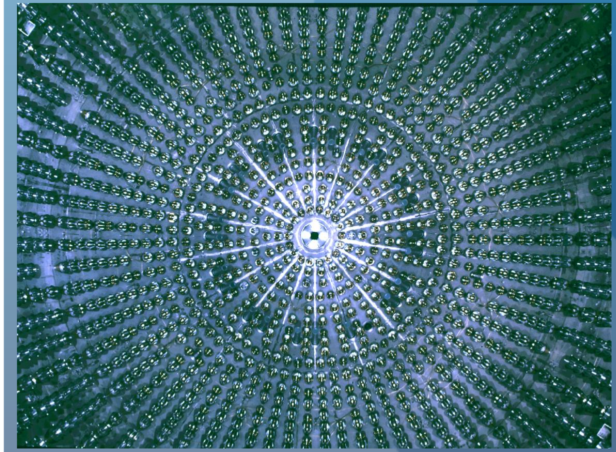
New results on solar neutrinos from Borexino

Sandra Zavatarelli INFN, Sezione di Genova (Italy)
on behalf of the Borexino Collaboration

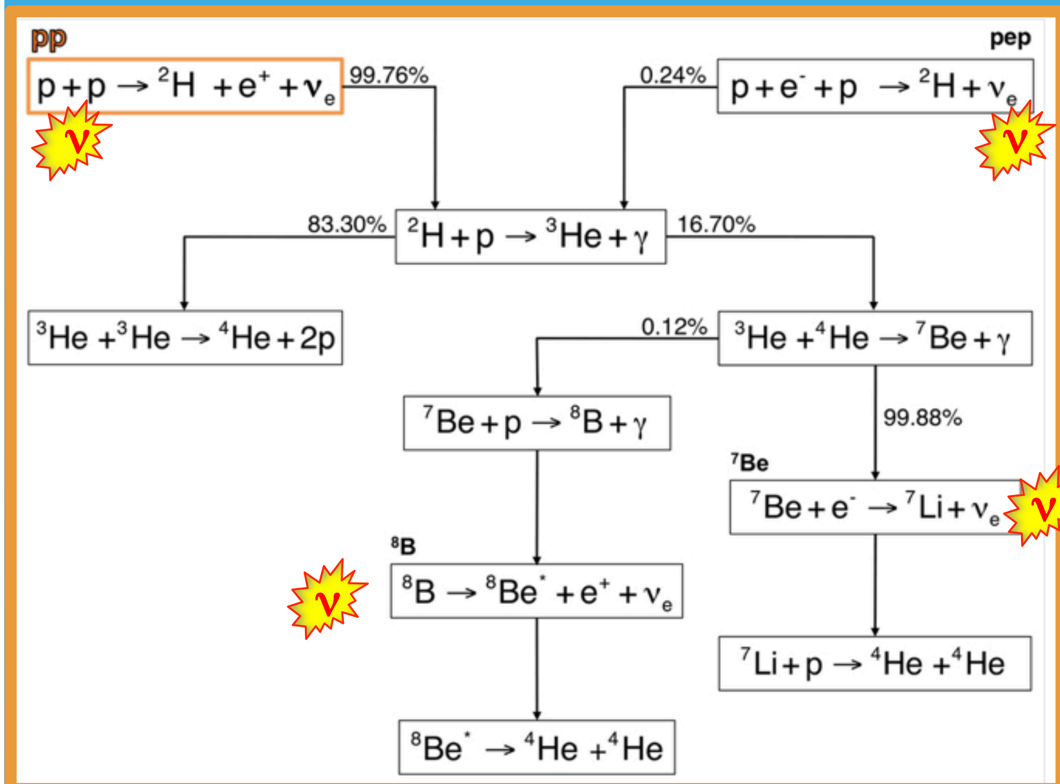


Outline

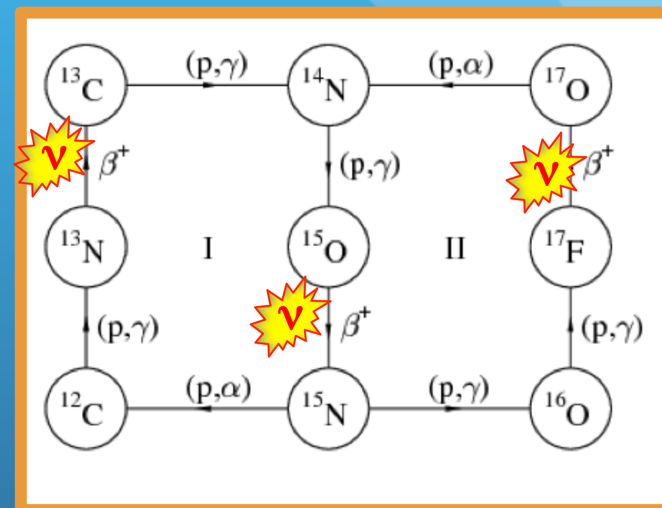
- Solar neutrino physics: a brief summary
- High precision solar neutrino spectroscopy with Borexino:
  - In 2017:
  - ➢ New updated results with the Phase II data on all the solar neutrino species: pp, ^{7}Be, pep, CNO and ^{8}B neutrinos;
  - ➢ New limit on the neutrino magnetic moment;
- The future

Solar ν as sensitive tool to test solar models

pp chain: 99 % of Sun Energy



CNO cycle: <1 % of Sun Energy

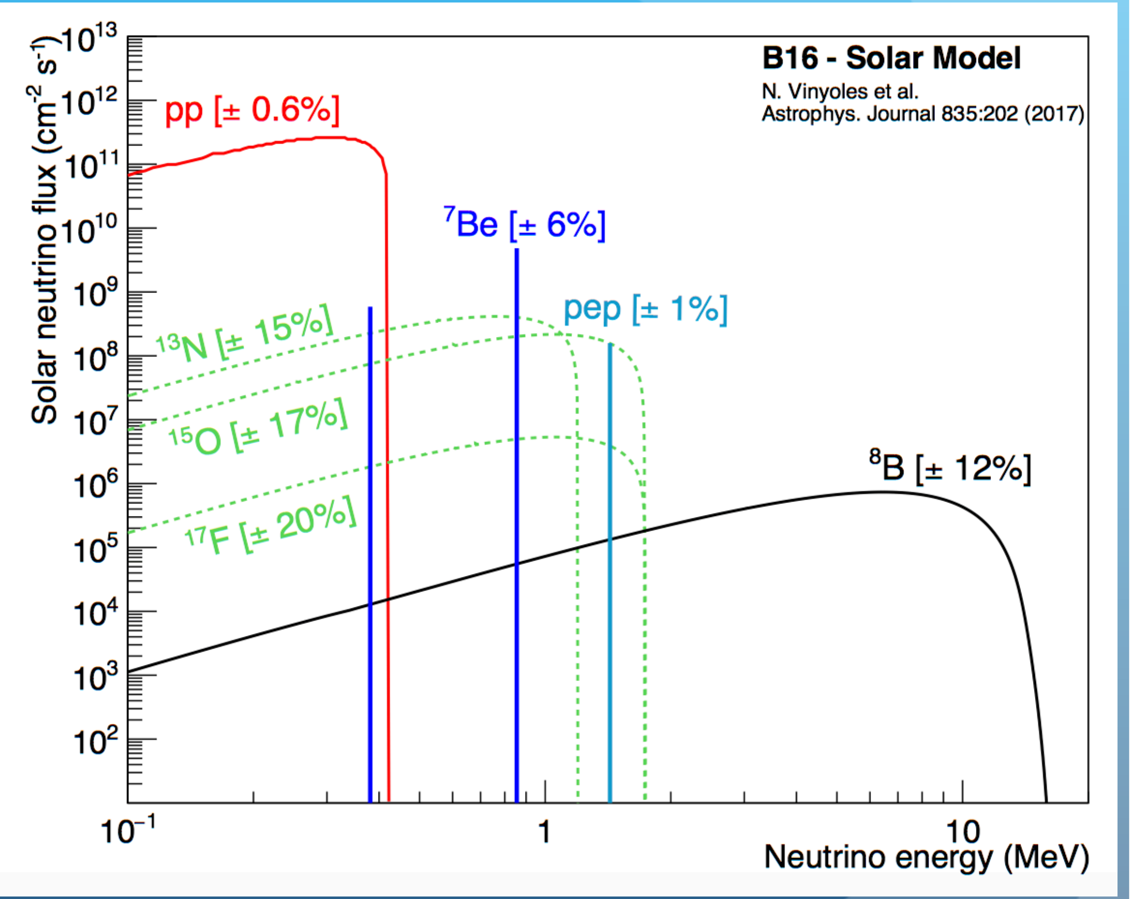


Original motivation of the first experiments on solar ν was to test the Standard Solar Model (SSM)

Solar ν as sensitive tool to test solar models: expected fluxes

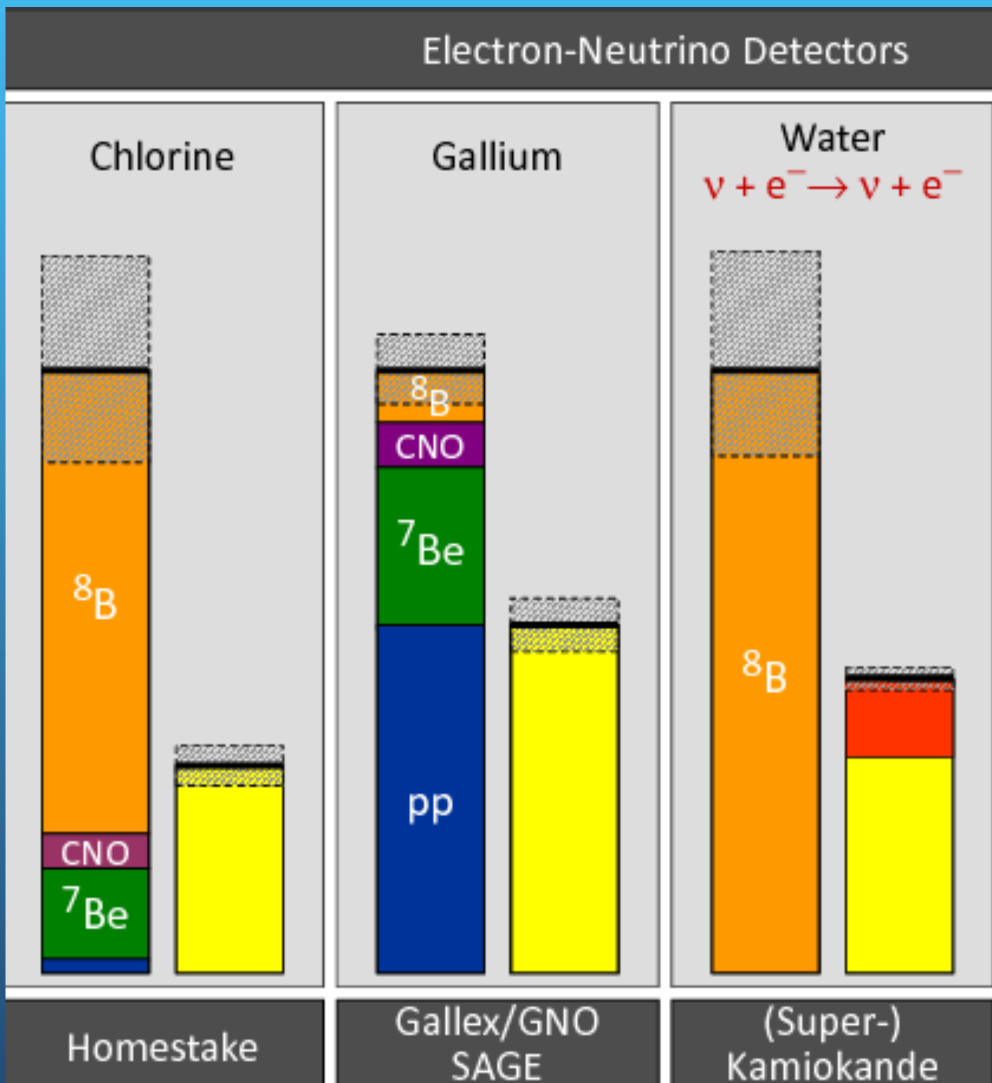
FLUX	B16-GS98
pp (10^{10} cm^{-2} s^{-1})	5.98(1±0.006)
pep (10^{8} cm^{-2} s^{-1})	1.44(1±0.01)
^{7}Be (10^{9} cm^{-2} s^{-1})	4.94(1±0.06)
^{8}B (10^{6} cm^{-2} s^{-1})	5.46(1±0.12)
^{13}N (10^{8} cm^{-2} s^{-1})	2.78(1±0.15)
^{15}O (10^{8} cm^{-2} s^{-1})	2.05(1±0.17)
^{17}F(10^{6} cm^{-2} s^{-1})	5.29(1±0.20)

N. Vinyoles et al., Astrophys. J. 836 (2017) 202



Original motivation of the first experiments on solar ν was to test the Standard Solar Model (SSM)

The solar neutrino problem: Homestake/Kamioka/Gallex-Sage



(years: 1970-2000)

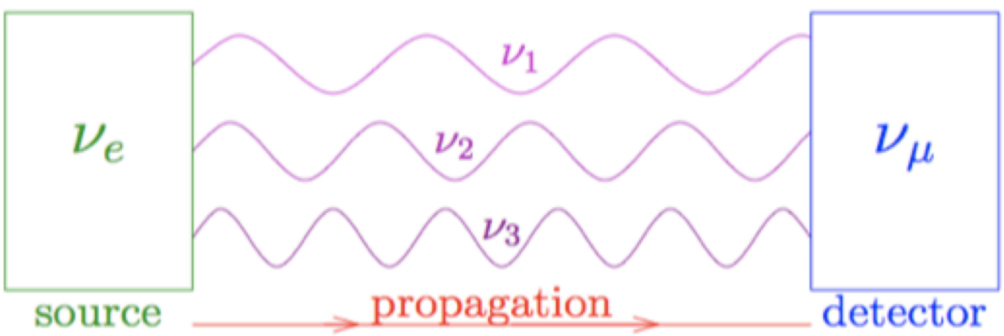
Solar Neutrino Problem:

Fluxes 1/2 or 1/3
of expectations!

The solar neutrino problem : possible explanations

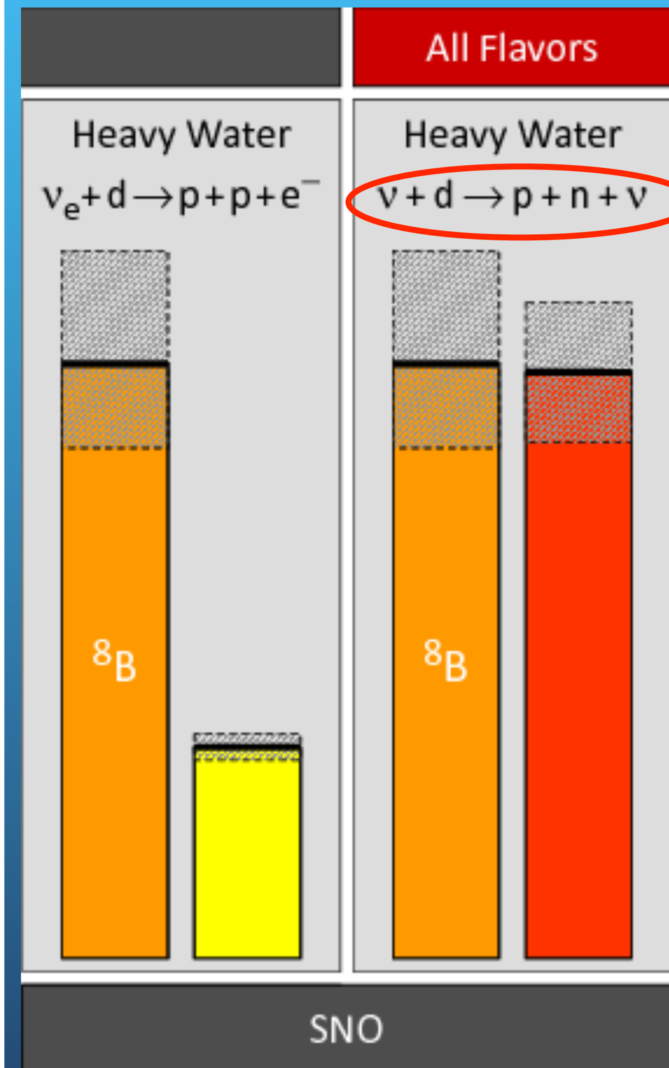
- Wrong experiments?
- Nuclear physics solution?
- If neutrinos are massive: flavour oscillations?

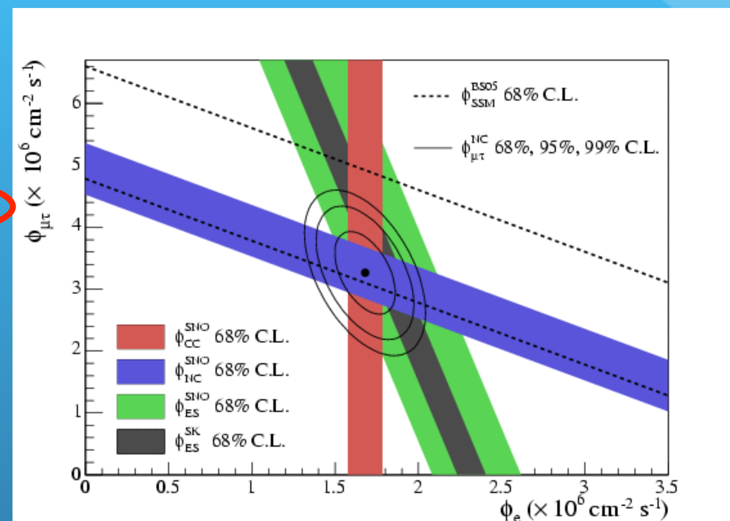
$$|\nu(t=0)\rangle = |\nu_e\rangle = U_{e1}\,|\nu_1\rangle + U_{e2}\,|\nu_2\rangle + U_{e3}\,|\nu_3\rangle$$



$$|\nu(t>0)\rangle = U_{e1}\,e^{-iE_1 t}\,|\nu_1\rangle + U_{e2}\,e^{-iE_2 t}\,|\nu_2\rangle + U_{e3}\,e^{-iE_3 t}\,|\nu_3\rangle \neq |\nu_e\rangle$$

The solution: SNO experiment (year:2000)



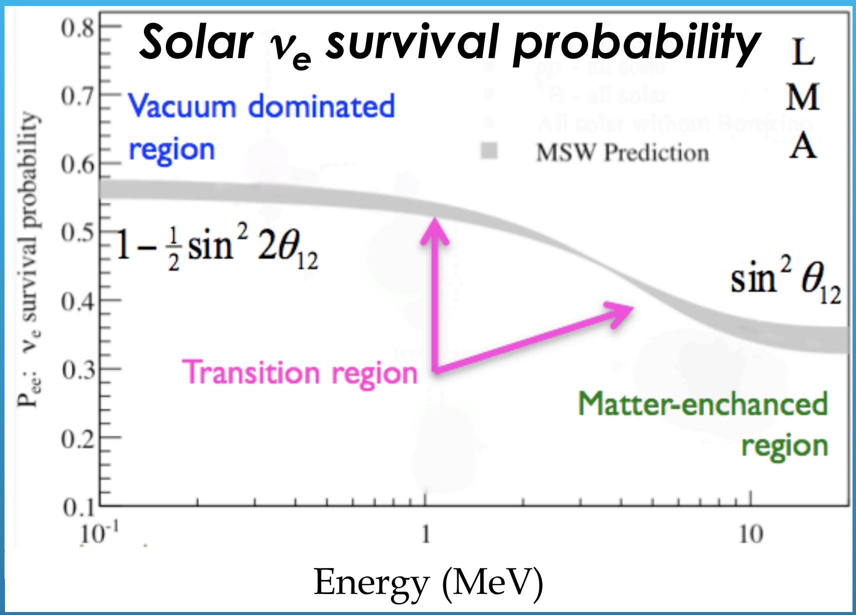


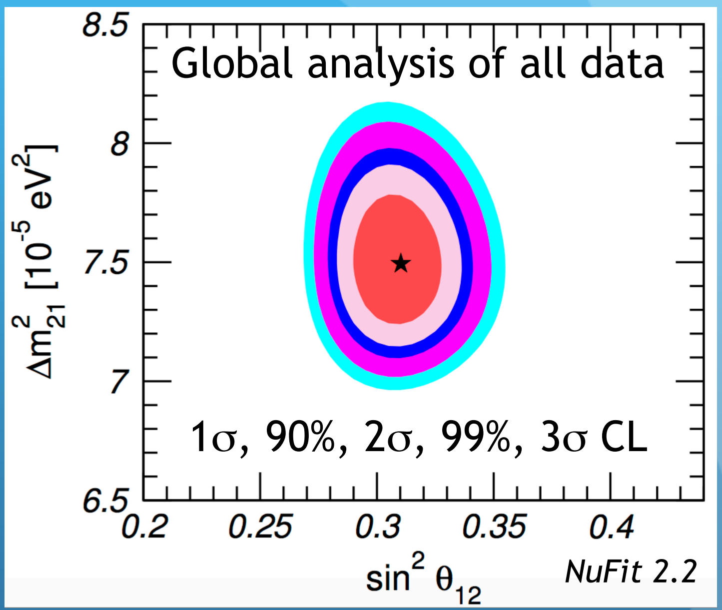
$\Phi_{NC}(\nu_x)$=(4.94 $\pm$ 0.21 (stat) $^{+0.38}_{-0.34}$ (syst.))x 10^6 cm^{-2}s^{-1}
391 days salt phase

$\Phi_{SSM}(\nu_x)$= 5.46 (1$\pm$ 0.12) x 10^6 cm^{-2}s^{-1}

The signal depends on the detection reaction and on the neutrino flavor composition at the detector

Flavour oscillations in the Sun





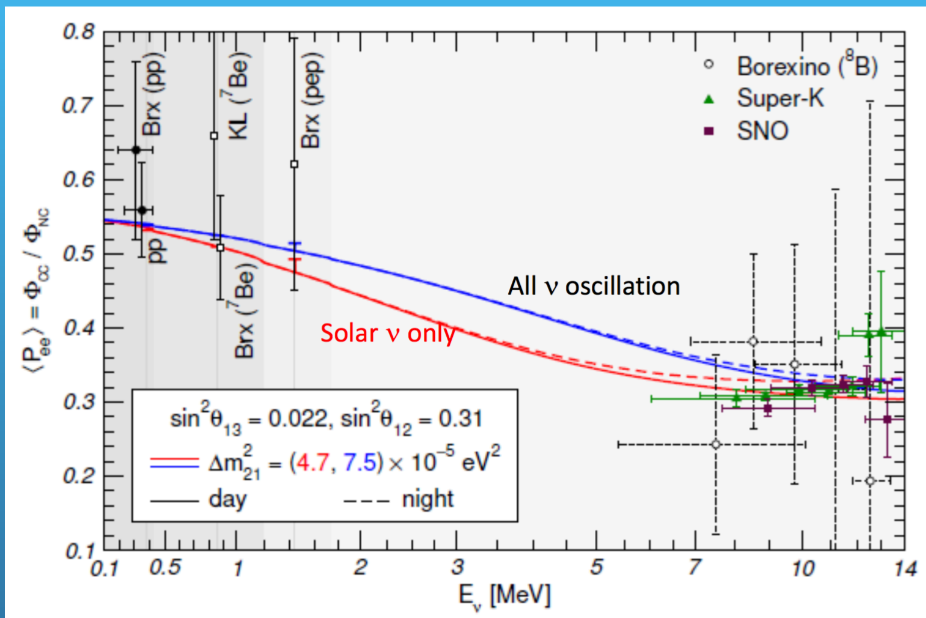
Enhanced conversion in the Sun for multi-MeV neutrinos because of ν_e forward scattering process with electrons (MSW effect)

$$P_{ee}^{3\nu} = \frac{1}{2}\cos^4\theta_{13}\left(1+\cos 2\theta_{12}^M \cos 2\theta_{12}\right)$$

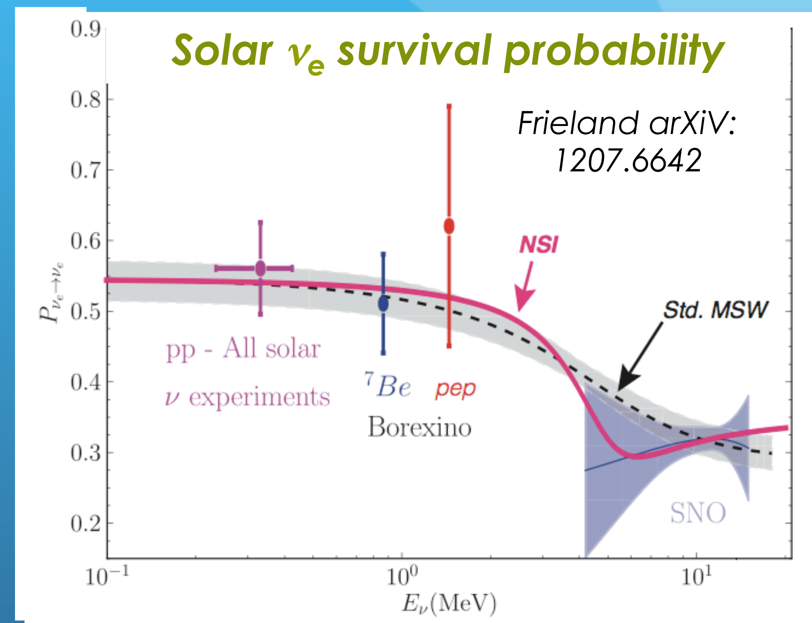
$$\cos 2\theta_{12}^M = \frac{\cos 2\theta_{12} - \beta}{\sqrt{(\cos 2\theta_{12}-\beta)^2 + \sin^2 2\theta_{12}}}$$

$$\beta = \frac{2\sqrt{2} G_F cos^2\theta_{13} n_e E_\nu}{\Delta m^2_{12}}$$

The importance of precision spectroscopy: Particle physics



Maltoni & Smirnov,Eur.Phys.J.2016

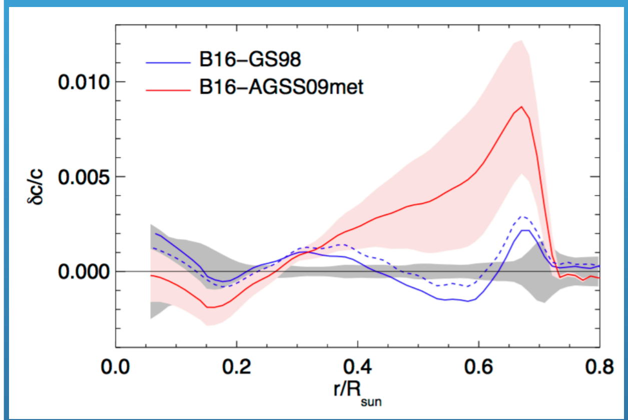


✓**Improve the knowledge of mixing parameters, confirm MSW-LMA or exploit possible traces of non-standard neutrino-matter interaction, sub-leading effects, mixing with light sterile ν's**

✓**Help to understand the high/Low metallicity solar model controversy**

The importance of precision spectroscopy: Sun physics

Metallicity puzzle



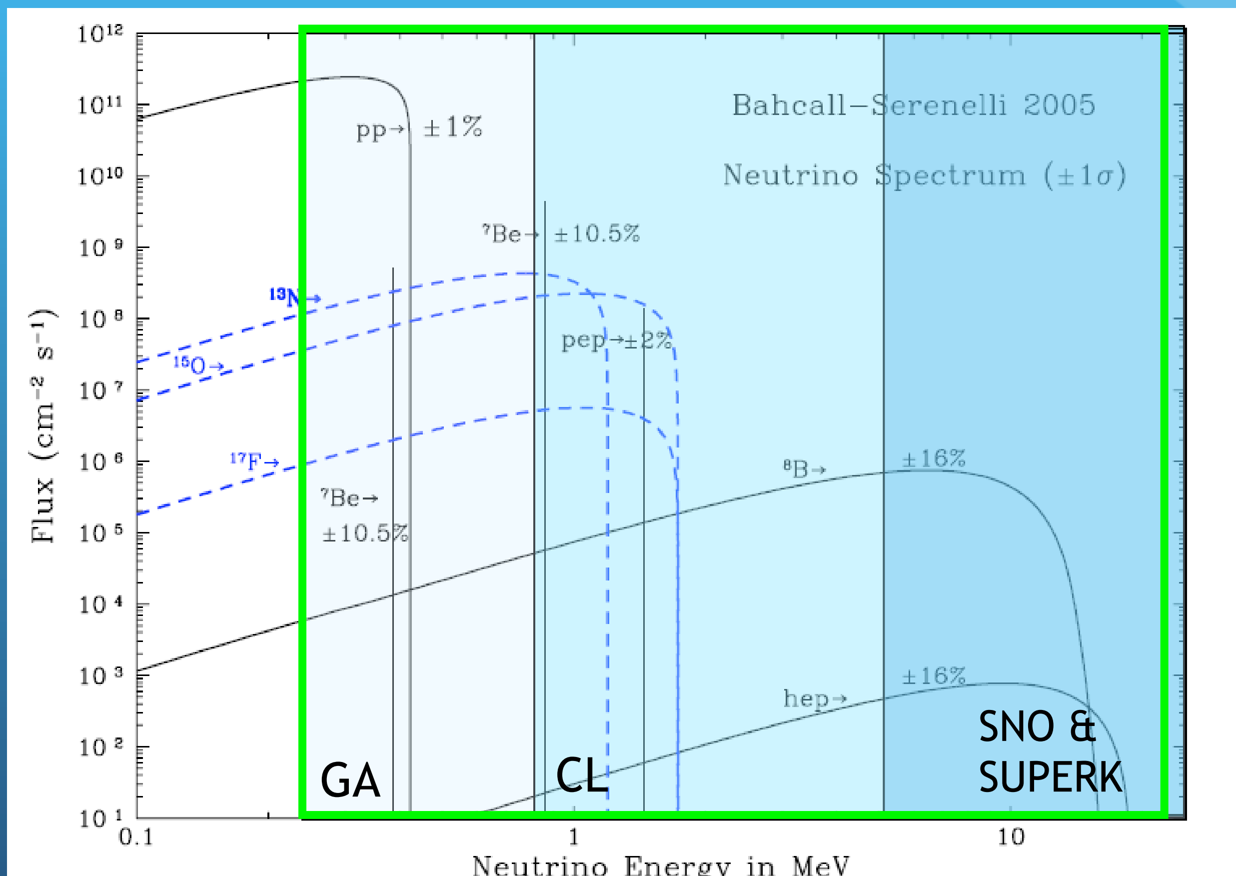
FLUX	B16-GS98	B16-AGSs09met	DIFF. (HZ-LZ)/HZ
pp (10^{10} cm^{-2} s^{-1})	5.98(1±0.006)	6.03(1±0.005)	-0.8%
pep (10^{8} cm^{-2} s^{-1})	1.44(1±0.01)	1.46(1±0.009)	-1.4%
^{7}Be (10^{9} cm^{-2} s^{-1})	4.94(1±0.06)	4.50(1±0.06)	8.9%
^{8}B (10^{6} cm^{-2} s^{-1})	5.46(1±0.12)	4.50(1±0.12)	17.6%
^{13}N (10^{8} cm^{-2} s^{-1})	2.78(1±0.15)	2.04(1±0.14)	26.6%
^{15}O (10^{8} cm^{-2} s^{-1})	2.05(1±0.17)	1.44(1±0.16)	29.7%
^{17}F(10^{6} cm^{-2} s^{-1})	5.29(1±0.20)	3.26(1±0.18)	38.3%

N. Vinyoles et al.,Astrophys. J. 836 (2017) 202

✓**Improve the knowledge of mixing parameters, confirm MSW-LMA or exploit possible traces of non-standard neutrino-matter interaction, sub-leading effects, mixing with light sterile ν's**

✓**Help to understand the high/Low metallicity solar model controversy**

Borexino goal: the measure in real time of the single ν components



BOREXINO

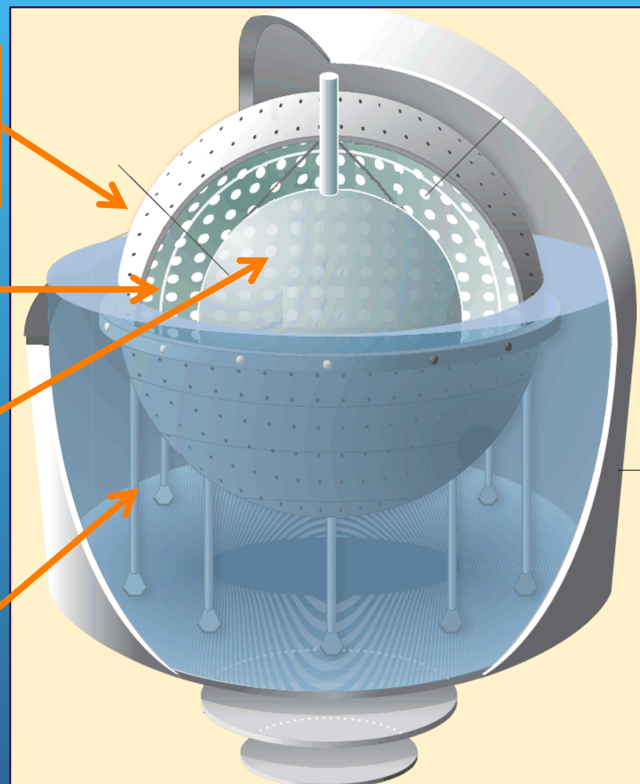
The Borexino detector

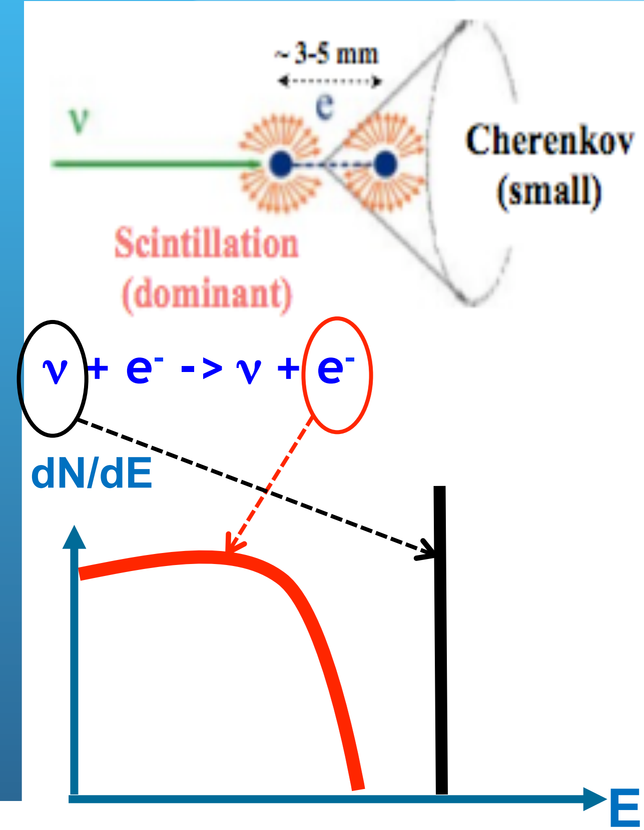
Stainless Steel Sphere:
R = 6.75 m, 1350 m^3 of water
Support for 2212 PMTs

Buffer region:
PC+DMP quencher (5 g/l)
4.25 m < R < 6.75 m

Scintillator:
270 t PC+PPO (1.5 g/l)
(R = 4.25 m)

Water Tank:
2100 m^3 of water
208 PMTs Cherenkoc





- Scintillation light detected by PMT's
  - # of photons ➔ energy
  - time of flight ➔ position
  - pulse shape ➔ α/β β+/β−

- Light yield: ~500 phe/MeV
- Energy resolution: 5% @ 1MeV
- Space resolution: 10cm@ 1 MeV
- Pulse shape capability

We measure the energy carried away by the electron!

Borexino phase II data

PHASE I | Scint.Purification | PHASE II | Sox

2007 | 2010 | 2012 | 2017 | 2018

^{7}Be, pep, ^{8}B, geo ν Rare process. Calibrations

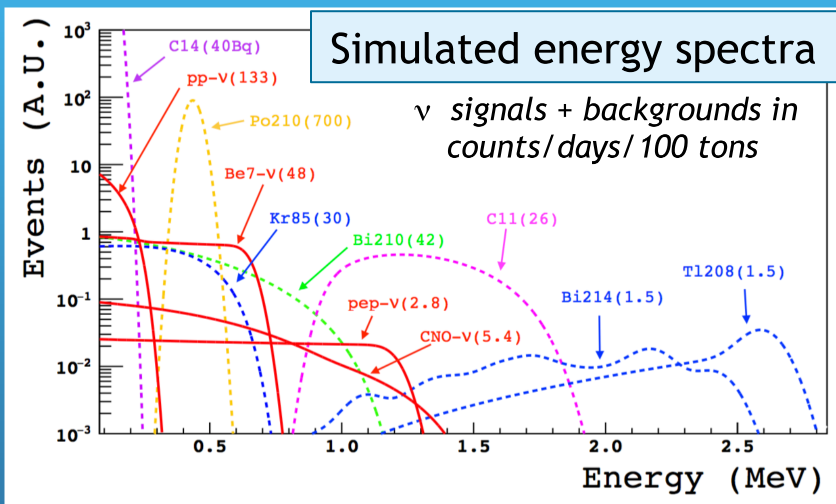
^{7}Be seasonal modulation pp, geo ν

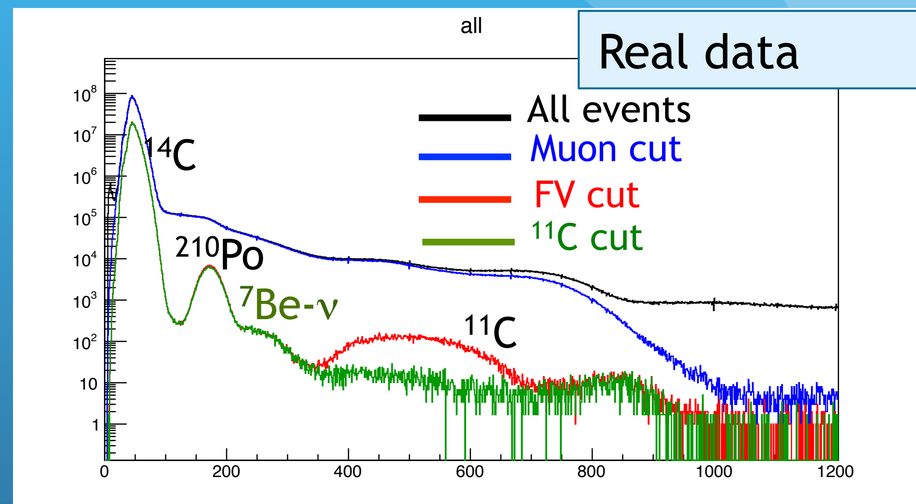
New phase II data

- Larger exposure;
- Background reduction;
- More accurate description of detector response

- **Spectral measurement of the pp rate (***Nature, Vol. 512 2014***)** with a dedicated analysis of the low energy portion of the spectrum;
- **Seasonal modulations of the ^{7}Be solar neutrino signal** *(Astr.Phys. 92 (2017) 21);* **NEW!**
- **First Simultaneuos Precision Spectroscopy of pp, ^{7}Be and pep Solar Neutrinos** *(arXiV:1707.09279);* **NEW!**
- **Updated ^{8}B result** *(arXiV: 0808.2868);* **NEW!**
- **New upper limit on neutrino magnetic moment** *(arXiV:1707.09355)* **NEW!**

Signal and backgrounds





After 2010 purifications:

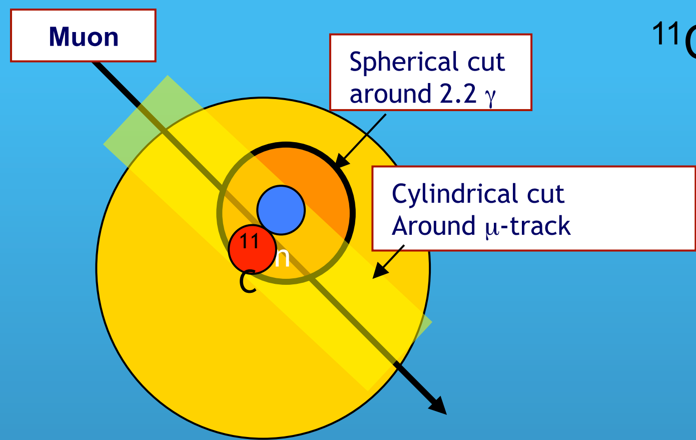
- ^{232}Th (from ^{212}Bi-Po): < 5.7 10^{-19} g/g at 95%C.L.
- ^{238}U (from ^{214}Bi-Po): < 9.4 10^{-20} g/g at 95%C.L.
- ^{85}Kr reduced by a factor 5 and ^{210}Bi by a factor 2.3

Event selection:

- Removal μ and conmogenics (1.5% dead time)
- Removal of ^{214}Bi-Po
- Noise events
- Fiducial Volume (71.3 tons)
- No α/β discrimination;

Good events removed by cuts :1.5%

^{11}C cut: 1) the three fold coincidence



^{11}C is produced by muons together with neutron(s);

$$\mu + {}^{12}C \rightarrow \mu + {}^{11}C + n$$

The likelihood that a certain event is ^{11}C is obtained using:

- Distance in space and time from the μ-track;
- Distance from the neutron;
- Neutron multiplicity;
- Muon dE/dx and number of muon clusters in an event;

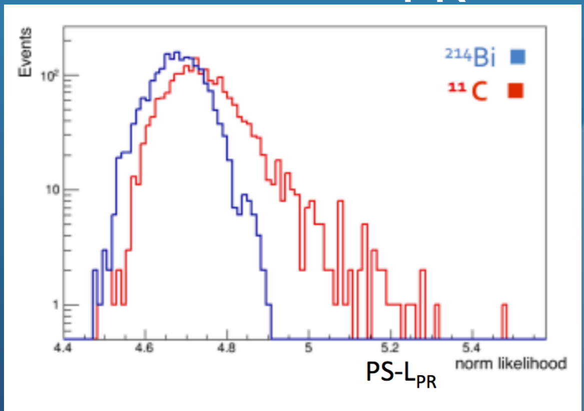
Performances: 92.4 ± 4 % tagging efficiency

Exposure: 64% in the ^{11}C subtracted spectrum

2) The β^+/β^- pulse-shape variable PS-L_{PR}:

^{11}C decays β^+ : the probability density function (PDF) of the scintillation time profile is different for e^- and e^+ for two reasons:

- in 50% of the case e^+ annihilation is delayed by ortho-positronium formation (τ~3ns);
- e^+ energy deposit is not point-like because of the two annihilation gammas;



New discrimination parameter based on the output likelihood of the pos-reco alghoritm

First simultaneous spectroscopy of pp, ^{7}Be and pep-ν: analysis method

The presence of residual backgrounds (^{14}C, pile-up, ^{85}Kr, ^{210}Bi, ^{210}Po, ^{11}C) makes it complex to extract the neutrino signal from our data;

Method: Maximize a binned likelihood through a multivariate approach

$$L(\vartheta) = L_{11C-sub}(\vartheta) \cdot L_{11C-tag}(\vartheta) \cdot L_{radial}(\vartheta) \cdot L_{PS-L_{PR}}(\vartheta)$$

We include in the likelihood:

- Energy spectrum (^{11}C-tagged and ^{11}C-subtracted)
- Pulse-shape distribution PS-L_{PR} ;
- Radial distribution;

to disentangle ^{11}C

to disentangle external background

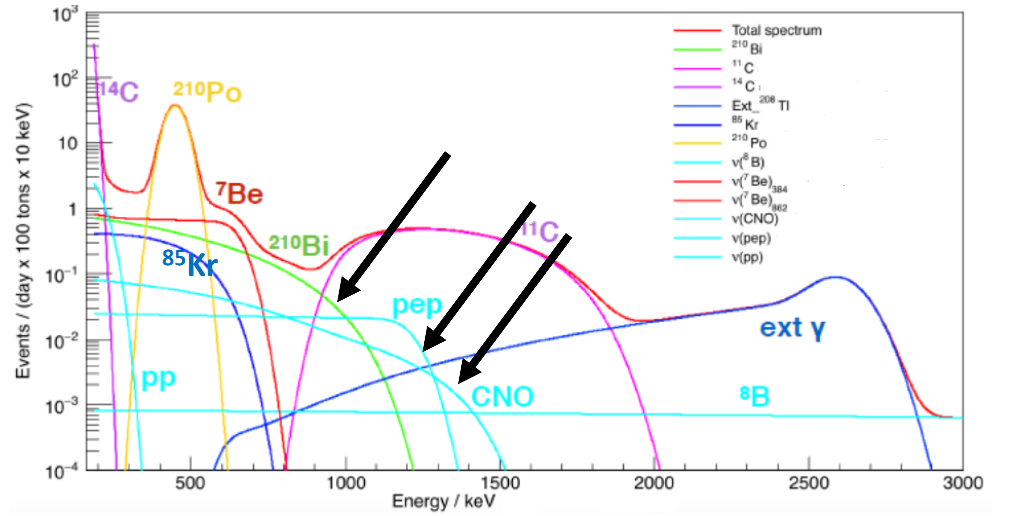
Checks for systematical effects:

- Fit performed in different conditions (energy range, energy variable, binning..);
- Developed a Toy-MC to :
  - ✓ Build MC data set with the same exposure as in the data
  - ✓ Fit with pdf used to fit the data
  - ✓ Check bias, sensitivity, correlations
- Energy fit performed both with the MonteCarlo and the Analytical methods.

First simultaneous spectroscopy of pp,^{7}Be and pep-ν: analysis method

Problem: CNO ν recoil and ^{210}Bi: very similar energy spectrum

Simulation of signal and background spectra



Analysis strategy

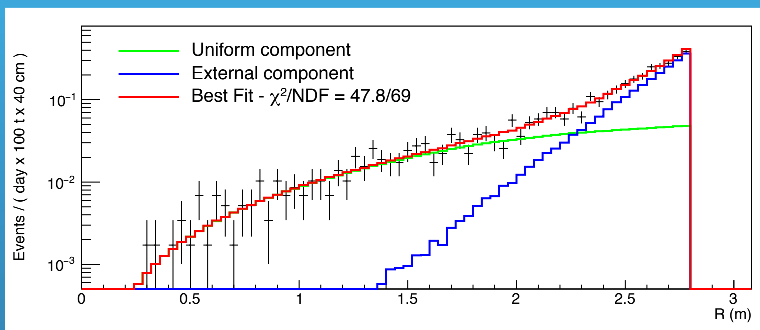
1) pp ^{7}Be pep flux measurement: set a constrain of the CNO rate to the HZ and LZ values

- *CNO HZ* = *(*4.92 $\pm$ 0.56) *cpd* /100*t*
- *CNO LZ* =*(*3.52 $\pm$ 0.37) *cpd* /100*t*

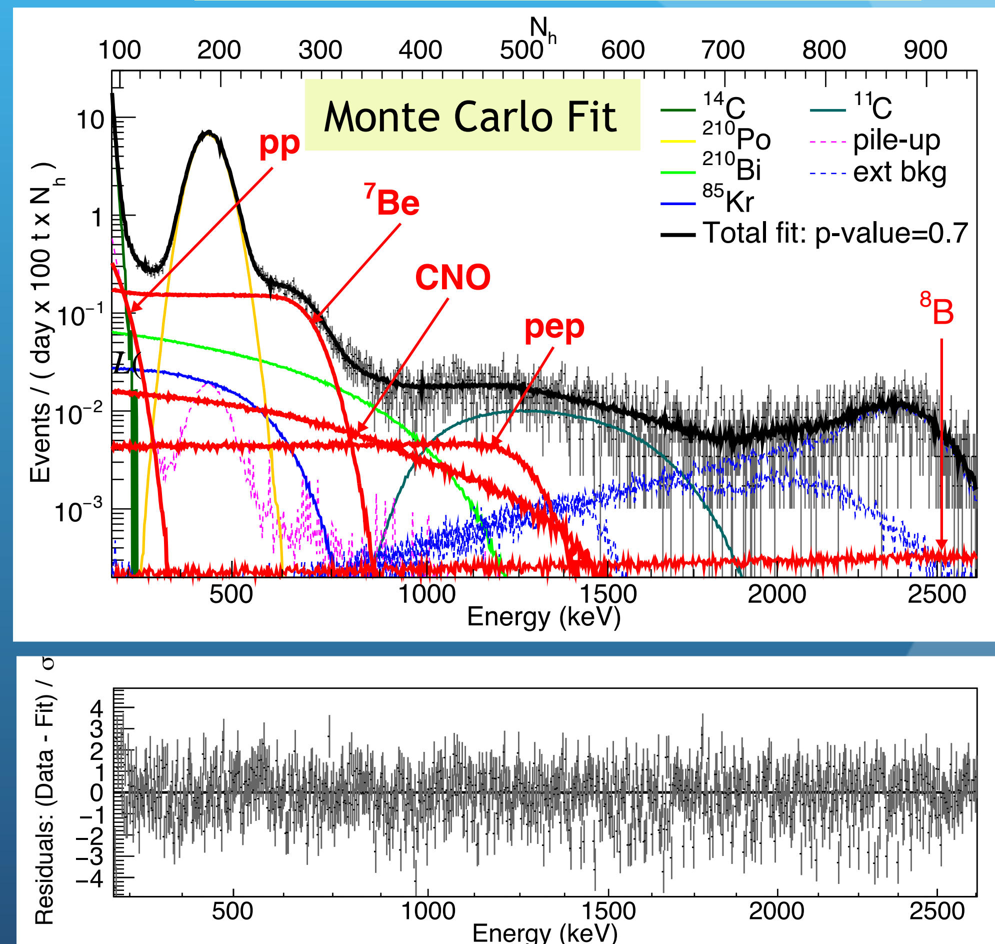
For details ..see M. Redchuk poster!

Results : example of multivariate fit of the data

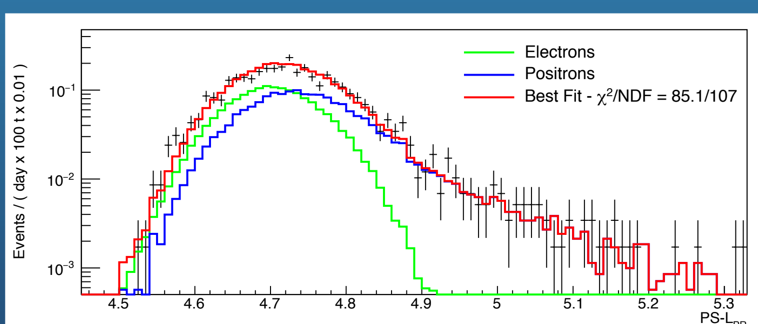
Radial distribution



Energy spectrum ^{11}C subtracted



PS-L_{PR}



Comparison between Phase I and Phase II results

arXiV:1707.09279

- **Data-set:** Dec 14th 2011- May 21st 2016;
- **Total exposure**: 1291.5 days x 71.3 tons= 252.3 ton*year;
- **Fit range**: (0.19-2.93) MeV;

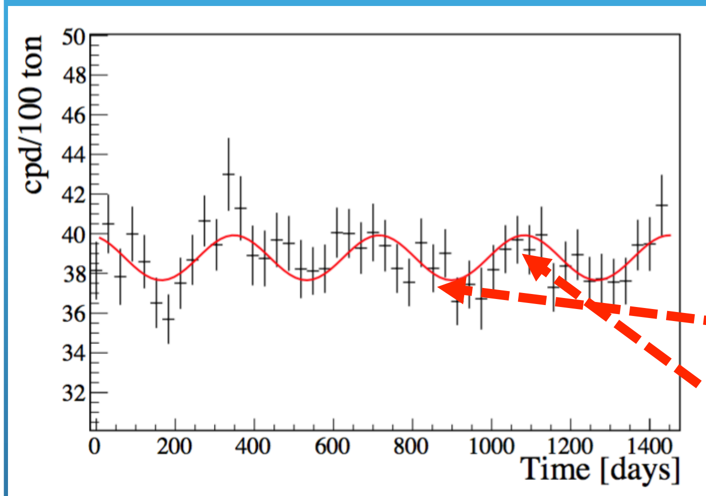
- All rates are fully compatible with and improve the uncertainty of the previously published Borexino results;

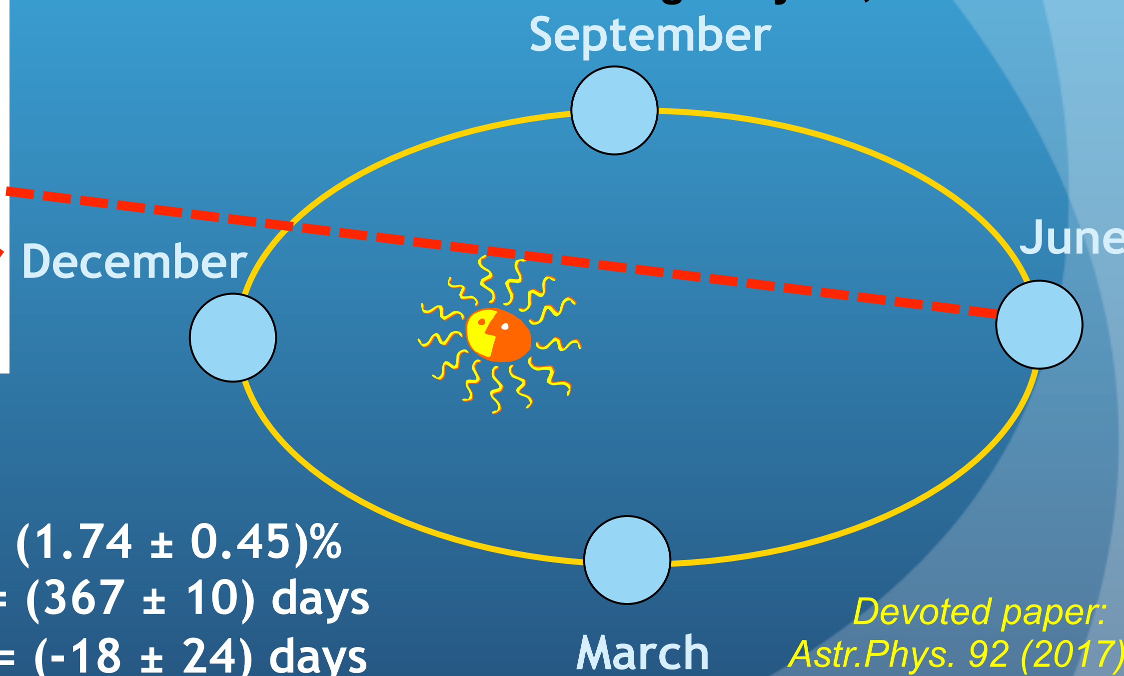
	Previous BX results (cpd/100t)	This work (cpd/100t)	Uncertainty reduction
pp	$144\pm13\pm10$	$134\pm10^{+6}_{-10}$	11 → 9%
^{7}Be(862 keV)	$46.0\pm1.5^{+1.6}_{-1.5}$	$46.3\pm1.1^{+0.4}_{-0.7}$	4.7 → 2.7%
pep	$3.1\pm0.6\pm0.3$	(HZ) $2.43\pm0.36^{+0.15}_{-0.22}$ (LZ) $2.65\pm0.36^{+0.15}_{-0.24}$	22-> 16%

Implications of Phase II results: ^{7}Be-ν seasonal modulation

Present precision on ^{7}Be flux : 2.7% , theoretical error : 7%

The stability and radiopurity of phase II allowed to observe the seasonal variations of the neutrino interaction rate due to the varying distance L(t) between Sun and Earth during the year;





Fit to the evolution of the rate in time (bin of 30 days) ⇒

ε = (1.74 ± 0.45)%
T = (367 ± 10) days
Φ = (-18 ± 24) days

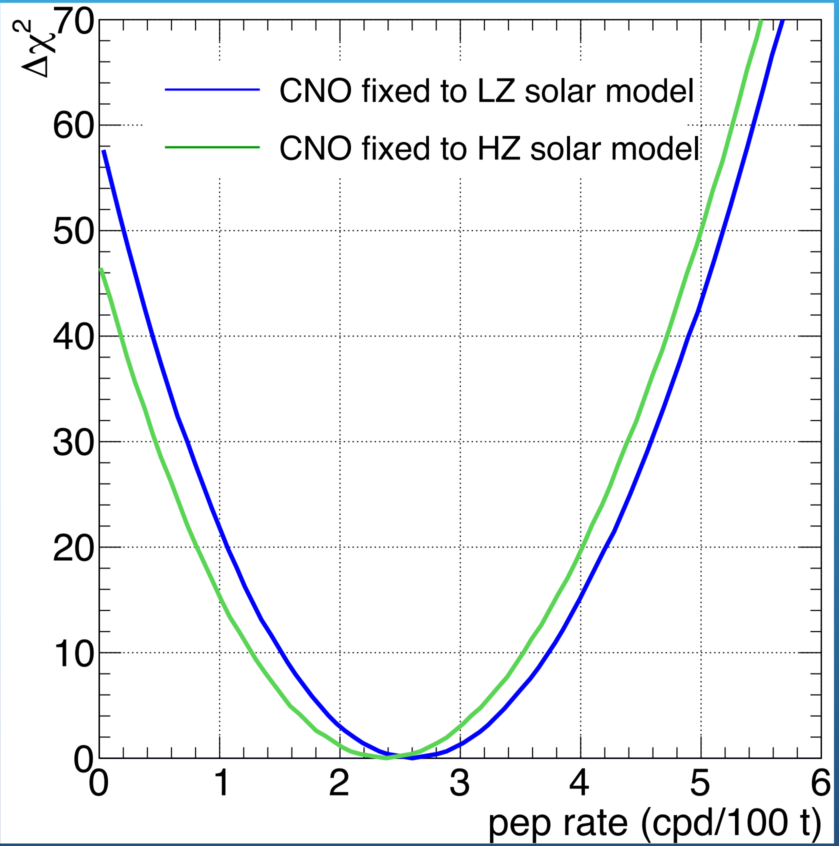
Devoted paper: Astr.Phys. 92 (2017) 21

Measurement of the astronomic year with solar neutrinos!

Implications of Phase II results: evidence of pep solar ν at 5σ

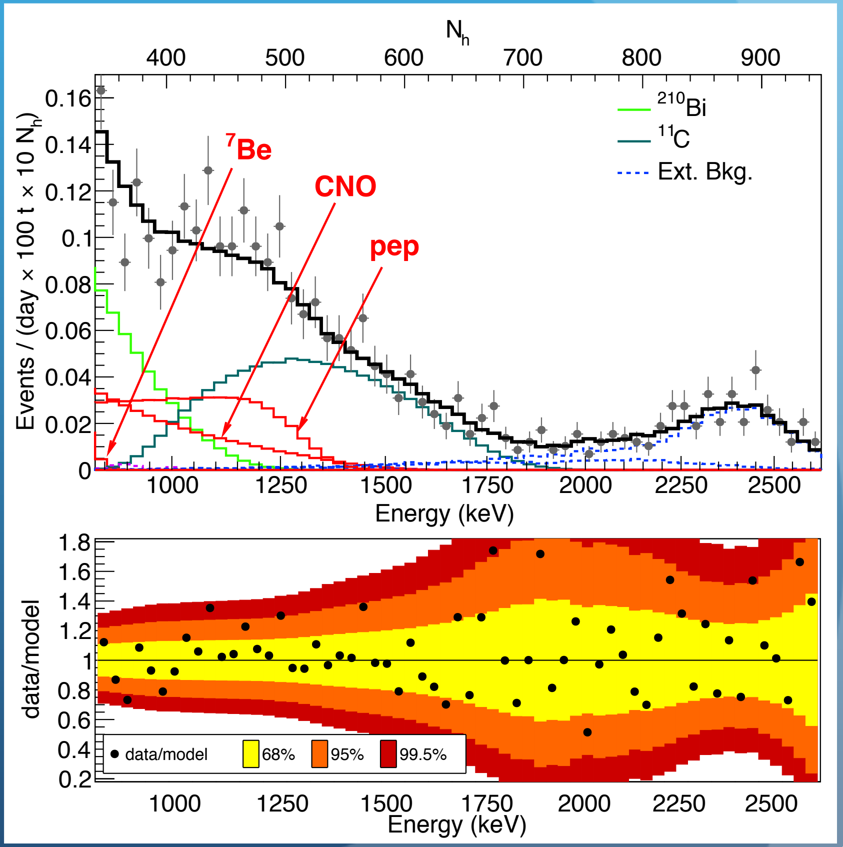
Likelihood profile resulting from the multivariate fit

(*systematical uncertainties included*)



Selected the innermost β-like events

Radius <2.4 m Ps-LPR < 4.8



Implications of Phase II results: Upper limit on the CNO flux

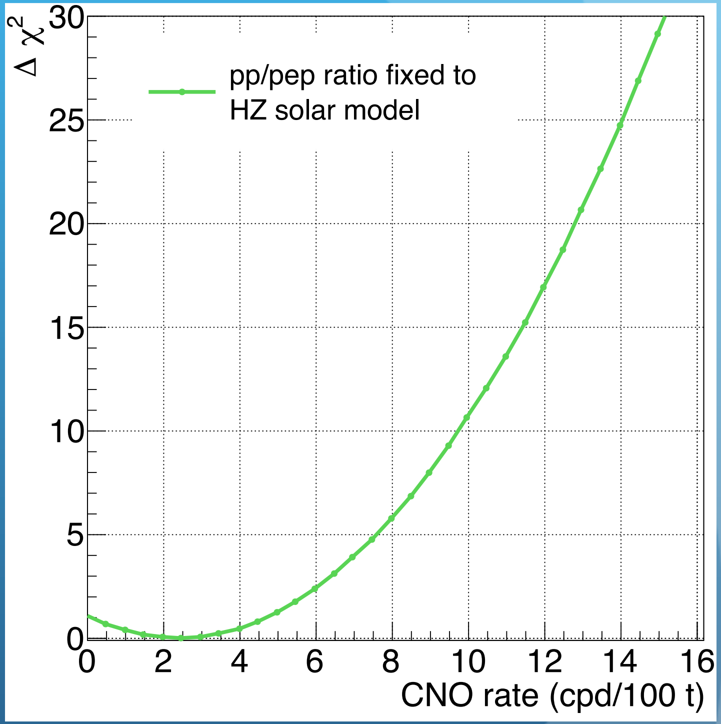
95% C.L. limit on the CNO-ν rate:

Rate < 8.1 cpd/100t

Flux $< 7.9\ 10^8\ cm^{-2}\ s^{-1}$

(including systematical uncertainties)

- *pp/pep ratio constrained: **(47.7±1.2)***
- *LMA-MSW included*
- *Toy MC to study the sensitivity:*
- *The median 95% C.L. is : - 9 cpd/100t (LZ)*
  - 10 cpd/100t (HZ)



	Borexino result	Expected HZ	Expected LZ
CNO ν (cpd/100t)	< 8.1 (95% C.L.)	4.91 $\pm$ 0.56	3.62 $\pm$ 0.37

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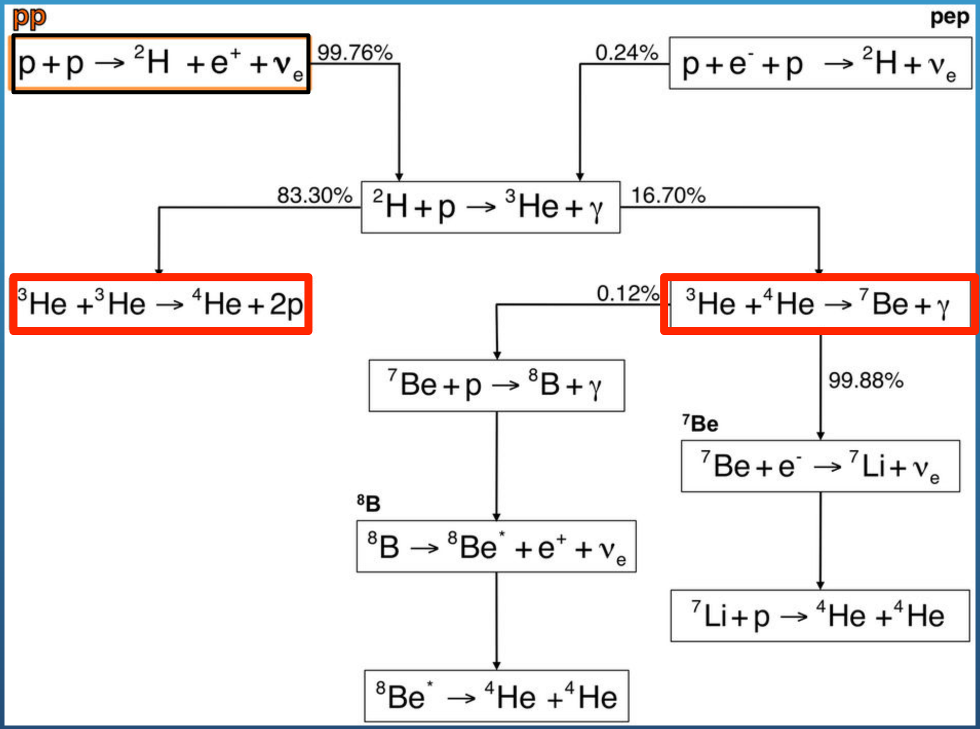
Implications of Phase II results: probe solar fusion with ν-fluxes rates

$$R = \frac{2\Phi(^{7}Be)}{\Phi(pp) - \Phi(^{7}Be)} = \frac{^{3}He\ +\ ^{4}He\ Rate}{^{3}He\ +\ ^{3}He\ Rate}$$

J. Bahcall 2003

Reactions of the pp chain



Expected values:

(from G. Pena-Garay priv. comm)

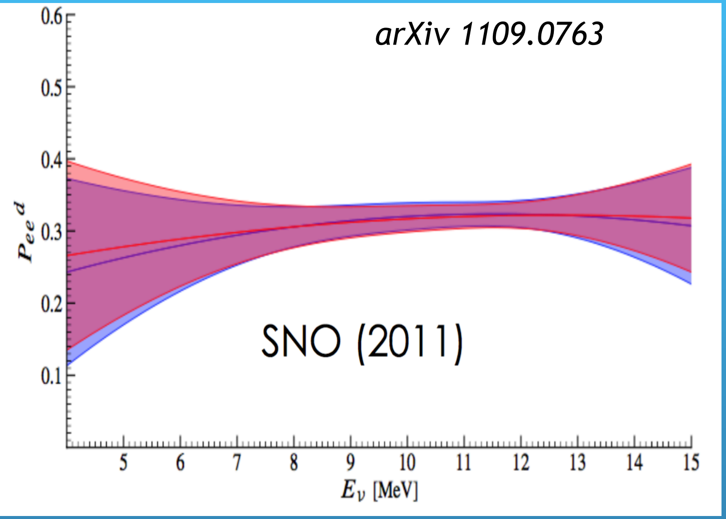
R= 0.180 $\pm$ 0.011 HZ
R= 0.161 $\pm$ 0.010 LZ

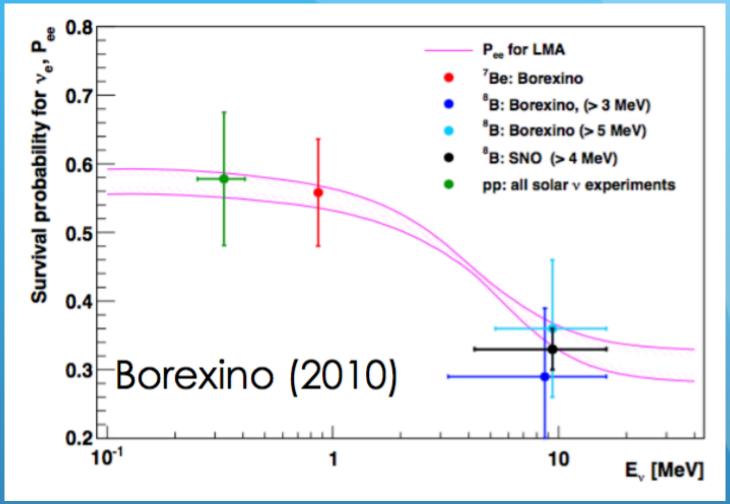
Measured value (Borexino):

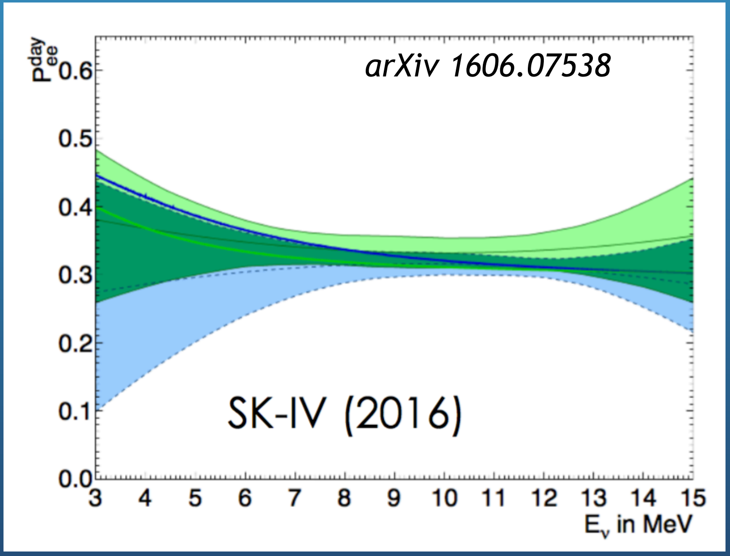
R= 0.18 $\pm$ 0.02

New! *arXiV: 0808.2868*

^{8}B-ν : up turn or downturn?





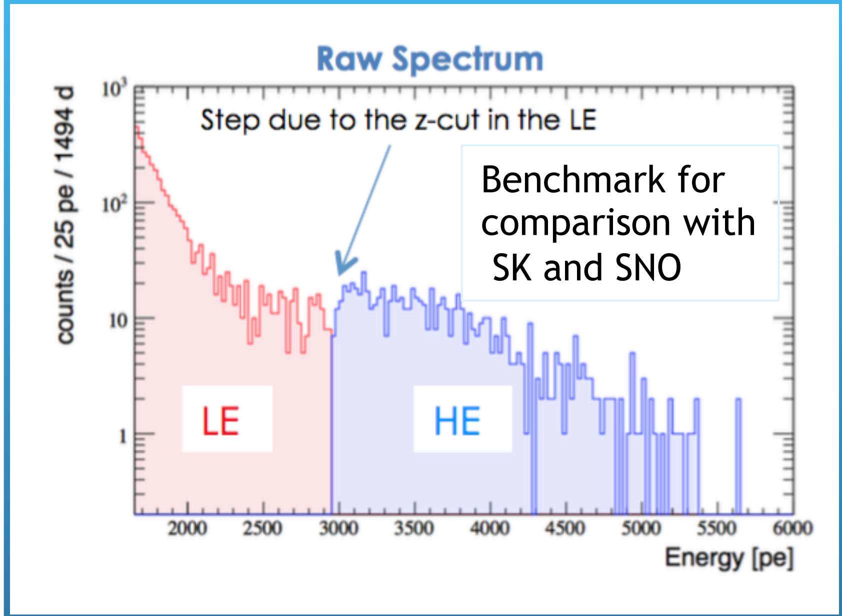


Borexino: 2010 analysis -> Present (2017)
488 days -> 2062 days

The fiducial mass has been extended from 100 tons to the whole FV (~ 300 tons)

Total exposure : 1.5 kton year
(11.5 – fold increase)

^{8}B-ν study: two energy windows



Multi-MeV range energy estimator: charge (p.e.)

Two ROI's	e- Recoil Energy	<Eν>
LE: 1560-2950 p.e.	~ 3-5 MeV	7.9 MeV
HE: 2950-8500 p.e.	~ 5-17 MeV	9.9 MeV

Backgrounds:

- HE: fraction of μ and fast cosmogenics surviving the cuts, ^{11}Be + external γ from (n,γ) reactions
- LE: faction of μ,n, fast cosmogenics and ^{214}Bi surving the cuts + ^{11}Be + ^{208}Tl + external γ from (n,γ) reactions

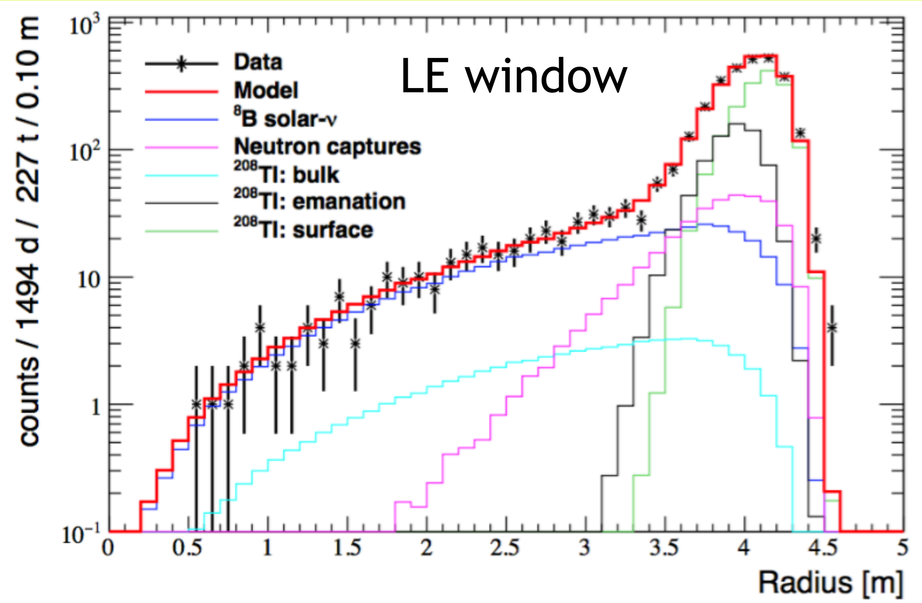
- *^{212}Bi-Po fast coincidence was used to quantify ^{208}Tl in the scintillator bulk:*

Selection cuts:

- Neutron cut : 6.5 veto after internal μ
- ^{10}C cut : like TFC, veto around each n after μ
- Run stop/start cut : 6.5 s veto after run start time
- Fast coincidence cut: no ^{214}Bi-Po
- Random coincidence cut: no events closer that 5 s

Dead Time : 27.6 %

^{8}B-ν : log-L fit of the radial distribution



Component	LE rate [cpd/227.8 t]	HE rate [cpd/266.0 t]
^{8}B neutrinos	0.310±0.029	0.235±0.021
External	0.224±0.078	0.239±0.022
^{208}Tl bulk	0.042±0.008	-
^{208}Tl emanation	0.469±0.063	-
^{208}Tl surface	1.090±0.046	-

Background	LE rate [10^{-4} cpd/100 t]	HE rate [10^{-4} cpd/100 t]
Fast cosmogenics	13.6±0.6	10.4±0.4
Muons	1.2±0.1	3.8±0.3
Neutrons	0.72±0.02	0
^{10}C	9.5±14.1	0
^{11}Be	$0^{+36.3}_{-0.0}$	$0^{+54.9}_{-0.0}$
^{214}Bi	2.2±1.0	0
Total	$27.2^{+38.9}_{-14.1}$	$14.2^{+54.9}_{-0.5}$

$$R_{LE} = 0.133^{+0.013}_{-0.013}\,(stat)\,^{+0.003}_{-0.003}\,(syst)\ \mathrm{cpd/100\,t},$$

$$R_{HE} = 0.087^{+0.08}_{-0.010}\,(stat)\,^{+0.005}_{-0.005}\,(syst)\ \mathrm{cpd/100\,t},$$

$$R_{LE+HE} = 0.220^{+0.015}_{-0.016}\,(stat)\,^{+0.006}_{-0.006}\,(syst)\ \mathrm{cpd/100\,t}.$$

Expected rate in the LE+HE range

0.211 ± 0.025 cpd/100t

Assuming B16(G98) SSM and MSW+LMA

Equivalent flavor-stable flux:

2010: $\Phi(^{8}B)=(2.4 \pm 0.4)\ 10^{6}\ cm^{-2}\ s^{-1}$

2017: $\Phi(^{8}B)=(2.55^{+0.19}_{-0.17}(stat)\ ^{+0.10}_{-0.06}(sys))10^{6}\ cm^{-2}\ s^{-1}$

Uncertainty reduced by a factor 2

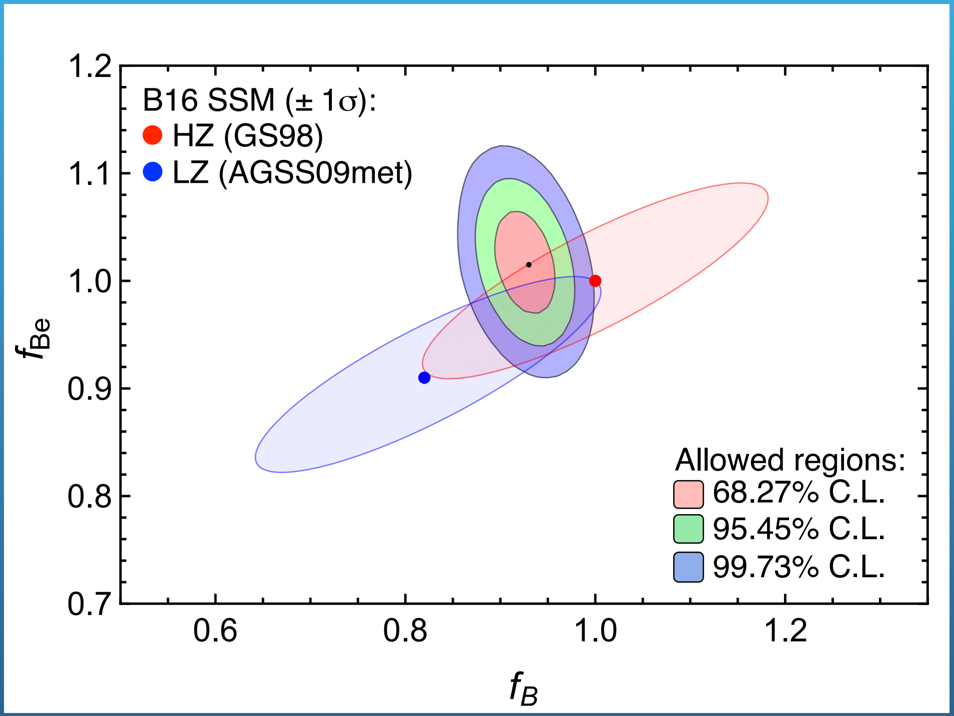
New pp, ^{7}Be, pep and ^{8}B-ν results

Rates	Borexino results cpd/100t	Expected HZ cpd/100t	Expected LZ cpd/100t
pp	$134 \pm 10^{+6}_{-10}$	131.0 ± 2.4	132.1 ± 2.4
^{7}Be (862+384 keV)	$48.3 \pm 1.1^{+0.4}_{-0.7}$	47.8 ± 2.9	43.7 ± 2.6
Pep (HZ)	$2.43 \pm 0.36^{+0.15}_{-0.22}$	2.74 ± 0.05	2.78 ± 0.05
Pep (LZ)	$2.65 \pm 0.36^{+0.15}_{-0.24}$	2.74 ± 0.05	2.78 ± 0.05
^{8}B (E_{e-}> 3MeV)	$0.220\ ^{+0.015}_{-0016} \pm 0.006$	0.211 ± 0.025	0.173 ± 0.021

Fluxes	Borexino results Flux ($cm^{-2}s^{-1}$)	Expected HZ Flux ($cm^{-2}s^{-1}$)	Expected LZ Flux ($cm^{-2}s^{-1}$)
pp	$(6.1 \pm 0.5^{+0.3}_{-0.5})10^{10}$	$5.98\ (1\pm 0.006)10^{10}$	$6.03\ (1\pm 0.005)10^{10}$
^{7}Be (862+384 keV)	$(4.99 \pm 0.13^{+0.07}_{-0.10})\ 10^{9}$	$4.93\ (1\pm 0.06)\ 10^{9}$	$4.50\ (1\pm 0.06)\ 10^{9}$
Pep (HZ)	$(1.27 \pm 0.19^{+0.08}_{-0.12})\ 10^{8}$	$1.44\ (1\pm 0.009)\ 10^{8}$	$1.46\ (1\pm 0.009)10^{8}$
Pep (LZ)	$(1.39 \pm 0.19^{+0.08}_{-0.13})\ 10^{8}$	$1.44\ (1\pm 0.009)\ 10^{8}$	$1.46\ (1\pm 0.009)10^{8}$

Implications of Phase II results: towards probing HZ and LZ

Global fit of all solar + Kamland reactors with the new Borexino results



$$f_{Be} = \frac{\Phi(Be)}{\Phi(Be)_{HZ}} = 1.01 \pm 0.03$$

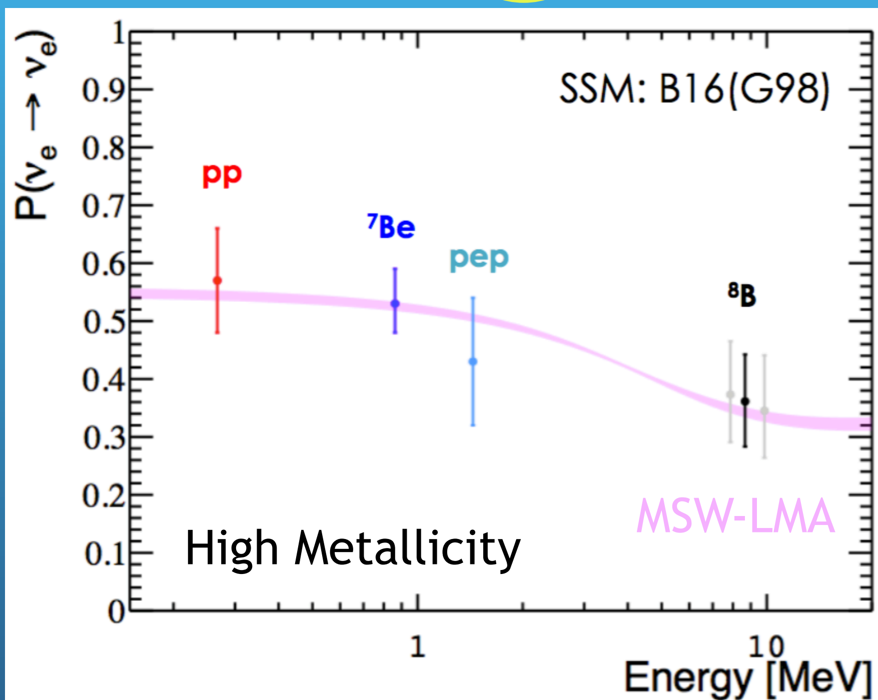
$$f_B = \frac{\Phi(B)}{\Phi(B)_{HZ}} = 0.93 \pm 0.02$$

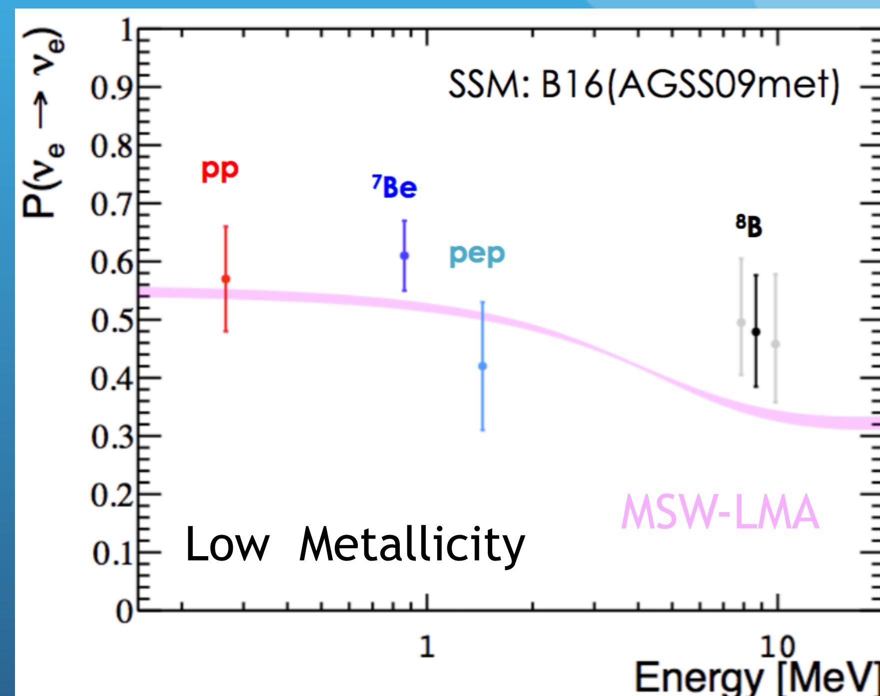
- Hints towards High Metallicity?
- Important to reduce the theoretical uncertainties

Only 1 σ theoretical uncertainty in the plot

Borexino: ν_e survival probability vs solar model metallicity

$P_{ee} = \Phi_{meas} / \Phi_{exp}$ It depends on the reference solar model





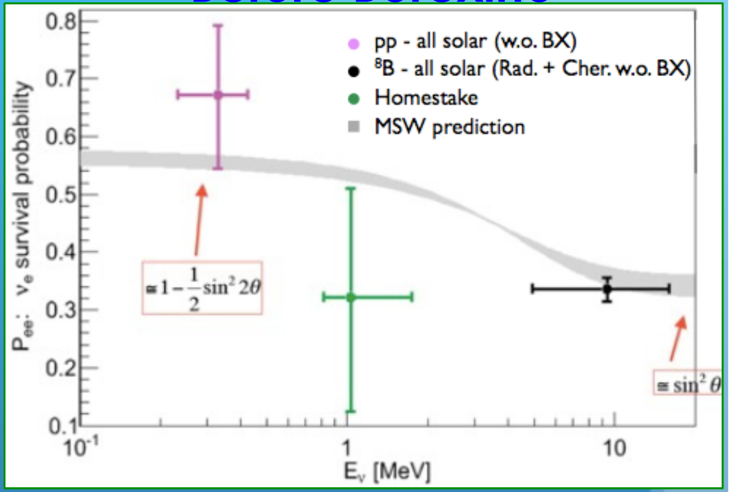
p-values:
Bx only: 0.998
All exp: 0.956

Hint toward
high metallicity?

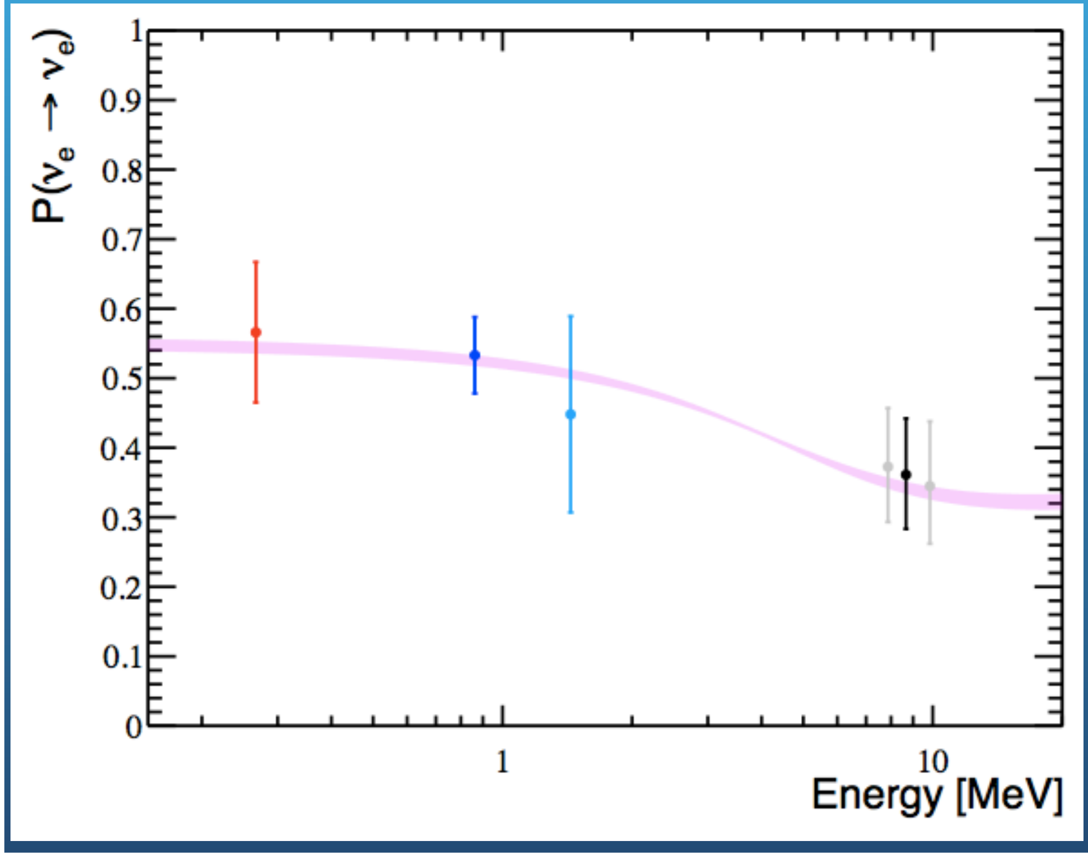
p-values:
Bx only: 0.362
All exp: 0.465

Neutrino survival probability P_{ee}: Borexino impact

Before Borexino



Borexino now



From the measured interacton rates and assuming HZ-SSM fluxes we get:

- $P_{ee}(pp)=0.57\pm0.10$
- $P_{ee}(^7Be,862keV)=0.53\pm0.05$
- $P_{ee}(pep)=0.43\pm0.11$
- $P_{ee}(^8B)= 0.36\pm0.08$ $\langle E_\nu\rangle=8.7$ MeV

New! *arXiV: 1707.0955*

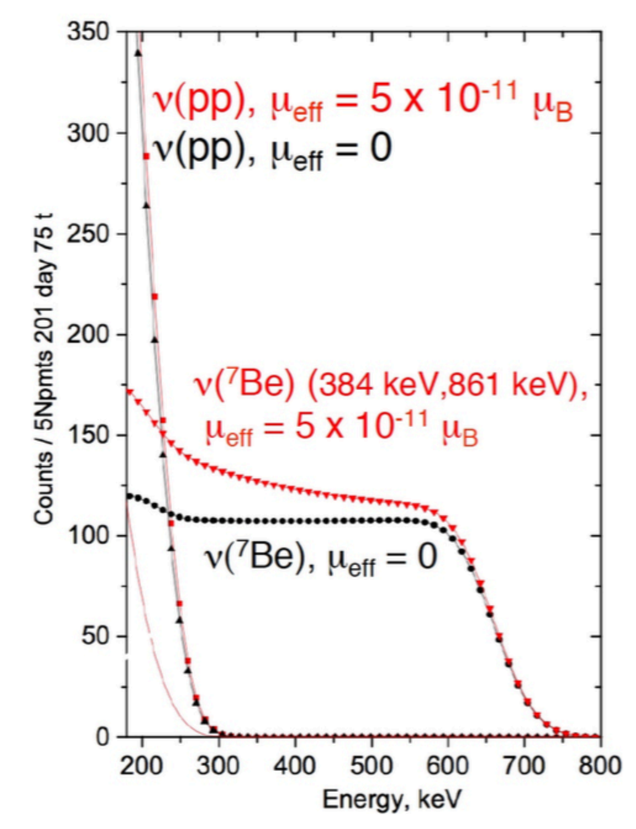
Neutrino magnetic moment

- In simple extension of SM, if $m_\nu > 0 \Rightarrow \mu_\nu > 0$

Additional EM term influencing the ν scattering cross section off electrons and thus the spectral shape:

$$\left(\frac{d\sigma}{dT}\right)_{EM} = \mu_{eff}^2 \frac{\pi\alpha_{em}^2}{m_e^2}\left(\frac{1}{T} - \frac{T}{E_\nu}\right)$$

$$\mu_{eff}^2 = P^{3\nu}\mu_e^2 + \left(1 - P^{3\nu}\right)\left(\cos^2\vartheta_{23}\cdot\mu_\mu^2 + \sin^2\vartheta_{23}\cdot\mu_\tau^2\right)$$



- **The limit on the neutrino effective magnetic moment has been obtained studying the X^2 profile as a function of the hypothetical EM contribution (proportional to μ_{eff}^2) and by using the radiochemical constraint .**

Exp.	Method	90% C.L. (10^{-11} μ_B)
Gemma	Reactor ν	<2.9
Borexino	^{7}Be –pp ν	<**2.8**

Best limit among solar-reactor experiments

Conclusions

In September 2017 Borexino has celebrated the 10 years of data taking!!

- With Phase-II data Borexino has entered the era of precision spectroscopy of solar neutrinos;
- Thanks to its exceptional radiopurity, Borexino has gone well beyond its original goal providing a complete study of solar neutrinos from the entire proton-proton chain;

The newest results:

- First simultaneaus extraction of pp, pep and ^{7}Be neutrino rate from the same multivariate fit;
- Improved precision in all flux measurements (notably ^{7}Be precision is now 2.7%);
- New determination of the ^{8}B neutrino flux (precision increased by 55%);
- $>5\sigma$ evidence of the pep neutrino signal;
- Hint towards the High Metallicity hypothesis coming from the ^{7}Be and ^{8}B ν measurement;
- First experimental determination of the ratio R between the ^{3}He-^{4}He and ^{3}He-^{3}He reactions in the Sun;
- New limit on neutrino magnetic moment :

The future : achieved a good thermal stabiitization of the detector
spring 2018 => Sox project (see M. Pallavicini talk!)

Thank you !!

First simultaneous spectroscopy of pp, ^{7}Be and pep-ν: analysis method

Two methods to determine the reference spectral shapes of signal and background:

MonteCarlo *arXiV:1703.02291*

- Full simulation of all processes: energy
- deposition, light production (scintillator and
- Cerenkov), propagation and collection;
- All known material properties included;
- Known time variations of the detector
- included (for example, number of live PMTs
- and electronics channels);
- Tuned on calibration data of Phase-I;
- **Free parameters in the fit: only the rates**
- **of signal and background;**

pros

- Tuning of the MC parameters is done on calibration data which is completeley independent from the data to be analyzed;

cons

- it cannot take into account unknown variations of the detector properties

Analytical *Phys.Rev.D **89**, 112007 (2014)*

- energy scale and response described analytically (including cerenkov, quenching);
- Spatial dependence of reconstructed E and σ(E); some parameters determined from calibrations and fixed in the fit (Birk's quenching factor..);
- **Free parameters in the fit: the rates of signal and background + 6 parameters of the response function (L.Y., 2 resol. parameters, ^{210}Po peak position and width, starting point of ^{11}C spectrum;**

pros

- More flexibility in case of unknown variations of the detector;

cons

- More free parameters → more prone to correlations

The two methods are complementary and provide internal cross-check to the analysis

Back-up slides

pp, ^{7}Be and pep-ν analysis: backgrounds from multivariate fit

Background species	Rate (cpd/100t)
^{14}C (Bq/100t)	40.0±2.0
^{85}Kr	6.8±1.8
^{210}Bi	17.5±1.9
^{11}C	26.8±0.2
^{210}Po	260.0±3.0
Ext ^{40}K	1.0±0.6
Ext ^{214}Bi	1.9±0.3
Ext ^{208}Tl	3.3±0.1

Factor 4.6 reduction with respect to Phase-I

Factor 2.3 reduction with respect to Phase-I

Statistical and systematical errors added in quadrature

pp, ^{7}Be and pep-ν analysis: systematical uncertainties

Energy estimators:
N_p, N_p^{dt2}, N_h, N_{pe}

- Energy scale
- Not uniformity of the
- energy responce
- ^{210}Bi spectral shape

	pp		^{7}Be		*pep*	
Source of uncertainty	−%	+%	−%	+%	−%	+%
Fit method (analytical/MC)	-1.2	1.2	-0.2	0.2	-4.0	4.0
Choice of energy estimator	-2.5	2.5	-0.1	0.1	-2.4	2.4
Pile-up modeling	-2.5	0.5	0	0	0	0
Fit range and binning	-3.0	3.0	-0.1	0.1	1.0	1.0
Fit models (see text)	-4.5	0.5	-1.0	0.2	-6.8	2.8
Inclusion of ^{85}Kr constraint	-2.2	2.2	0	0.4	-3.2	0
Live Time	-0.05	0.05	-0.05	0.05	-0.05	0.05
Scintillator density	-0.05	0.05	-0.05	0.05	-0.05	0.05
Fiducial volume	-1.1	0.6	-1.1	0.6	-1.1	0.6
Total systematics (%)	-7.1	4.7	-1.5	0.8	-9.0	5.6

^{8}B analysis: systematical uncertainties

	LE	HE	LE+HE
Source	σ	σ	σ
Active mass	2.0	2.0	2.0
Energy scale	0.5	4.9	1.7
z-cut	0.7	0.0	0.4
Live time	0.05	0.05	0.05
Scintillator density	0.5	0.5	0.5
Total [%]	2.2	5.3	2.7

CNO-ν : perspectives for the future

- **Need for a stabilization in temperature of the detector**;
- Insulation of the detector with a 20cm-thick layer of rock wool : work completed in dec 2015