard Solar Models

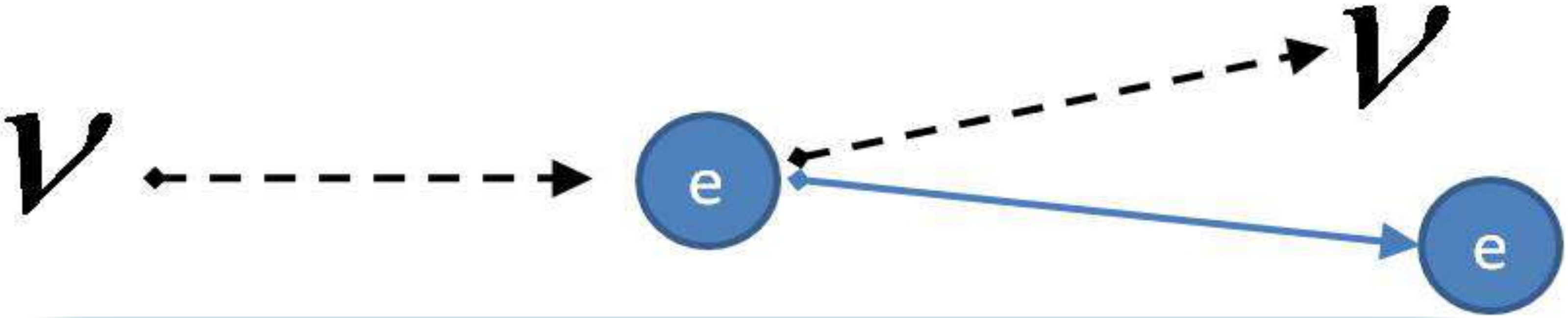
Núria Vinyoles[1], Aldo M. Se ncesco L. Villante[2,3], Sarbani Basu[4],
Johannes Bergström[5], M. C. Go arcia[5,6,7], Michele Maltoni[8], Carlos Peña-Garay[9,10],
and Ningqiang Song[7]

Published 2017 January 31 • © 2017. The American Astronomical Society. All rights reserved.

The Astrophysical Journal, Volume 835, Number 2

Abstract

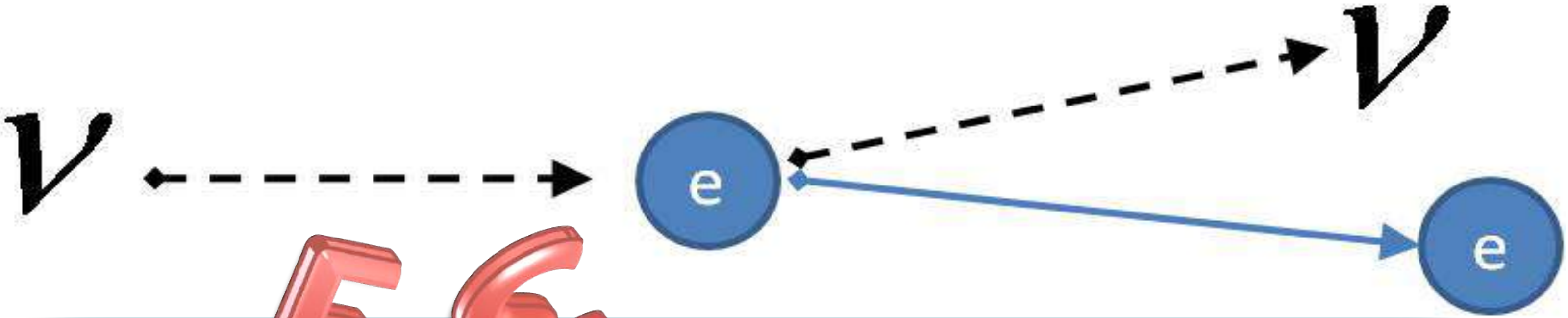
We compute a new generation of standard solar models (SSMs) that includes recent updates on some important nuclear reaction rates and a more consistent treatment of the equation of state. Models also include a novel and flexible treatment of opacity uncertainties based on opacity kernels, required in light of recent theoretical and experimental works on radiative opacity. Two large sets of SSMs, each based on a different canonical set of solar abundances with high and low metallicity (Z), are computed to determine model uncertainties and correlations among different observables. We present detailed comparisons of high- and low-Z models against different ensembles of solar observables, including solar neutrinos, surface helium abundance, depth of the convective envelope, and sound speed profile. A global comparison, including all observables, yields a p-value of 2.7σ for the high-Z model and 4.7σ for the low-Z one. When the sound speed differences in the narrow region of $0.65 < r/R_\odot < 0.70$ are excluded from the analysis, results are 0.9σ and 3.0σ for high- and low-Z models respectively. These results show that high-Z models agree well with solar data but have a systematic problem right below the bottom of the convective envelope linked to steepness of molecular weight and temperature gradients, and that low-Z models lead to a much more general disagreement with solar data. We also show that, while simple parametrizations of opacity uncertainties can strongly alleviate the solar abundance problem, they are insufficient to substantially improve the agreement of SSMs with helioseismic data beyond that obtained for high-Z models due to the intrinsic correlations of theoretical predictions.



This cross section (ES) is theoretically clean &
allows us to get info on solar neutrino spectrum

In scintillators detectors, **e$^-$** above 150 keV
are visible with few % energy
resolution. But, direction cannot be seen

Background cannot be discriminated:
Ultrahigh radio-purity is required



E.S.

This cross section (ES) is theoretically clean & allows us to get info on solar neutrino spectrum

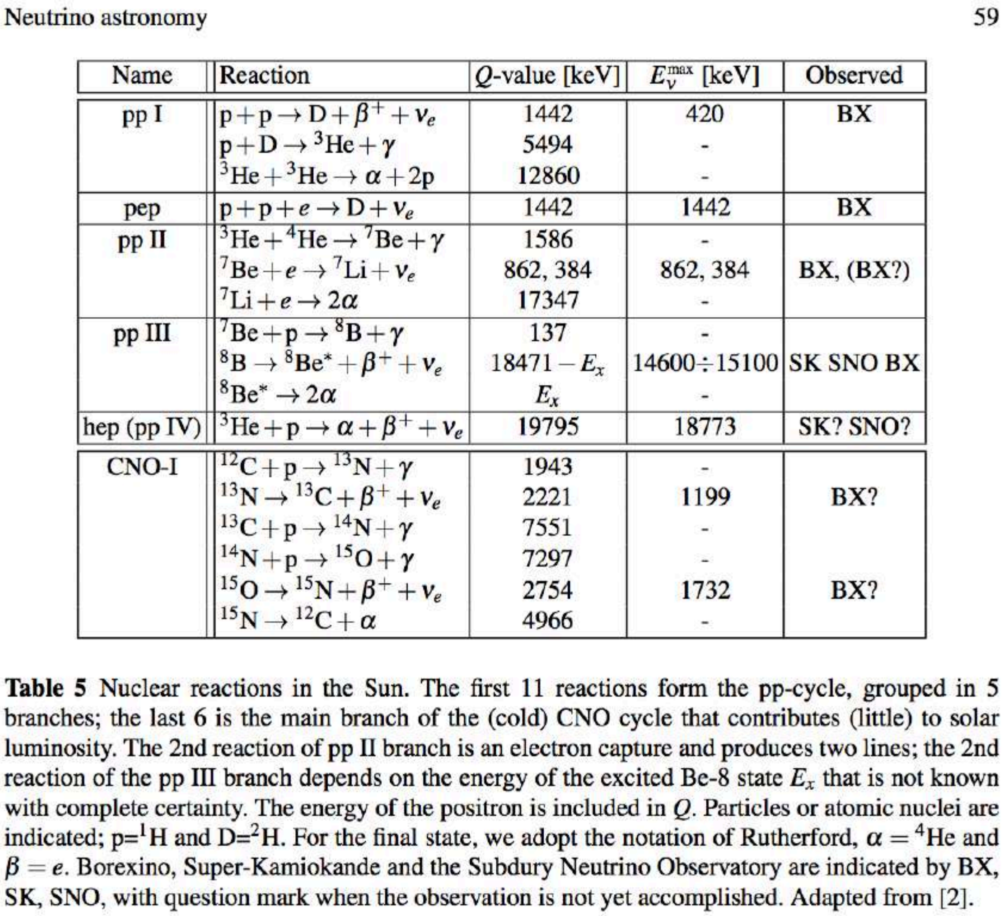
In scintillators detectors, **e$^-$** above 150 keV are visible with few % energy resolution. But, direction cannot be re[illegible]

Background cannot be discriminated: Ultrahigh radio-purity is required

Borexino

radiopurity

Components of the Flux and their Measurements

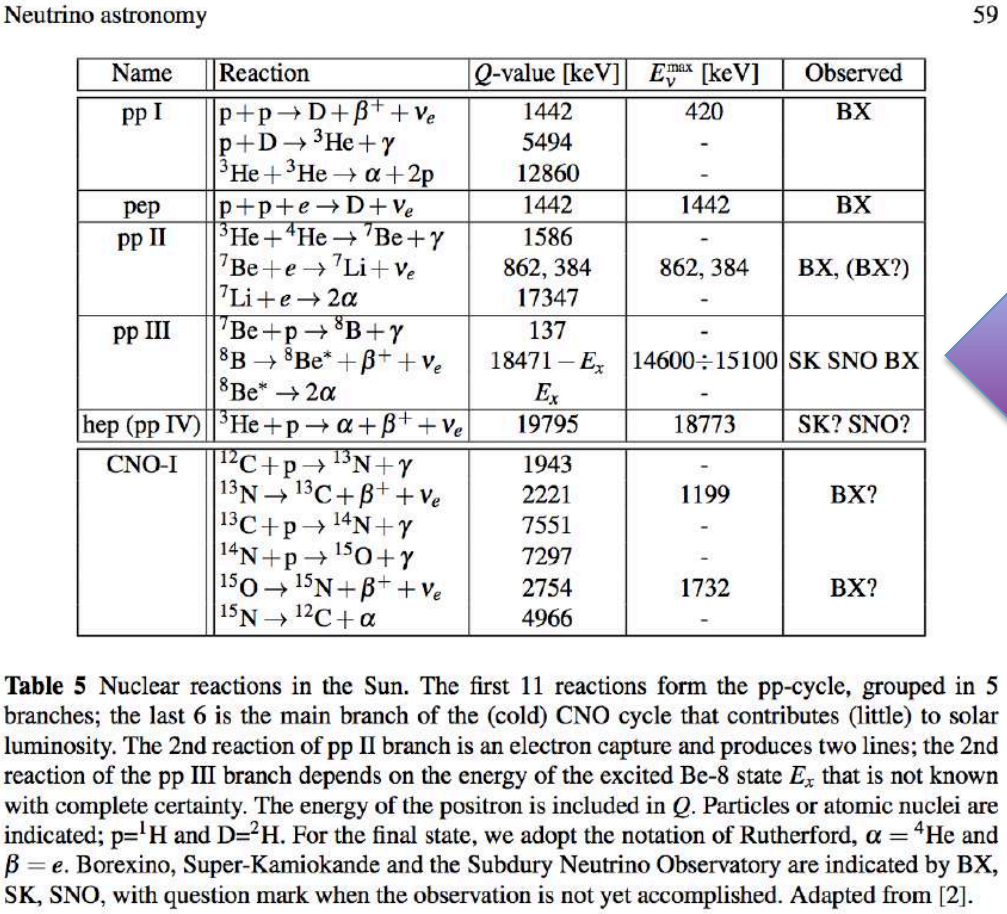


Neutrino astronomy 59

Name	Reaction	Q-value [keV]	$E_\nu^{\max}$ [keV]	Observed
pp I	$\mathrm{p}+\mathrm{p}\to\mathrm{D}+\beta^++\nu_e$	1442	420	BX
	$\mathrm{p}+\mathrm{D}\to{}^3\mathrm{He}+\gamma$	5494	-	
	${}^3\mathrm{He}+{}^3\mathrm{He}\to\alpha+2\mathrm{p}$	12860	-	
pep	$\mathrm{p}+\mathrm{p}+e\to\mathrm{D}+\nu_e$	1442	1442	BX
pp II	${}^3\mathrm{He}+{}^4\mathrm{He}\to{}^7\mathrm{Be}+\gamma$	1586	-	
	${}^7\mathrm{Be}+e\to{}^7\mathrm{Li}+\nu_e$	862, 384	862, 384	BX, (BX?)
	${}^7\mathrm{Li}+e\to2\alpha$	17347	-	
pp III	${}^7\mathrm{Be}+\mathrm{p}\to{}^8\mathrm{B}+\gamma$	137	-	
	${}^8\mathrm{B}\to{}^8\mathrm{Be}^*+\beta^++\nu_e$	$18471-E_x$	14600÷15100	SK SNO BX
	${}^8\mathrm{Be}^*\to2\alpha$	E_x	-	
hep (pp IV)	${}^3\mathrm{He}+\mathrm{p}\to\alpha+\beta^++\nu_e$	19795	18773	SK? SNO?
CNO-I	${}^{12}\mathrm{C}+\mathrm{p}\to{}^{13}\mathrm{N}+\gamma$	1943	-	
	${}^{13}\mathrm{N}\to{}^{13}\mathrm{C}+\beta^++\nu_e$	2221	1199	BX?
	${}^{13}\mathrm{C}+\mathrm{p}\to{}^{14}\mathrm{N}+\gamma$	7551	-	
	${}^{14}\mathrm{N}+\mathrm{p}\to{}^{15}\mathrm{O}+\gamma$	7297	-	
	${}^{15}\mathrm{O}\to{}^{15}\mathrm{N}+\beta^++\nu_e$	2754	1732	BX?
	${}^{15}\mathrm{N}\to{}^{12}\mathrm{C}+\alpha$	4966	-	

Table 5 Nuclear reactions in the Sun. The first 11 reactions form the pp-cycle, grouped in 5 branches; the last 6 is the main branch of the (cold) CNO cycle that contributes (little) to solar luminosity. The 2nd reaction of pp II branch is an electron capture and produces two lines; the 2nd reaction of the pp III branch depends on the energy of the excited Be-8 state E_x that is not known with complete certainty. The energy of the positron is included in Q. Particles or atomic nuclei are indicated; p=^{1}H and D=^{2}H. For the final state, we adopt the notation of Rutherford, $\alpha={}^4$He and $\beta=e$. Borexino, Super-Kamiokande and the Subdury Neutrino Observatory are indicated by BX, SK, SNO, with question mark when the observation is not yet accomplished. Adapted from [2].

Components of the Flux and their Measurements



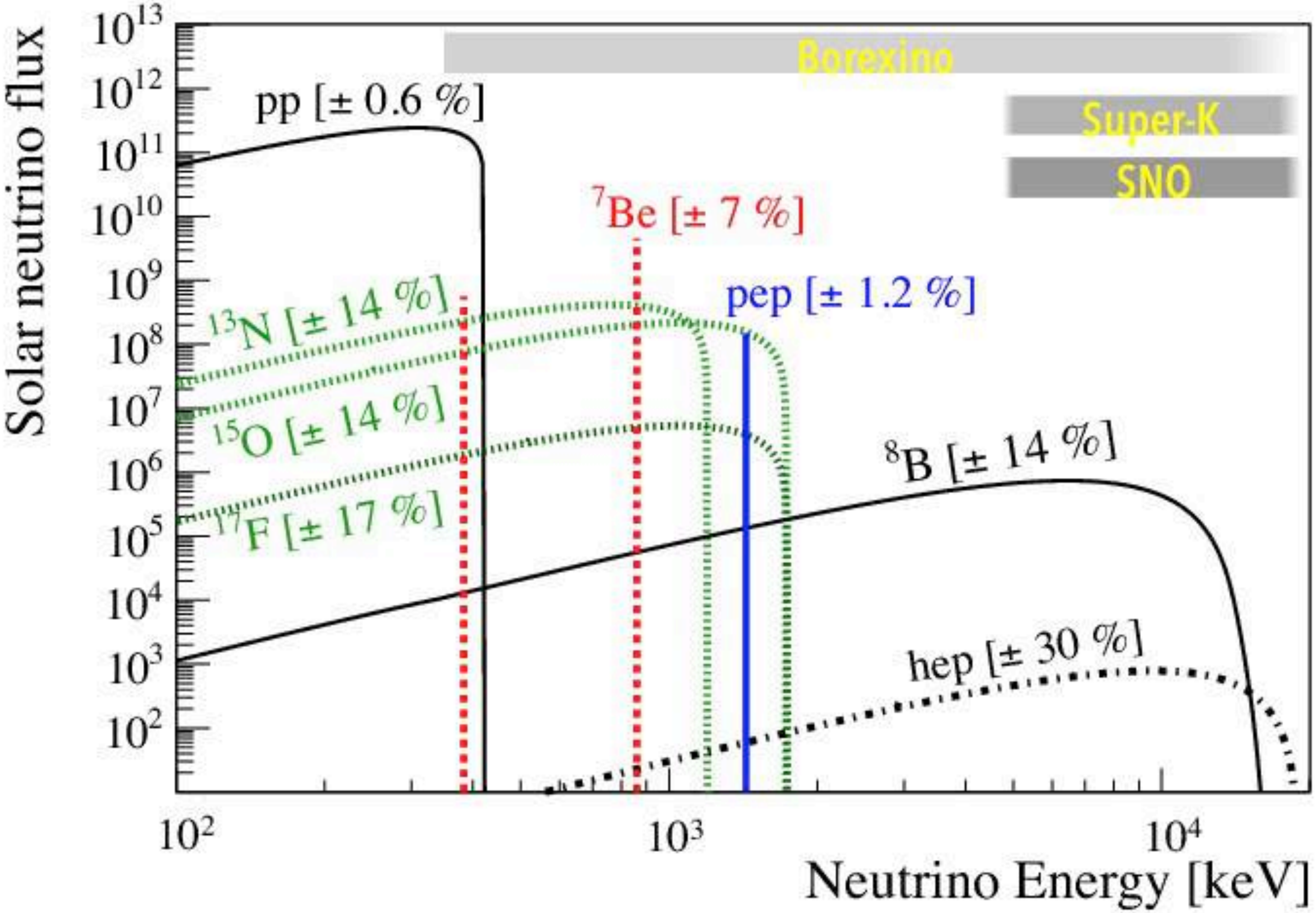
Neutrino astronomy 59

Name	Reaction	Q-value [keV]	$E_\nu^{\max}$ [keV]	Observed
pp I	$\mathrm{p}+\mathrm{p}\to\mathrm{D}+\beta^{+}+\nu_e$	1442	420	BX
	$\mathrm{p}+\mathrm{D}\to{}^{3}\mathrm{He}+\gamma$	5494	-	
	${}^{3}\mathrm{He}+{}^{3}\mathrm{He}\to\alpha+2\mathrm{p}$	12860	-	
pep	$\mathrm{p}+\mathrm{p}+e\to\mathrm{D}+\nu_e$	1442	1442	BX
pp II	${}^{3}\mathrm{He}+{}^{4}\mathrm{He}\to{}^{7}\mathrm{Be}+\gamma$	1586	-	
	${}^{7}\mathrm{Be}+e\to{}^{7}\mathrm{Li}+\nu_e$	862, 384	862, 384	BX, (BX?)
	${}^{7}\mathrm{Li}+e\to2\alpha$	17347	-	
pp III	${}^{7}\mathrm{Be}+\mathrm{p}\to{}^{8}\mathrm{B}+\gamma$	137	-	
	${}^{8}\mathrm{B}\to{}^{8}\mathrm{Be}^{*}+\beta^{+}+\nu_e$	$18471-E_x$	$14600\div15100$	SK SNO BX
	${}^{8}\mathrm{Be}^{*}\to2\alpha$	E_x	-	
hep (pp IV)	${}^{3}\mathrm{He}+\mathrm{p}\to\alpha+\beta^{+}+\nu_e$	19795	18773	SK? SNO?
CNO-I	${}^{12}\mathrm{C}+\mathrm{p}\to{}^{13}\mathrm{N}+\gamma$	1943	-	
	${}^{13}\mathrm{N}\to{}^{13}\mathrm{C}+\beta^{+}+\nu_e$	2221	1199	BX?
	${}^{13}\mathrm{C}+\mathrm{p}\to{}^{14}\mathrm{N}+\gamma$	7551	-	
	${}^{14}\mathrm{N}+\mathrm{p}\to{}^{15}\mathrm{O}+\gamma$	7297	-	
	${}^{15}\mathrm{O}\to{}^{15}\mathrm{N}+\beta^{+}+\nu_e$	2754	1732	BX?
	${}^{15}\mathrm{N}\to{}^{12}\mathrm{C}+\alpha$	4966	-	

Table 5 Nuclear reactions in the Sun. The first 11 reactions form the pp-cycle, grouped in 5 branches; the last 6 is the main branch of the (cold) CNO cycle that contributes (little) to solar luminosity. The 2nd reaction of pp II branch is an electron capture and produces two lines; the 2nd reaction of the pp III branch depends on the energy of the excited Be-8 state E_x that is not known with complete certainty. The energy of the positron is included in Q. Particles or atomic nuclei are indicated; p=^{1}H and D=^{2}H. For the final state, we adopt the notation of Rutherford, $\alpha = {}^4$He and $\beta = e$. Borexino, Super-Kamiokande and the Subdury Neutrino Observatory are indicated by BX, SK, SNO, with question mark when the observation is not yet accomplished. Adapted from [2].

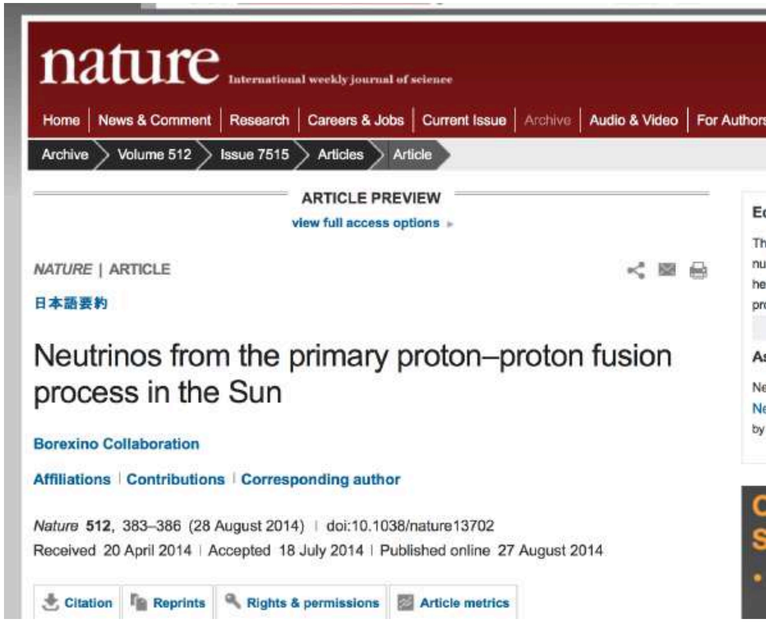
SK and SNO probe 0.02% of SSM ν flux

Components of the Flux and their Measurements



Name	Reaction	Q-value [keV]	$E_\nu^{\max}$ [keV]	Observed
pp I	$p+p \to D+\beta^+ + \nu_e$	1442	420	BX
	$p+D \to {}^3He+\gamma$	5494	-	
	${}^3He+{}^3He \to \alpha+2p$	12860	-	
pep	$p+p+e \to D+\nu_e$	1442	1442	BX
pp II	${}^3He+{}^4He \to {}^7Be+\gamma$	1586	-	
	${}^7Be+e \to {}^7Li+\nu_e$	862, 384	862, 384	BX, (BX?)
	${}^7Li+e \to 2\alpha$	17347	-	
pp III	${}^7Be+p \to {}^8B+\gamma$	137	-	
	${}^8B \to {}^8Be^* + \beta^+ + \nu_e$	$18471 - E_x$	$14600 \div 15100$	SK SNO BX
	${}^8Be^* \to 2\alpha$	E_x	-	
hep (pp IV)	${}^3He+p \to \alpha+\beta^+ + \nu_e$	19795	18773	SK? SNO?
CNO-I	${}^{12}C+p \to {}^{13}N+\gamma$	1943	-	
	${}^{13}N \to {}^{13}C+\beta^+ + \nu_e$	2221	1199	BX?
	${}^{13}C+p \to {}^{14}N+\gamma$	7551	-	
	${}^{14}N+p \to {}^{15}O+\gamma$	7297	-	
	${}^{15}O \to {}^{15}N+\beta^+ + \nu_e$	2754	1732	BX?
	${}^{15}N \to {}^{12}C+\alpha$	4966	-	

Table 5 Nuclear reactions in the Sun. The first 11 reactions form the pp-cycle, grouped in 5 branches; the last 6 is the main branch of the (cold) CNO cycle that contributes (little) to solar luminosity. The 2nd reaction of pp II branch is an electron capture and produces two lines; the 2nd reaction of the pp III branch depends on the energy of the excited Be-8 state E_x that is not known with complete certainty. The energy of the positron is included in Q. Particles or atomic nuclei are indicated; p=^{1}H and D=^{2}H. For the final state, we adopt the notation of Rutherford, $\alpha = {}^4$He and $\beta = e$. Borexino, Super-Kamiokande and the Subdury Neutrino Observatory are indicated by BX, SK, SNO, with question mark when the observation is not yet accomplished. Adapted from [2].



ARTICLE PREVIEW

view full access options ▸

NATURE | ARTICLE

日本語要約

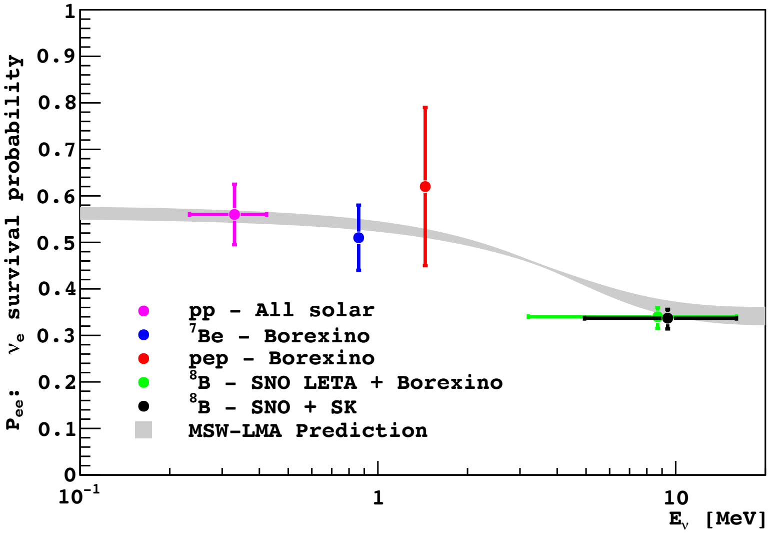
Neutrinos from the primary proton–proton fusion process in the Sun

Borexino Collaboration

Affiliations | Contributions | Corresponding author

Nature **512**, 383–386 (28 August 2014) | doi:10.1038/nature13702

Received 20 April 2014 | Accepted 18 July 2014 | Published online 27 August 2014



Name	Reaction	Q-value [keV]	$E_\nu^{\max}$ [keV]	Observed
pp I	$p+p \to D+\beta^+ + \nu_e$	1442	420	BX
	$p+D \to {}^3He+\gamma$	5494	-	
	${}^3He+{}^3He \to \alpha+2p$	12860	-	
pep	$p+p+e \to D+\nu_e$	1442	1442	BX
pp II	${}^3He+{}^4He \to {}^7Be+\gamma$	1586	-	
	${}^7Be+e \to {}^7Li+\nu_e$	862, 384	862, 384	BX, (BX?)
	${}^7Li+e \to 2\alpha$	17347	-	
pp III	${}^7Be+p \to {}^8B+\gamma$	137	-	
	${}^8B \to {}^8Be^* + \beta^+ + \nu_e$	$18471-E_x$	14600÷15100	SK SNO BX
	${}^8Be^* \to 2\alpha$	E_x	-	
hep (pp IV)	${}^3He+p \to \alpha+\beta^+ + \nu_e$	19795	18773	SK? SNO?
CNO-I	${}^{12}C+p \to {}^{13}N+\gamma$	1943	-	
	${}^{13}N \to {}^{13}C+\beta^+ + \nu_e$	2221	1199	BX?
	${}^{13}C+p \to {}^{14}N+\gamma$	7551	-	
	${}^{14}N+p \to {}^{15}O+\gamma$	7297	-	
	${}^{15}O \to {}^{15}N+\beta^+ + \nu_e$	2754	1732	BX?
	${}^{15}N \to {}^{12}C+\alpha$	4966	-	

Table 5 Nuclear reactions in the Sun. The first 11 reactions form the pp-cycle, grouped in 5 branches; the last 6 is the main branch of the (cold) CNO cycle that contributes (little) to solar luminosity. The 2nd reaction of pp II branch is an electron capture and produces two lines; the 2nd reaction of the pp III branch depends on the energy of the excited Be-8 state E_x that is not known with complete certainty. The energy of the positron is included in Q. Particles or atomic nuclei are indicated; p=^{1}H and D=^{2}H. For the final state, we adopt the notation of Rutherford, $\alpha = {}^4$He and $\beta = e$. Borexino, Super-Kamiokande and the Subdury Neutrino Observatory are indicated by BX, SK, SNO, with question mark when the observation is not yet accomplished. Adapted from [2].

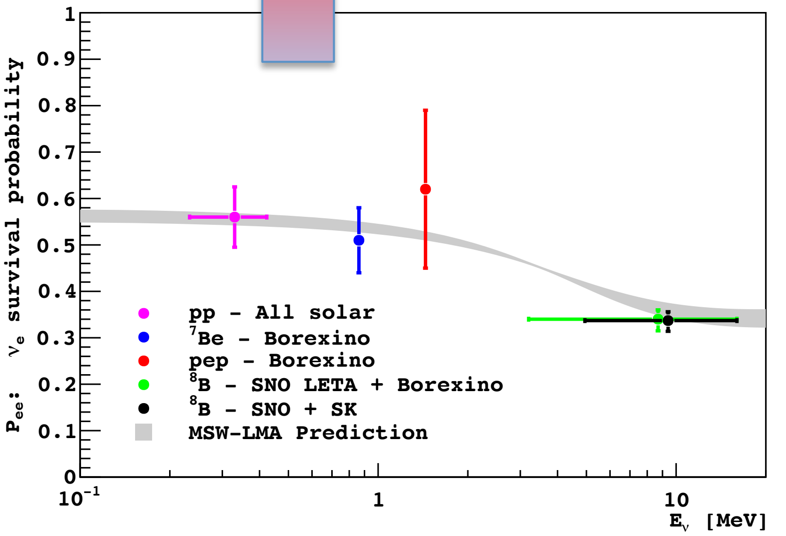
Neutrinos from imary proton–proton fusion process in the S

Borexino Collaboration

Affiliations | Contributions | nding author

Nature **512**, 383–386 (28 August 2014) | doi:10.1038/nature13702

Received 20 April 2014 | Accepted 18 July 2014 | Published online 27 August 2014



Neutrino astronomy 59

Name	Reaction	Q-value [keV]	$E_\nu^{\max}$ [keV]	Observed
pp I	$p+p\to D+\beta^++\nu_e$	1442	420	BX
	$p+D\to {}^3He+\gamma$	5494	-	
	${}^3He+{}^3He\to\alpha+2p$	12860	-	
pep	$p+p+e\to D+\nu_e$	1442	1442	BX
pp II	${}^3He+{}^4He\to{}^7Be+\gamma$	1586	-	
	${}^7Be+e\to{}^7Li+\nu_e$	862, 384	862, 384	BX, (BX?)
	${}^7Li+e\to 2\alpha$	17347	-	
pp III	${}^7Be+p\to{}^8B+\gamma$	137	-	
	${}^8B\to{}^8Be^*+\beta^++\nu_e$	$18471-E_x$	14600÷15100	SK SNO BX
	${}^8Be^*\to 2\alpha$	E_x	-	
hep (pp IV)	${}^3He+p\to\alpha+\beta^++\nu_e$	19795	18773	SK? SNO?
CNO-I	${}^{12}C+p\to{}^{13}N+\gamma$	1943	-	
	${}^{13}N\to{}^{13}C+\beta^++\nu_e$	2221	1199	BX?
	${}^{13}C+p\to{}^{14}N+\gamma$	7551	-	
	${}^{14}N+p\to{}^{15}O+\gamma$	7297	-	
	${}^{15}O\to{}^{15}N+\beta^++\nu_e$	2754	1732	BX?
	${}^{15}N\to{}^{12}C+\alpha$	4966	-	

Table 5 Nuclear reactions in the Sun. The first 11 reactions form the pp-cycle, grouped in 5 branches; the last 6 is the main branch of the (cold) CNO cycle that contributes (little) to solar luminosity. The 2nd reaction of pp II branch is an electron capture and produces two lines; the 2nd reaction of the pp III branch depends on the energy of the excited Be-8 state E_x that is not known with complete certainty. The energy of the positron is included in Q. Particles or atomic nuclei are indicated; p=^{1}H and D=^{2}H. For the final state, we adopt the notation of Rutherford, $\alpha={}^4$He and $\beta=e$. Borexino, Super-Kamiokande and the Subdury Neutrino Observatory are indicated by BX, SK, SNO, with question mark when the observation is not yet accomplished. Adapted from [2].

nature International weekly journal of science

Home | News & Comment | Research | Careers & Jobs | Current Issue | Archive | Audio & Video | For Authors

Archive > Volume 512 > Issue 7515 > Articles > Article

ARTICLE PREVIEW

view full access options

NATURE | ARTICLE

日本語要約

Neutrinos from t imary p ot n–p ot n fu ion process in the S

Borex Col orati

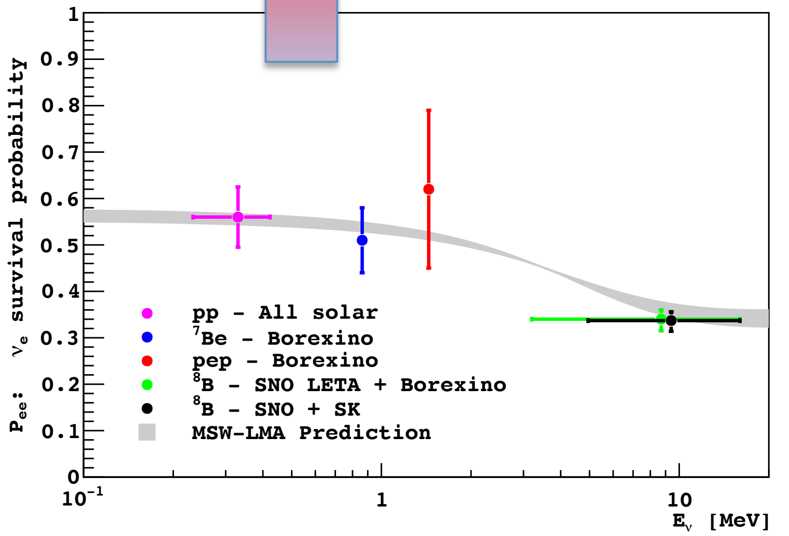
Affiliatio bu s ing au or

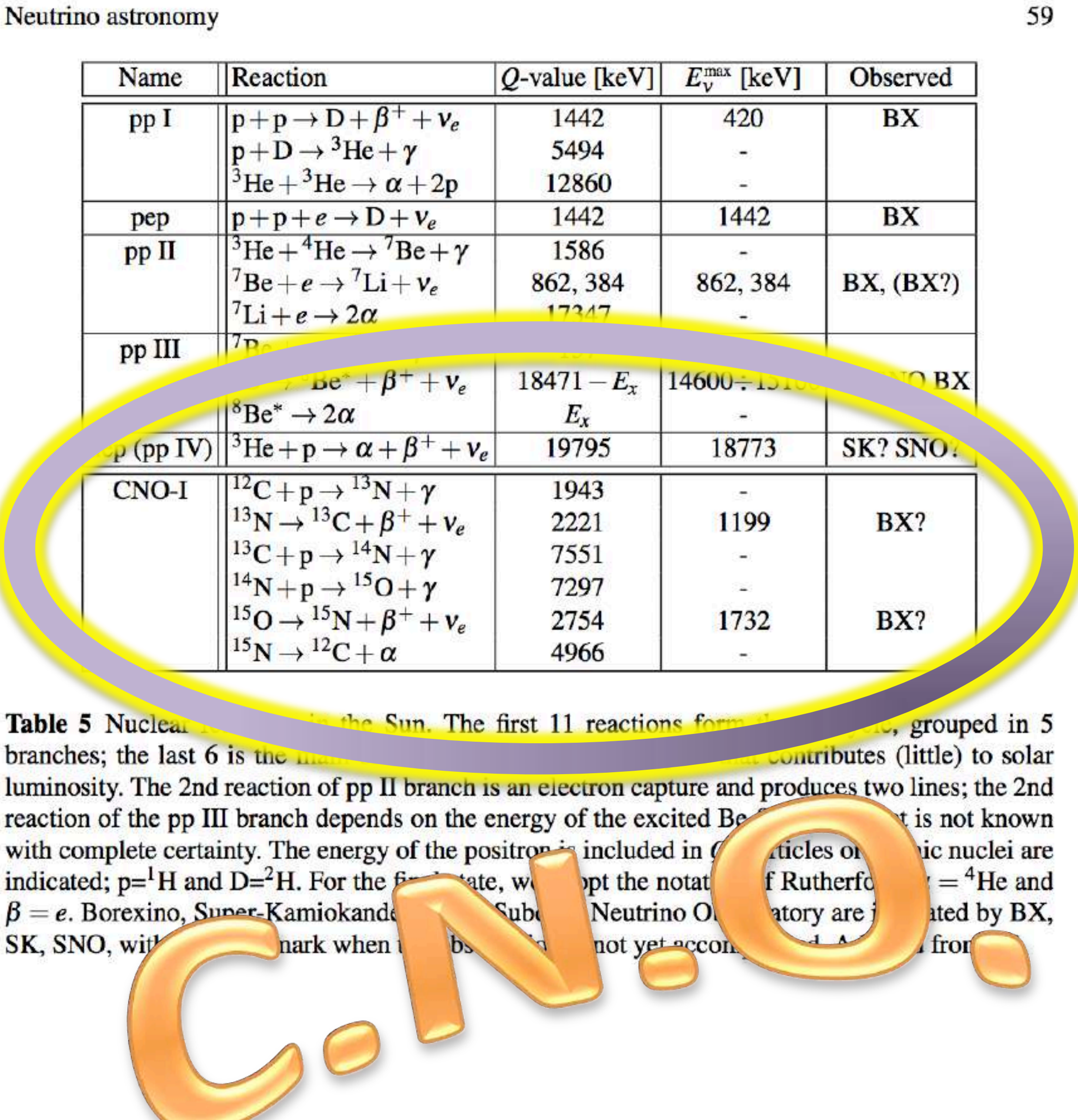
Nature 512 (28 4) 10.103 370

Received 20 April 2014 | Accepted 18 July 2014 | Published online 27 August 2014

Citation | Reprints | issions | Article metrics

Borexino



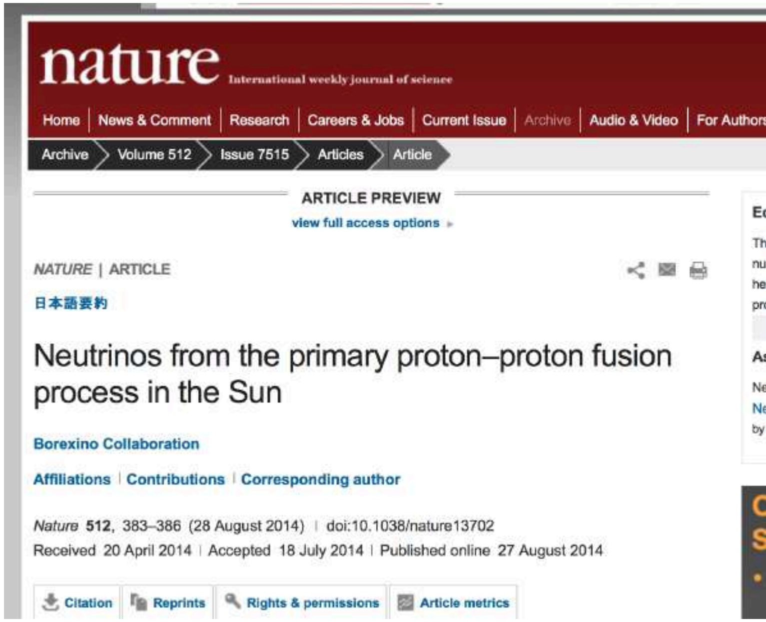


Neutrino astronomy 59

Name	Reaction	Q-value [keV]	E_ν^{max} [keV]	Observed
pp I	$p+p \to D+\beta^+ +\nu_e$ $p+D \to {}^3He+\gamma$ ${}^3He+{}^3He \to \alpha+2p$	1442 5494 12860	420 - -	BX
pep	$p+p+e \to D+\nu_e$	1442	1442	BX
pp II	${}^3He+{}^4He \to {}^7Be+\gamma$ ${}^7Be+e \to {}^7Li+\nu_e$ ${}^7Li+e \to 2\alpha$	1586 862, 384 17347	- 862, 384 -	BX, (BX?)
pp III	^{7}B [illegible] [illegible] ${}^8Be^* +\beta^+ +\nu_e$ ${}^8Be^* \to 2\alpha$	[illegible] $18471 - E_x$ E_x	 14600÷15[illegible] -	[illegible]O BX
[illegible]p (pp IV)	${}^3He+p \to \alpha+\beta^+ +\nu_e$	19795	18773	SK? SNO?
CNO-I	${}^{12}C+p \to {}^{13}N+\gamma$ ${}^{13}N \to {}^{13}C+\beta^+ +\nu_e$ ${}^{13}C+p \to {}^{14}N+\gamma$ ${}^{14}N+p \to {}^{15}O+\gamma$ ${}^{15}O \to {}^{15}N+\beta^+ +\nu_e$ ${}^{15}N \to {}^{12}C+\alpha$	1943 2221 7551 7297 2754 4966	- 1199 - - 1732 -	 BX? BX?

Table 5 Nuclear [illegible] the Sun. The first 11 reactions form [illegible], grouped in 5 branches; the last 6 is the [illegible] contributes (little) to solar luminosity. The 2nd reaction of pp II branch is an electron capture and produces two lines; the 2nd reaction of the pp III branch depends on the energy of the excited Be [illegible] it is not known with complete certainty. The energy of the positron [illegible] included in [illegible] ticles or [illegible] ic nuclei are indicated; p=^{1}H and D=^{2}H. For the [illegible] state, we [illegible] opt the notat[illegible] f Rutherfo[illegible] $= {}^4$He and $\beta = e$. Borexino, Super-Kamiokande [illegible] Sub[illegible] Neutrino O[illegible] atory are [illegible] ated by BX, SK, SNO, wit[illegible] mark when [illegible] not yet accom[illegible] fro[illegible]

C.N.O.



nature International weekly journal of science

ARTICLE PREVIEW

view full access options

NATURE | ARTICLE

日本語要約

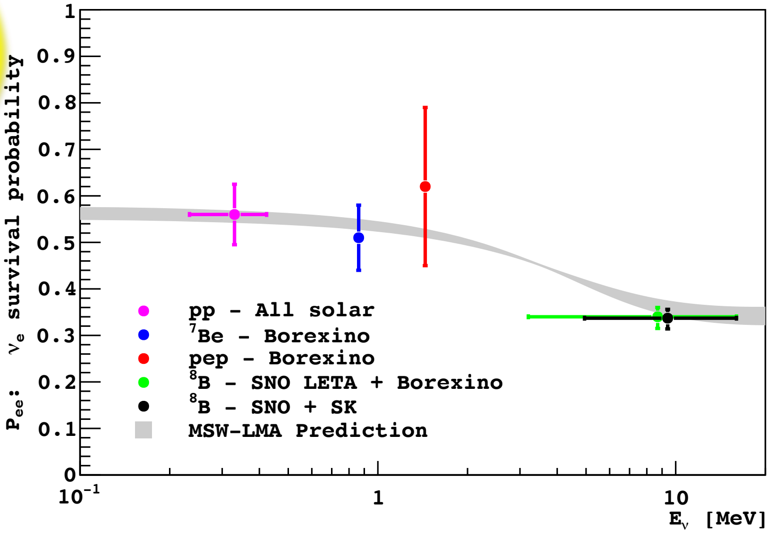
Neutrinos from the primary proton–proton fusion process in the Sun

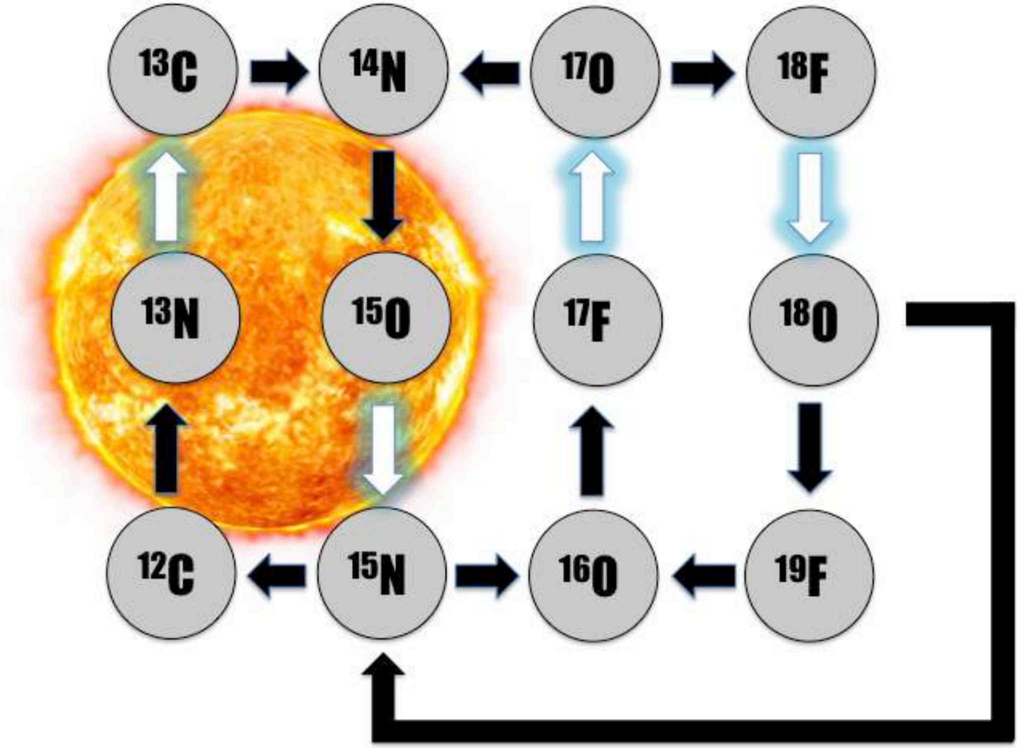
Borexino Collaboration

Affiliations | Contributions | Corresponding author

Nature 512, 383–386 (28 August 2014) | doi:10.1038/nature13702

Received 20 April 2014 | Accepted 18 July 2014 | Published online 27 August 2014

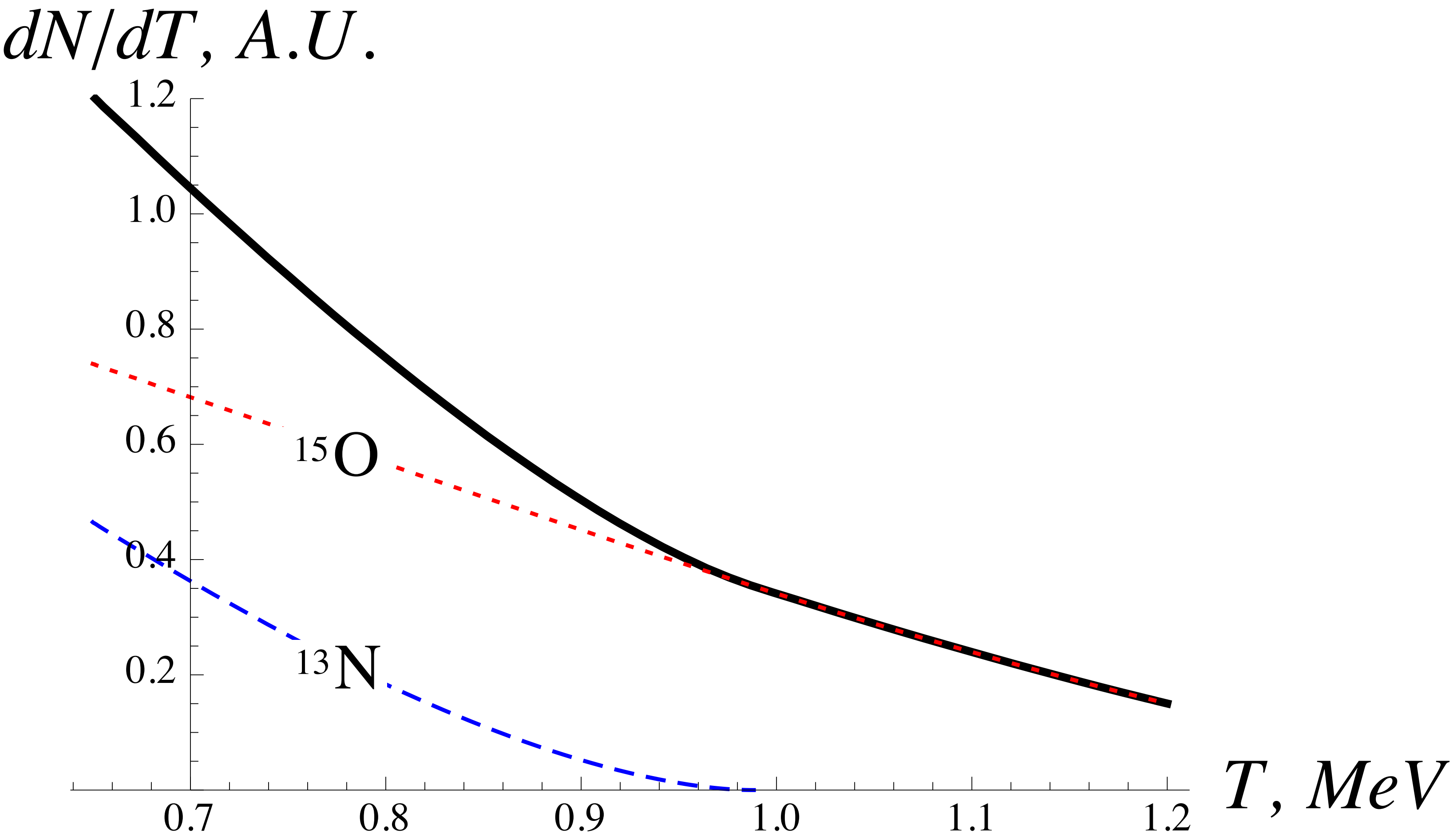


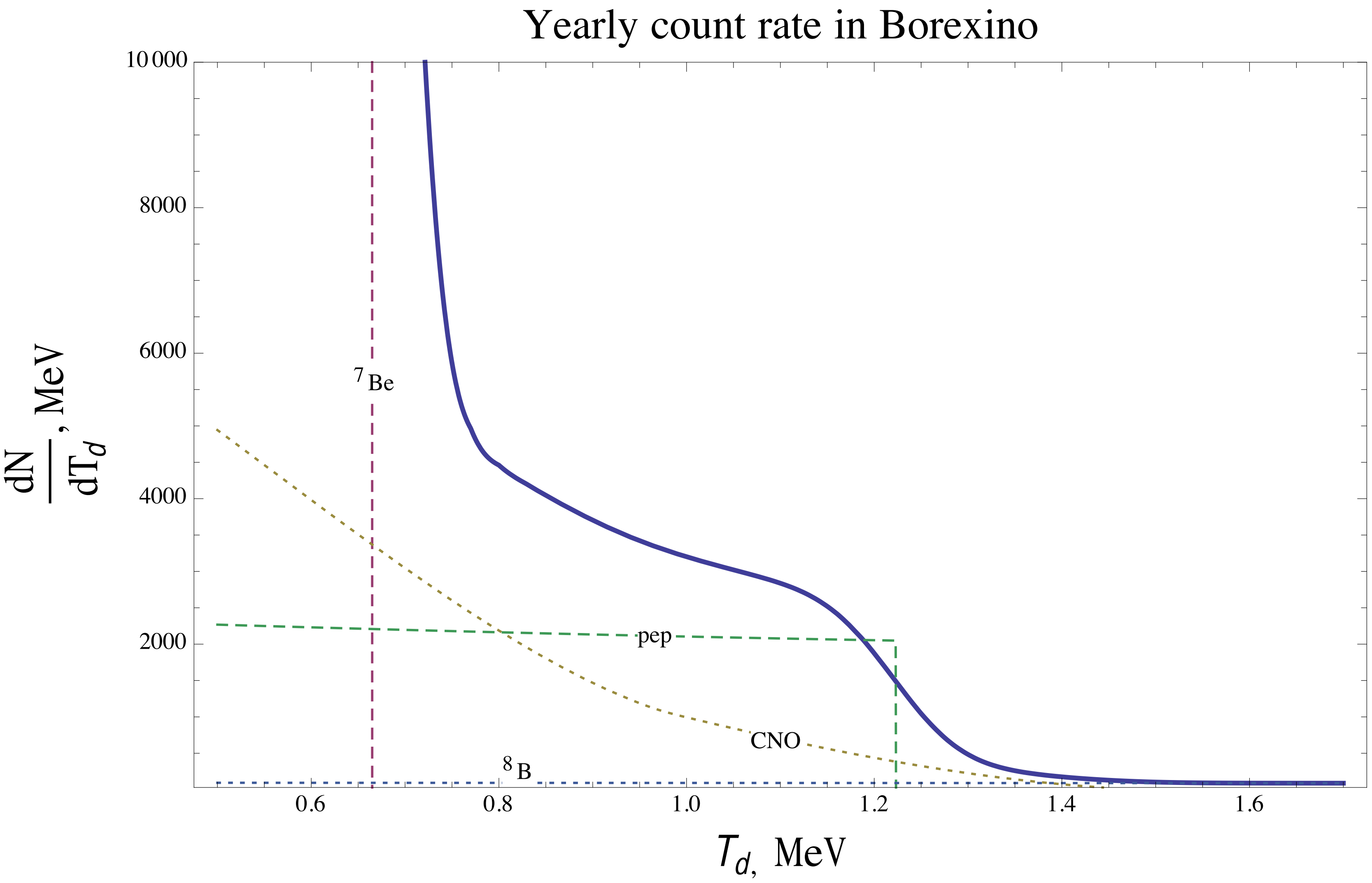


A chance to learn how stars work: Study CNO!

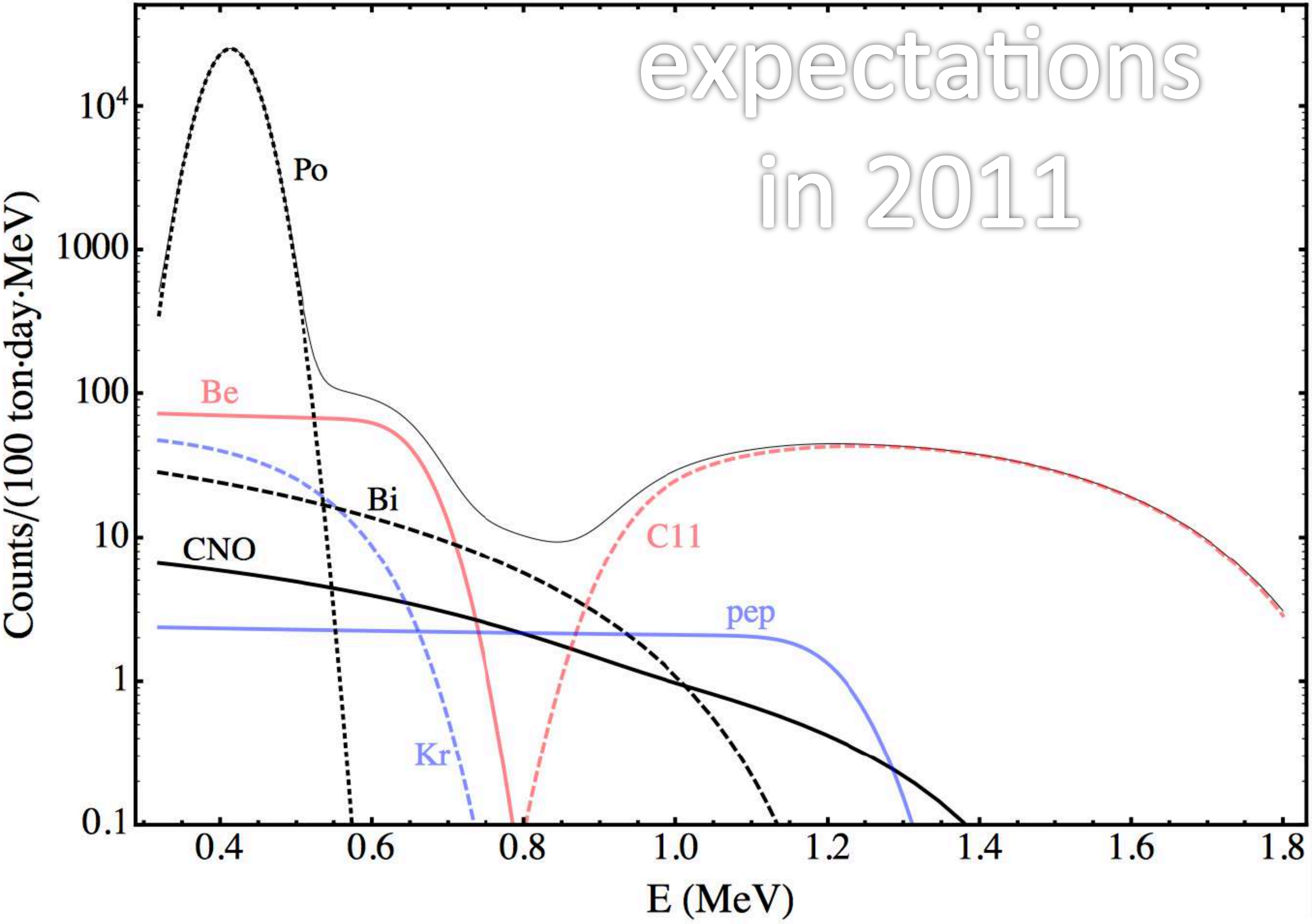
The pp-cycle has been explored almost completely, excepting the hep branch. **The CNO cycle** instead, that is the main cycle of the most massive stars and should yield 1-2 % of the solar luminosity, **is not explored yet**. Its measurement may help us to fix the pending issues of SSM.

Shape of the ES spectrum due to CNO

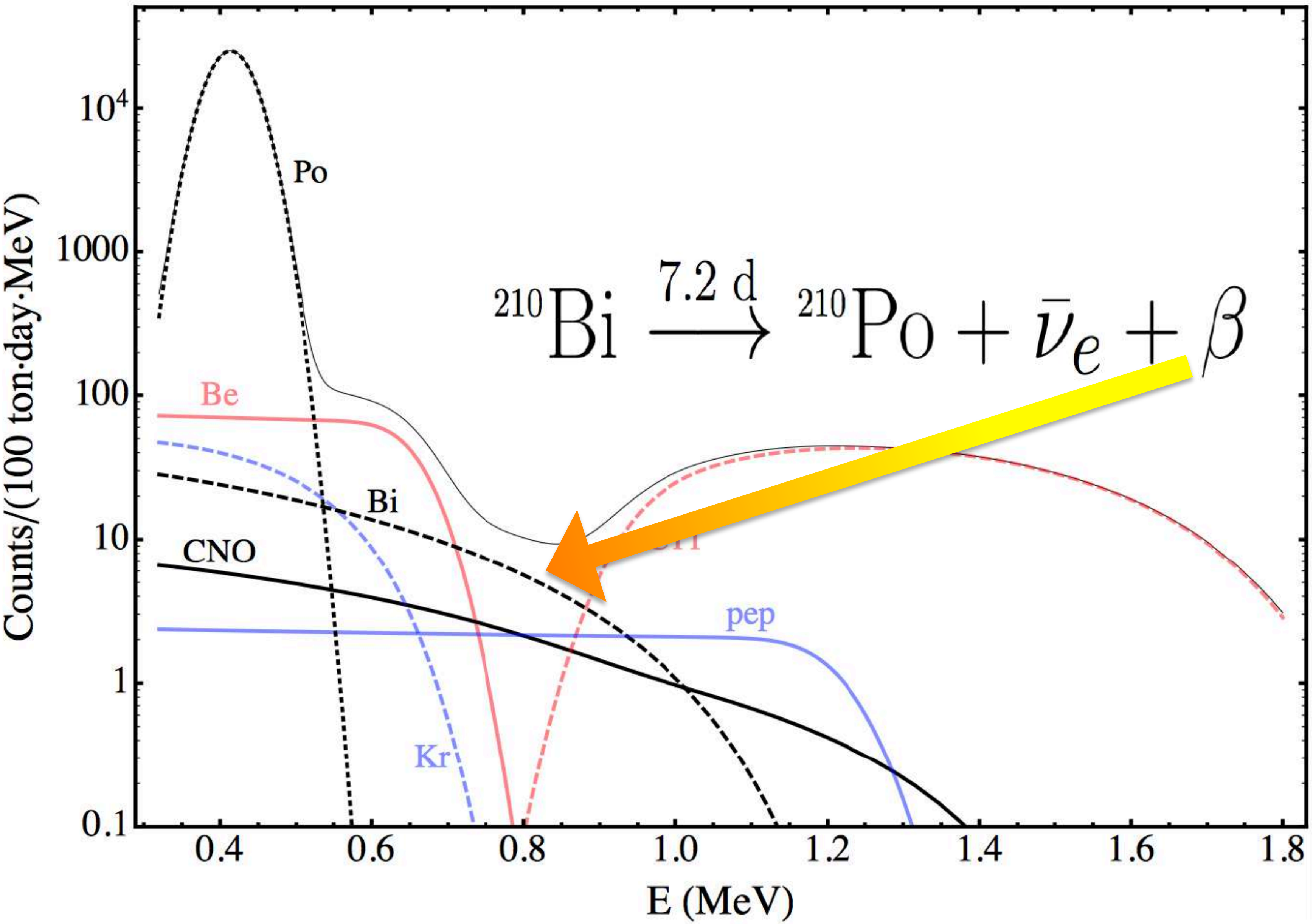



Yearly count rate in Borexino
10 000
8000
6000
4000
2000
0.6
0.8
1.0
1.2
1.4
1.6
$\frac{dN}{dT_d}$, MeV
$T_{d,}$ MeV
^{7}Be
pep
CNO
^{8}B

expectations in 2011

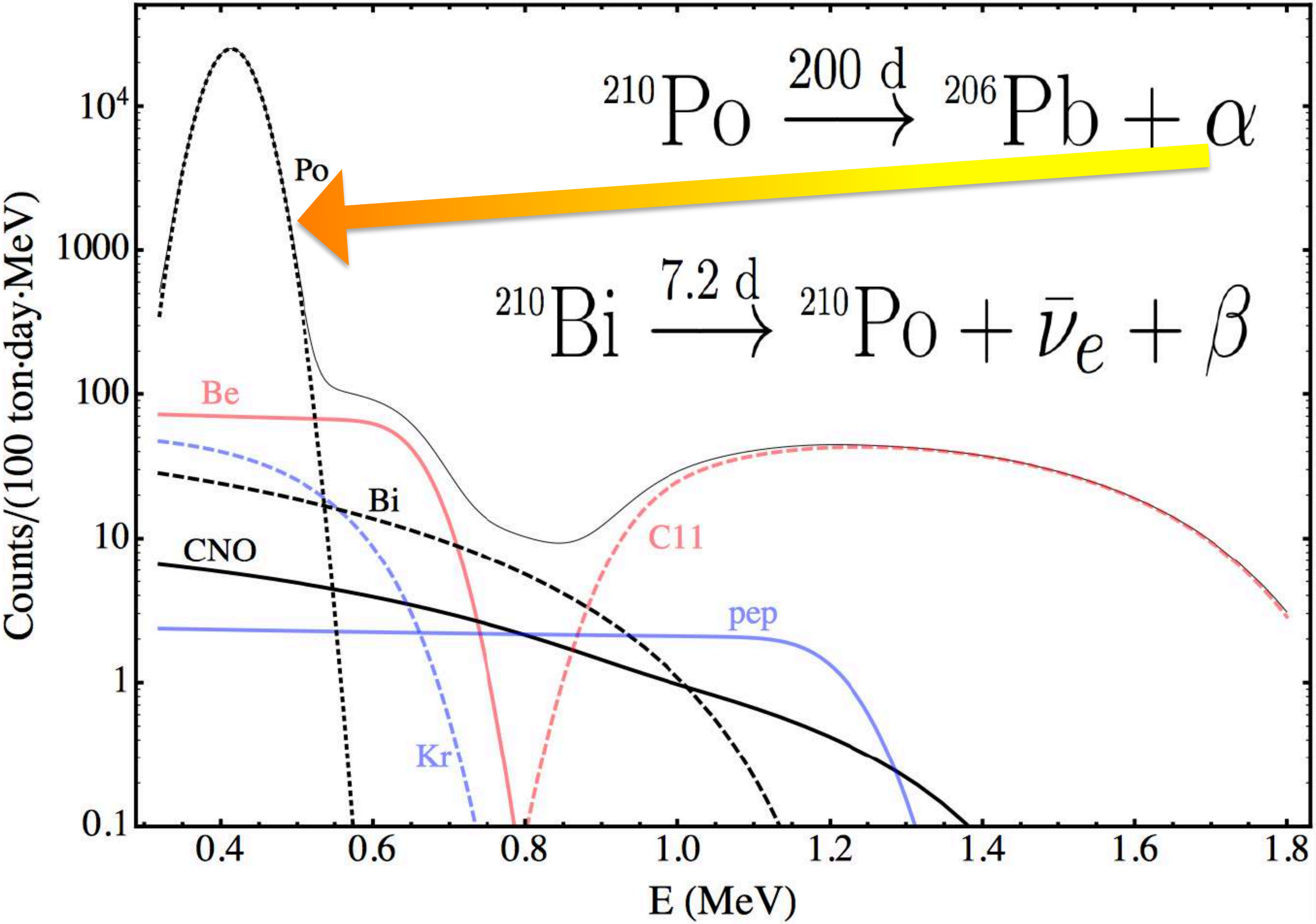


F.L. Villante et al, Phys.Lett. B701 (2011) 336



$$^{210}\mathrm{Bi} \xrightarrow{7.2\ \mathrm{d}} {}^{210}\mathrm{Po} + \bar{\nu}_e + \beta$$

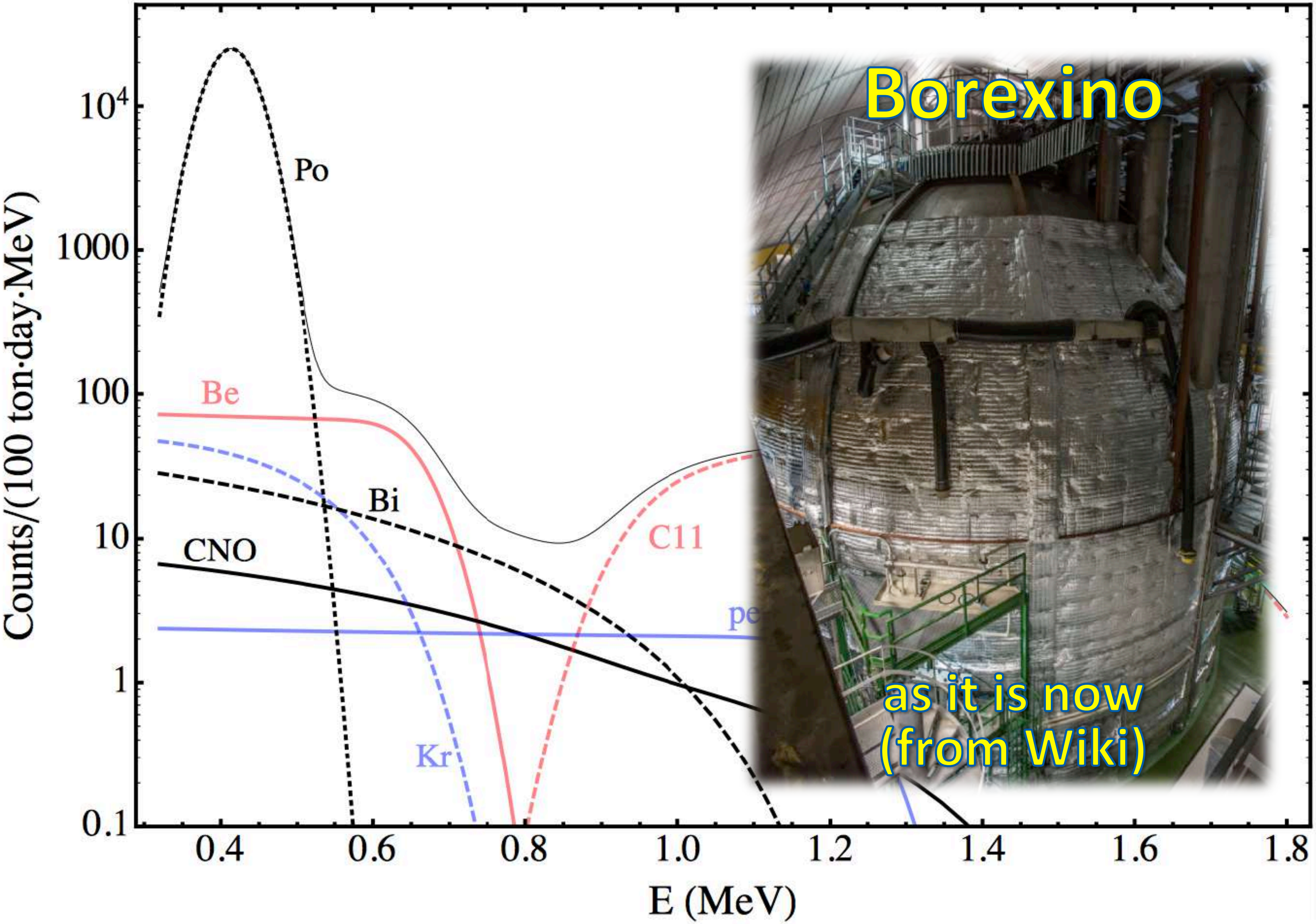
F.L. Villante et al, Phys.Lett. B701 (2011) 336



$$^{210}\mathrm{Po} \xrightarrow{200\ \mathrm{d}} {}^{206}\mathrm{Pb} + \alpha$$

$$^{210}\mathrm{Bi} \xrightarrow{7.2\ \mathrm{d}} {}^{210}\mathrm{Po} + \bar{\nu}_e + \beta$$

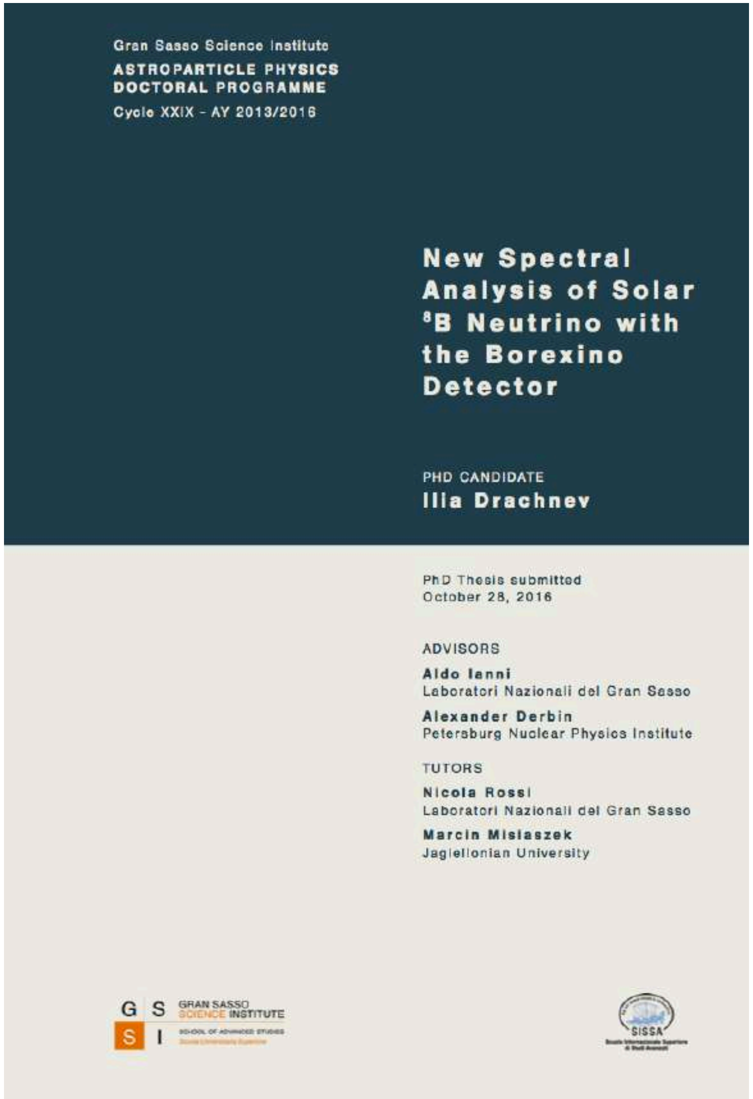
F.L. Villante et al, Phys.Lett. B701 (2011) 336



Borexino

as it is now (from Wiki)

Work in progress!



Gran Sasso Science Institute
ASTROPARTICLE PHYSICS
DOCTORAL PROGRAMME
Cycle XXIX - AY 2013/2016

New Spectral Analysis of Solar ^{8}B Neutrino with the Borexino Detector

PHD CANDIDATE
Ilia Drachnev

PhD Thesis submitted
October 28, 2016

ADVISORS
Aldo Ianni
Laboratori Nazionali del Gran Sasso
Alexander Derbin
Petersburg Nuclear Physics Institute

TUTORS
Nicola Rossi
Laboratori Nazionali del Gran Sasso
Marcin Misiaszek
Jagiellonian University

GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES

SISSA

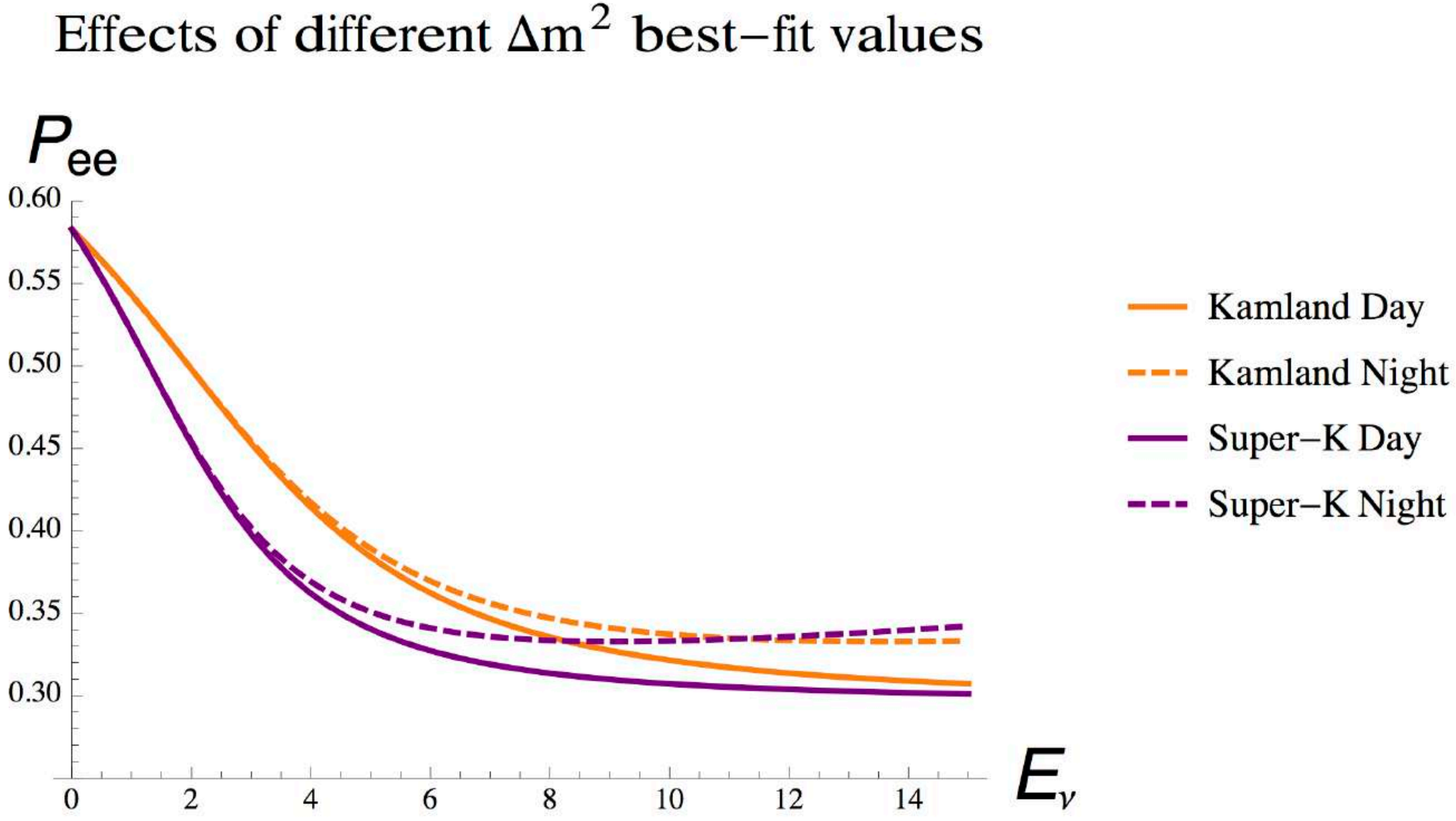
[e.g., from Drachnev 2016:]

…

Borexino detector has *statistical sensitivity* to CNO and pep neutrinos when the dedicated analysis here developed is applied. Central values are **$5.2\pm1.8\times10^6$ cm^{-2}s^{-1}** and $1.31\pm0.35\times10^9$ cm^{-2}s^{-1}

…

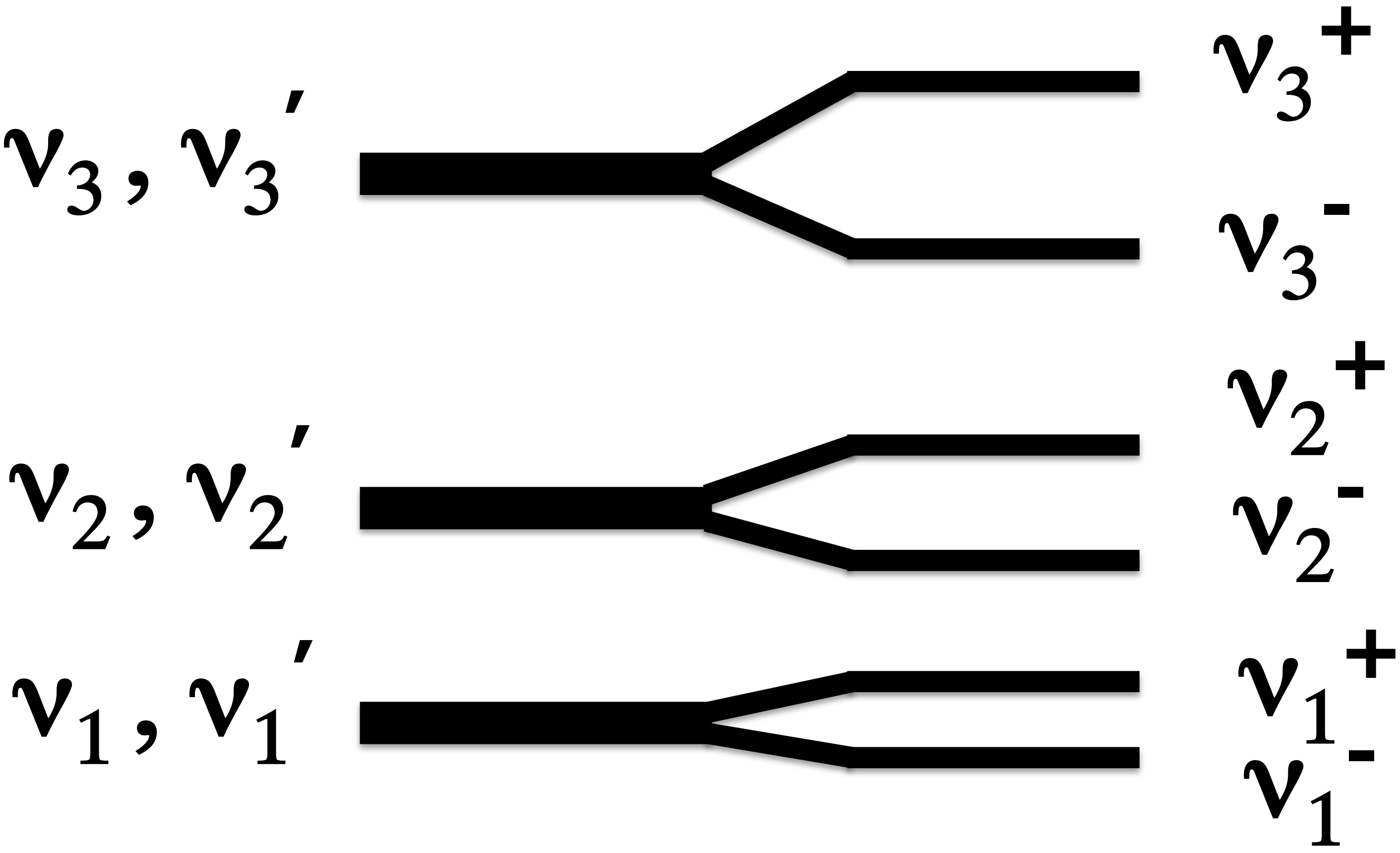
The MSW Theory



Speculations on particle physics

- other light (sterile) neutrinos / shape, NC
- new oscillations on cosmic scales / low energy data
- neutrino decay / flavor structure
- neutrino magnetic moments / solar antinu
- non-standard interactions / new matter effect
- axions / energy loss
- WIMPs in the Sun / solar structure, HE neutrinos
- CPT violation / compare with nubar data
- ....

New oscillations on cosmic scales



$\nu_3 , \nu_3{}'$ → $\nu_3{}^+$, $\nu_3{}^-$

$\nu_2 , \nu_2{}'$ → $\nu_2{}^+$, $\nu_2{}^-$

$\nu_1 , \nu_1{}'$ → $\nu_1{}^+$, $\nu_1{}^-$

Berezinsky et al, 2002

A motivated model for sterile neutrinos is the mirror model. Ordinary and mirror neutrinos mix and give rise to new oscillations. Potential source of ultra high energy neutrinos. In this model, dark matter can be accounted for in terms of mirror baryons. Not particularly favored, but not excluded, by a straightforward interpretation of SN1987A data.

Other light neutrinos?

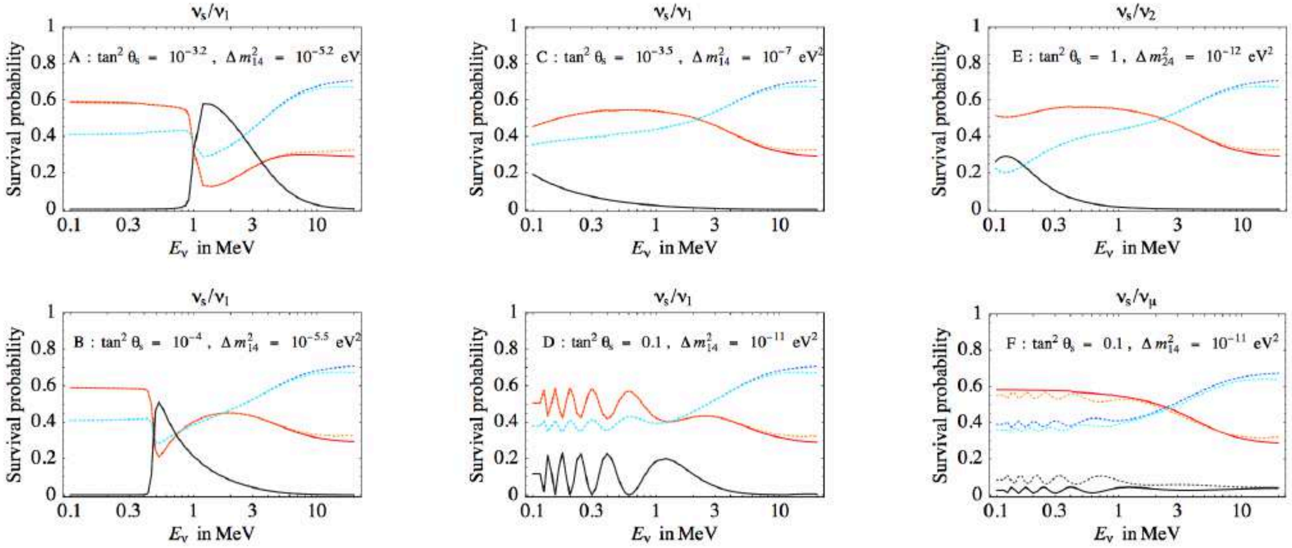


Figure 7: *A few samples of still allowed sterile effects in solar neutrinos. We plot, as function of the neutrino energy,* $P(\nu_e \to \nu_e)$ *(decreasing red curve),* $P(\nu_e \to \nu_{\mu,\tau})$ *(increasing blue curve) and* $P(\nu_e \to \nu_s)$ *(lower black curve). The continuous (dotted) curve are the values during day (night). The sample points* A,…, F *are drawn in fig. 6 as dots.*

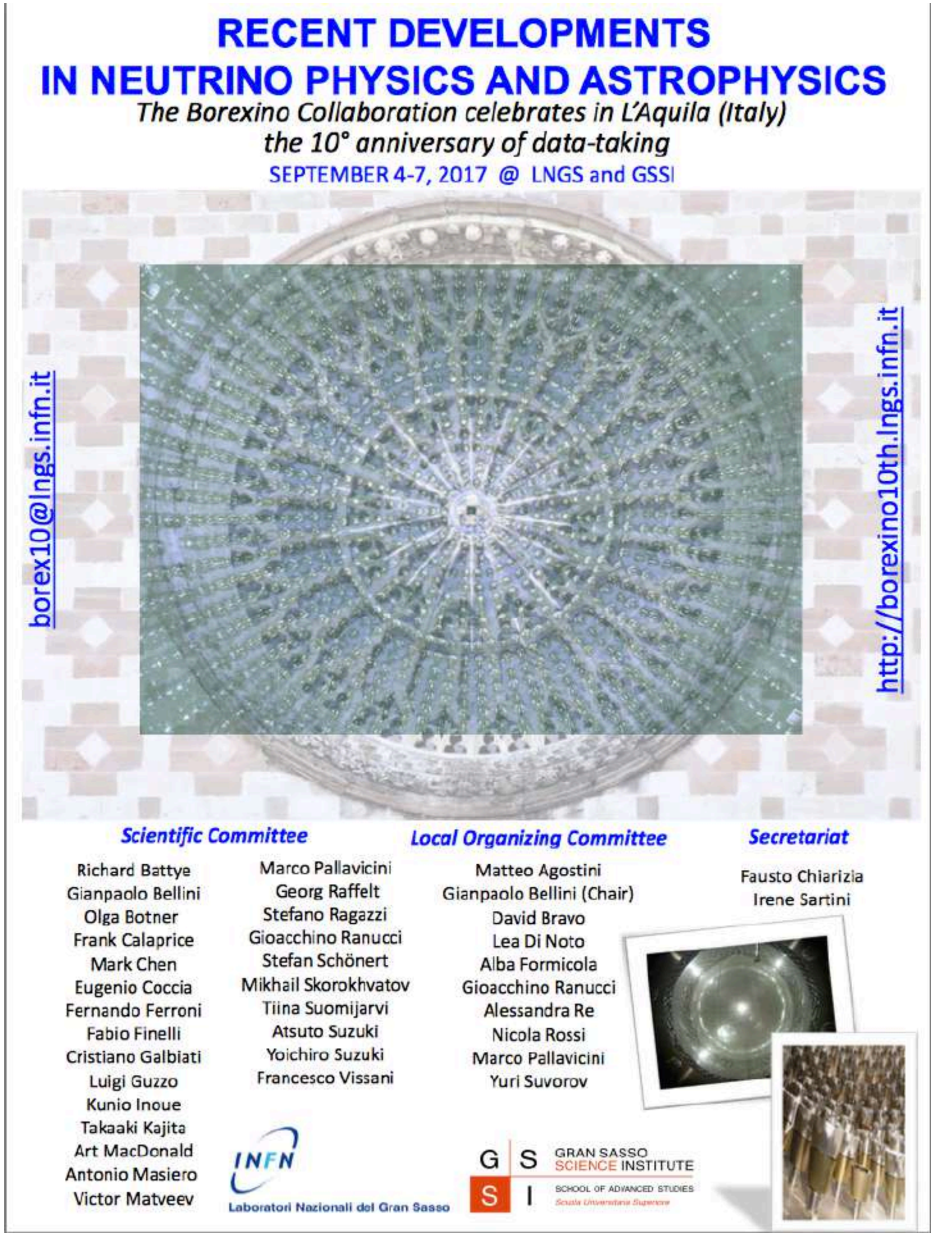
M. Cirelli et al, Nucl. Phys. B708 (2005) 215

A li'l advert

A conference on Neutrinos, with special reference to Solar Neutrinos, will take place on next September.

Please come for the latest analyses and news -- CNO and much more!

You are all welcome to come and visit the Astroparticle physics center of LNGS, GSSI and L'Aquila U



RECENT DEVELOPMENTS IN NEUTRINO PHYSICS AND ASTROPHYSICS

The Borexino Collaboration celebrates in L'Aquila (Italy)
the 10° anniversary of data-taking

SEPTEMBER 4-7, 2017 @ LNGS and GSSI

borex10@lngs.infn.it

http://borexino10th.lngs.infn.it

Scientific Committee

Richard Battye
Gianpaolo Bellini
Olga Botner
Frank Calaprice
Mark Chen
Eugenio Coccia
Fernando Ferroni
Fabio Finelli
Cristiano Galbiati
Luigi Guzzo
Kunio Inoue
Takaaki Kajita
Art MacDonald
Antonio Masiero
Victor Matveev
Marco Pallavicini
Georg Raffelt
Stefano Ragazzi
Gioacchino Ranucci
Stefan Schönert
Mikhail Skorokhvatov
Tiina Suomijarvi
Atsuto Suzuki
Yoichiro Suzuki
Francesco Vissani

Local Organizing Committee

Matteo Agostini
Gianpaolo Bellini (Chair)
David Bravo
Lea Di Noto
Alba Formicola
Gioacchino Ranucci
Alessandra Re
Nicola Rossi
Marco Pallavicini
Yuri Suvorov

Secretariat

Fausto Chiarizia
Irene Sartini

INFN
Laboratori Nazionali del Gran Sasso

GSSI
GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES
Scuola Universitaria Superiore

Remarks for particle physicists

- The 1st remark is quite general: Whether we want it or not, **neutrino astronomy** is in our hands
- A definitive understanding of ***how the Sun functions*** was obtained only 3 years ago by Borexino @ Gran Sasso lab
- The same team is progressing with more goals ahead: We are on the verge of learning on CNO, surprises may occur
- Do not forget that such topics are of great interest for a **very wide audience** and not only – Nobel 2002