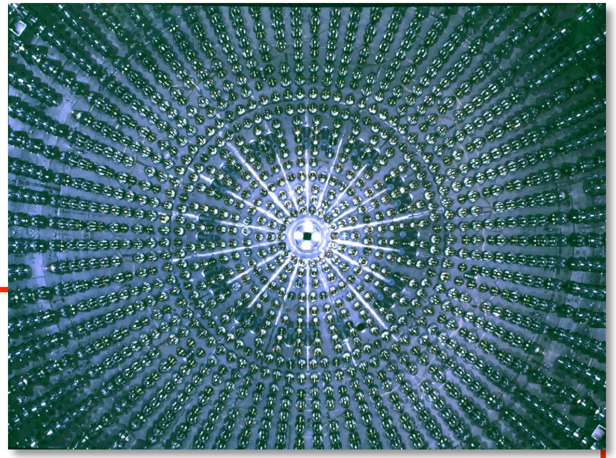
Borexino

2012/2013



- *Attività sul rivelatore*
  - *presa dati*
  - *Manutenzione elettronica*

- *Analisi concluse in questo anno*
  - *Update dell' analisi dei geo-neutrinos*
  - *Studio della produzione nuclidi cosmogenici*
  - *Studio della modulazione annuale dei neutrini solari*

Analisi in progress
- *Analisi del flusso dei neutrini da pp ;*
- *Update della ricerca di processi rari*
- *Analisi del flusso dei neutrini dal ciclo CNO*
- *Proposal per lo studio di oscillazione in ν sterile*

PUBBLICAZIONI 2012/13

✧ *Measurement of geo-neutrinos from 1353 days of Borexino*
Physics Letters B 722 (2013) 295–300

SUBMITTED:

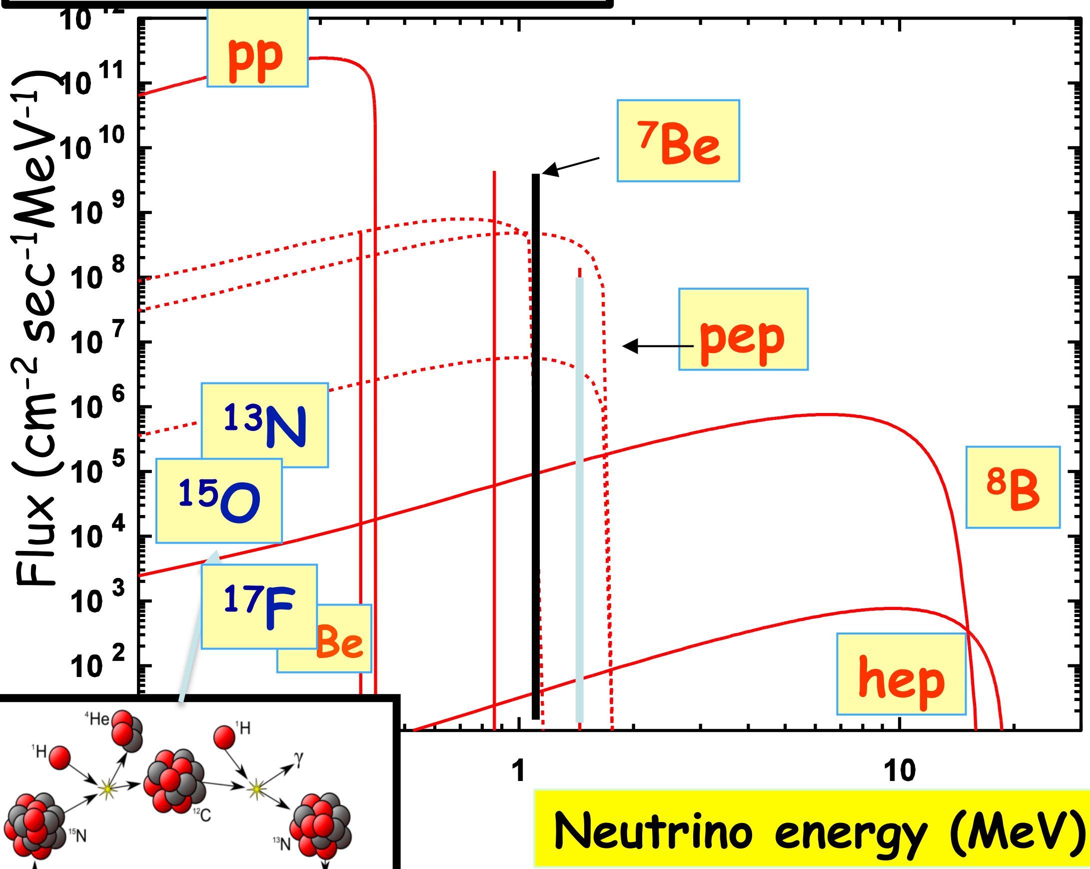
✧ *Cosmogenic Backgrounds in Borexino at 3800 m water-equivalent depth*
✧ New limits on heavy sterile neutrino mixing in 8B-decay obtained with the Borexino *detector*
✧ *SOX: Short distance neutrino Oscillations with BoreXino*
✧ *Lifetime measuremets of ^{214}Po and ^{210}Po in the CTF liquid scintillator detector at LNGS*

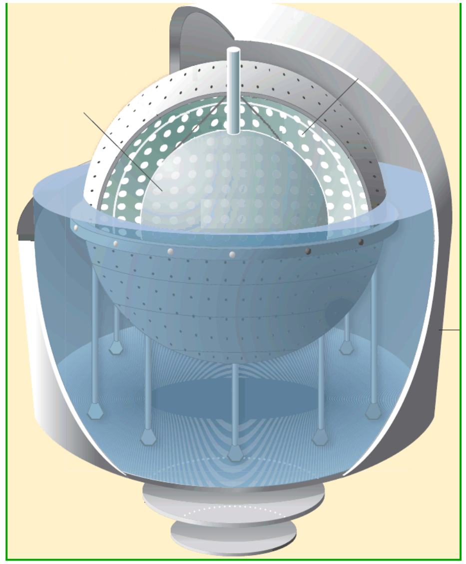
PUBBLICAZIONI recenti ma già discusse nel 2012

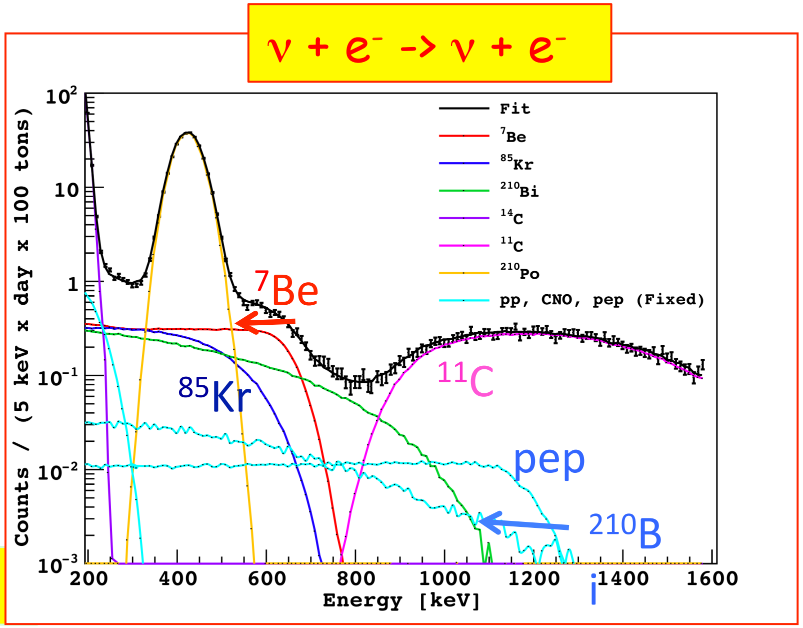
✧ *First Evidence of pep Solar Neutrinos by Direct Detection in Borexino*
PRL 108, 051302 (2012); ➔ selezionato da APS per essere inserito negli Highlights
✧ *Cosmic-muon flux and annual modulation in Borexino at 3800 m water-equivalent depth,*
Journal of Cosmology and Astroparticle Physics Volume 2012 May 2012
✧ *Search for Solar Axions Produced in p(d, ^3He)A Reaction with Borexino Detector,*
Phys. Rev. D, Volume 85, Issue 9 (2012)

Solar neutrino spectrum

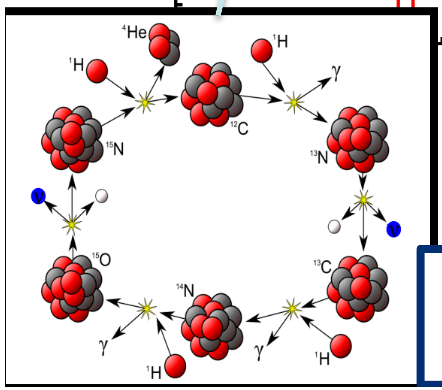
pp CYCLE:
~99% of the sun energy







e- Energy (keV)



CNO CYCLE:
<1% of the sun energy

Borexino: Phase 1 and Phase 2

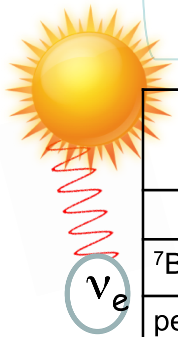
Data taking from May 2007

Solar ν PHASE 1 — Data taking and calibration (May 2007 – May 2010)

Scintillator Purification (^{85}Kr, ^{210}Bi) (May 2010 – Aug. 2011)

Solar ν PHASE 2 (from Oct. 2011)

May 2007 | May 2010 | Aug. 2011 | Oct. 2011

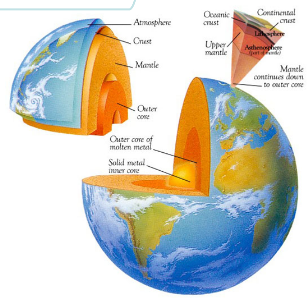


ν	Interaction Rate	DATA/SSM (high metall.)
	Counts/(days 100 t)	ratio
^{7}Be	46±1.5(stat)$^{+1.5}_{-1.6}$(sys)	1.02±0.1
pep	3.1±0.6 (stat) ± 0.3(sys)	1.1±0.2
CNO	<7.9	<1.5
^{8}B>3MeV	0.22 ±0.04(stat)±0.01(sys)	

$$A_{DN} = \frac{N-D}{(N+D)/2} = 0.001 \pm 0.012\,(stat) \pm 0.007(sys)$$

- Geo ν measurement
- Muon analysis
- Limit on rare processes
- evidence of ^{7}Be ν seasonal modulation

New geoν results:
Dec2007-Aug2012
P.L. B 722 (2013)



After the purification of the scintillator

1) Kr: strongly reduced: consistent with zero cpd/100t from spectral fit
2) ^{210}Bi : from ~70 cpd/100tons to 20 cpd/100t) ;
3) ^{238}U (from ^{214}Bi-Po tagging) < 9.7 10^{-19} g/g at 95% C.L.
4) ^{232}Th < 2.9 10^{-18} g/g at 95% C.L.

Importance of studying solar neutrinos

Astrophysics:
Open issues: solar metallicity controversy

- Metallicity (the abundance of elements heavier than He) is used as input in the Standard Solar Model;
- The neutrino fluxes depend on it;
- Differences as large as 30-40% (for CNO);
- Differences of ~9% for ^{7}Be ν

Sources	$\Phi(\nu\ sec^{-1}\ cm^{2})$ *high-metallicity*	$\Phi(\nu\ sec^{-1}\ cm^{2})$ *low-metallicity*	Difference %
pp	$5.98(1\pm0.006)\times10^{10}$	$6.03(1\pm0.006)\times10^{10}$	0.8
pep	$1.44(1\pm0.012)\times10^{8}$	$1.47(1\pm0.012)\times10^{8}$	2.1
hep	$8.04(1\pm0.300)\times10^{3}$	$8.31(1\pm0.300)\times10^{3}$	3.3
^{7}Be	$5.00(1\pm0.070)\times10^{9}$	$4.56(1\pm0.070)\times10^{9}$	8.8
^{8}B	$5.58(1\pm0.140)\times10^{6}$	$4.59(1\pm0.140)\times10^{6}$	17.7
^{13}N	$2.96(1\pm0.140)\times10^{8}$	$2.17(1\pm0.140)\times10^{8}$	26.7
^{15}O	$2.23(1\pm0.150)\times10^{8}$	$1.56(1\pm0.150)\times10^{8}$	30.0
^{17}F	$5.52(1\pm0.170)\times10^{6}$	$3.40(1\pm0.160)\times10^{6}$	38.4

- **Solar Model:** Serenelli, Haxton and Pena-Garay arXiV:1104.1639
- **High metallicity GS98** = Grevesse et al.*S. Sci. Rev. 85,161 ('98);*
- ***Low metallicity AGS09*** = *Asplund, et al,* A.R.A.&A. 47(2009)481

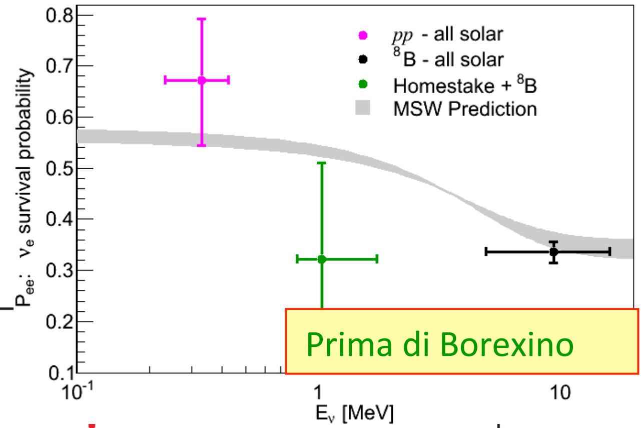
Particle physics: the so-called "solar neutrino problem" has provided one of the first hints towards neutrino oscillations;

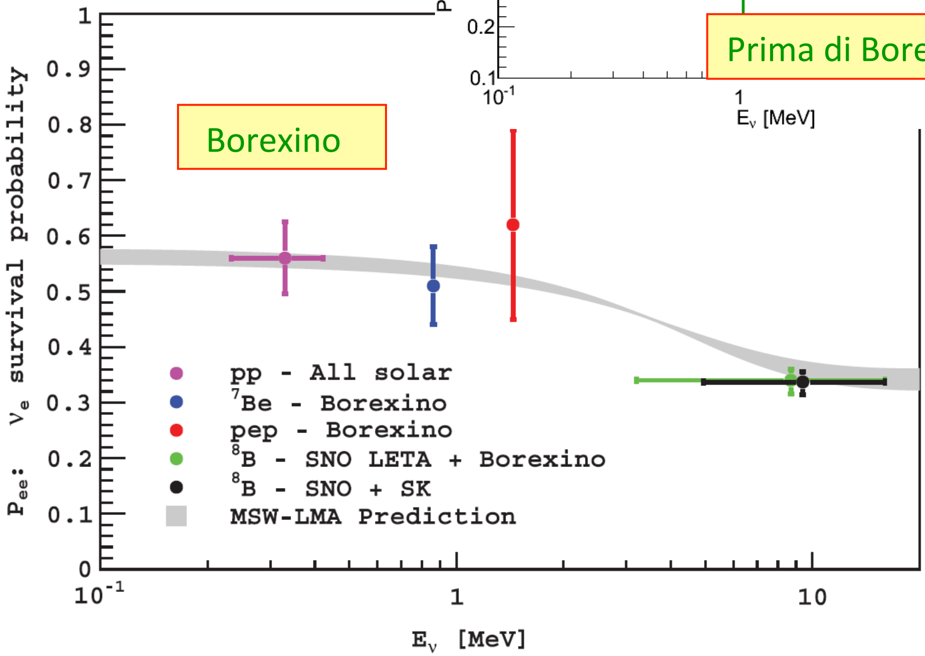
- Now we know that neutrinos oscillate in their path from Sun to Earth;
- "LMA solution": $\Delta m^2 = 7.6\times10^{-5}$ eV^2; tg$^2\theta$ = 0.468

Open issues: precision measurements of solar neutrino sources at low energies probe P_{ee} in the vacuum to matter transition region which is sensitive to new physics;

Physics implication of the solar ν Borexino results:

Borexino has been able of probing Pee at different energies, giving a confirmation of the LMA hypothesis

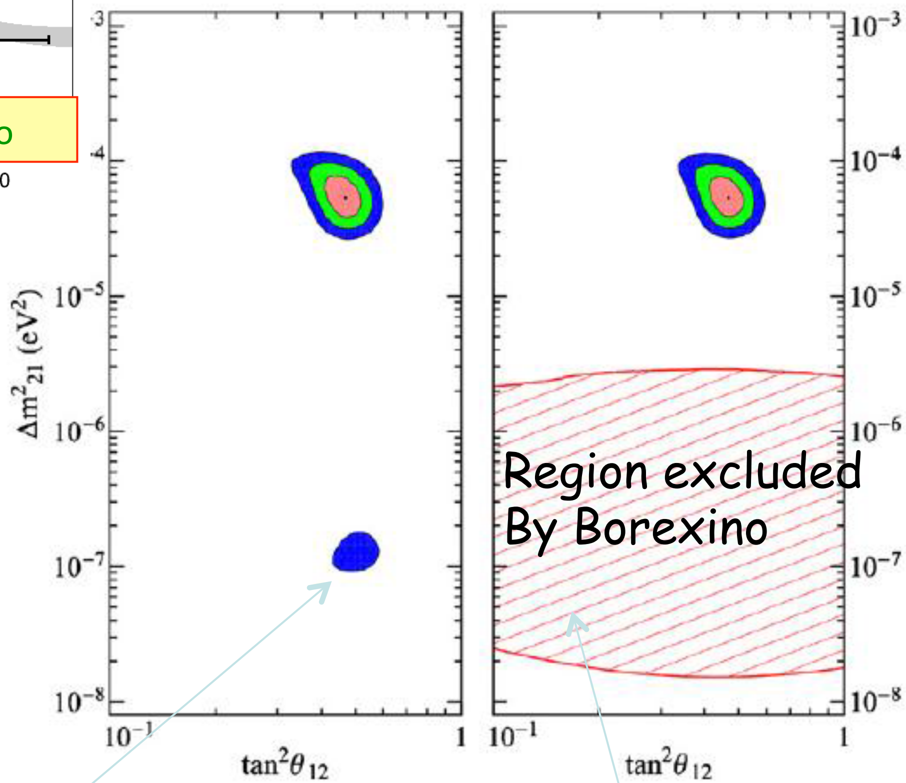




Oscillation parameter regions allowed by solar ν experiments (and without anti ν form Kamland)

All solar exp. without Borexino

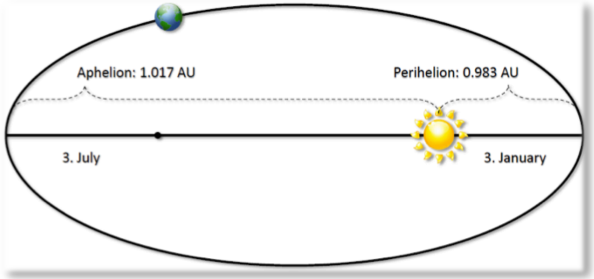
All solar exp. including Borexino



A small portion of the "LOW" region is not excluded

Borexino (mainly the A_{dn} data) + all solars select the LMA region without anti-ν data (Kamland)

New result: annual modulation of the ν signal (PHASE 1)



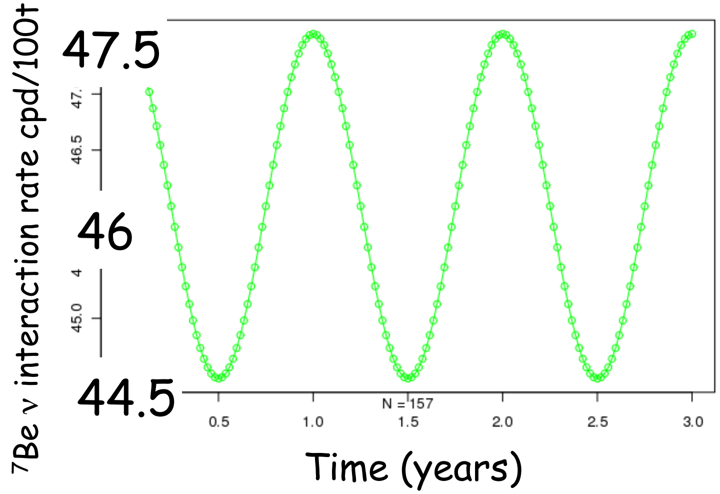
max flux: Jan. 3rd

ε=0.0167

$$\Phi_E = \Phi_0 \left(1 + 2\varepsilon \cos\left(\frac{2\pi}{T} - \varphi \right) \right)$$

Normal oscillation $\phi \div 1/r^2$

Expected amplitute of ^{7}Be ν signal
6.8% peak-to-peak

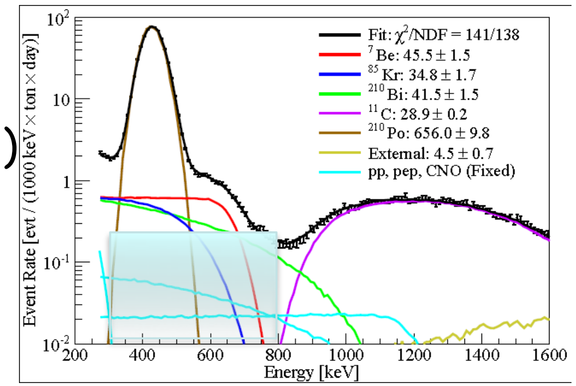


Spectral fit in sub-periods: too large stat. errors
Analysis method:

- Select a proper energy region, group data in time bins and search for a periodical component
- Enlarge the fiducial volume (with respect to the ^{7}Be flux meas.)

3 methods (consistent results)

- Fit of the rate vs time
- Lomb Scargle analysis
- Empirical Mode Decomposition



New result: annual modulation of the ν signal (PHASE 1)

DETECTOR RESPONSE very stable:

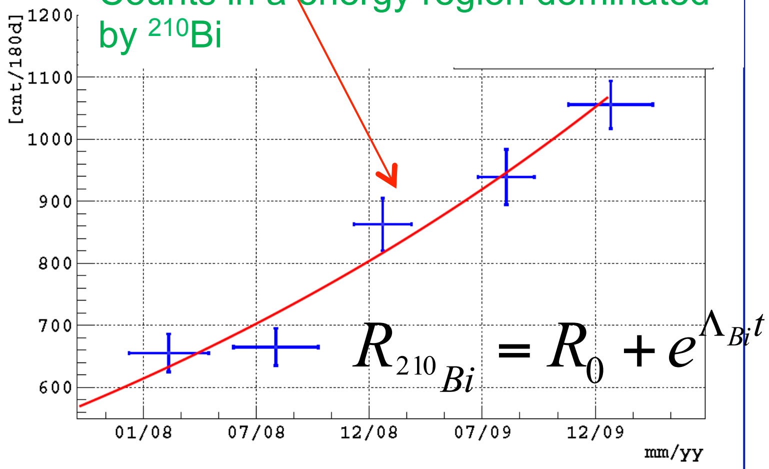
•Energy scale stability:
^{210}Po peak statibility in the enlarged (145 t) FV : rms/peak 0.8 %

• Pulse shape discrimination and position reconstruction:
no detectable issue about stability

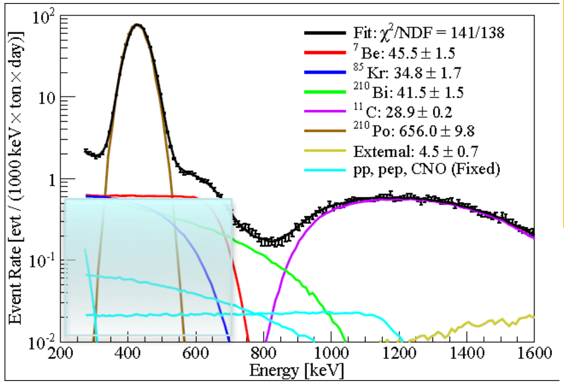
^{210}Po peak distribution in PHASE 1

• The challenge: amplitude of some untaggable background (^{210}Bi) not stable in time
• Background shape reproducible during time (no new components!)

Counts in a energy region dominated by ^{210}Bi



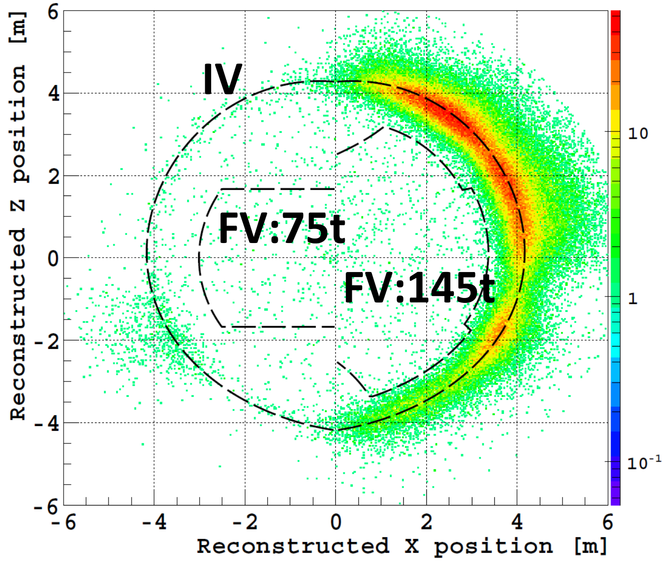
Data selection and FV



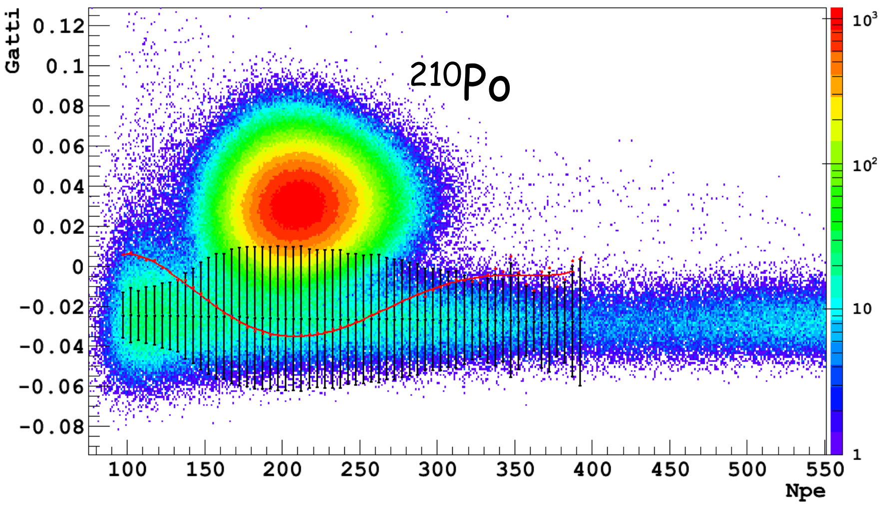
DATA sample for seasonal variation analysis:

- Standard cut as in the ^{7}Be flux
- ^{210}Po rate is also time dependent
- Remove ^{210}Po by pulse shape discrimination
- Hard cut

+ removal of the events above the red line



Pulse shape discrimination parameter vs energy (Npe)



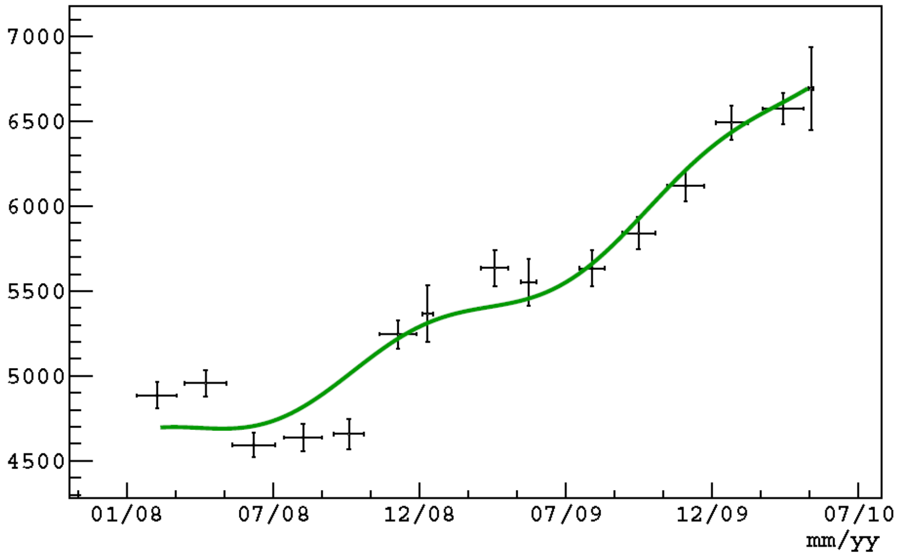
IV dependent Ext_ γ:

- Enlarged (double) FV compared to ^{7}Be flux meas
- affected by the Ext_ Gamma's,
- Spatial cut defined using Ext_source calibration data.
- Vessel shape and position change during time
- Measure week by week the vessel shape and position

(using radioctive decay of vessel contaminants)

Annual modulation of the ν signal (PHASE 1): counts vs time

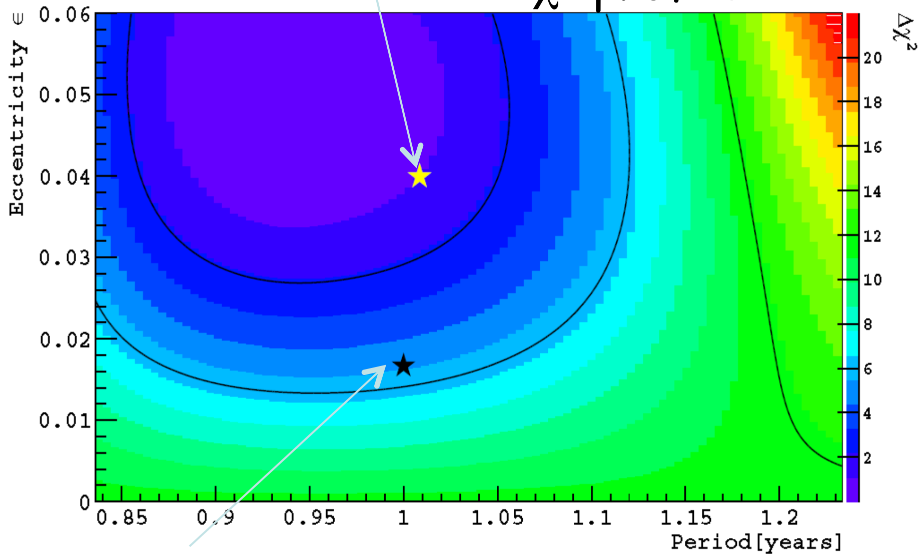
Counts in 60 days



$$R = R_0 + e^{\Lambda_{Bi} t} + \overline{R}\left[1 + 2\varepsilon \cos\left(\frac{2\pi}{T} - \varphi\right)\right]$$

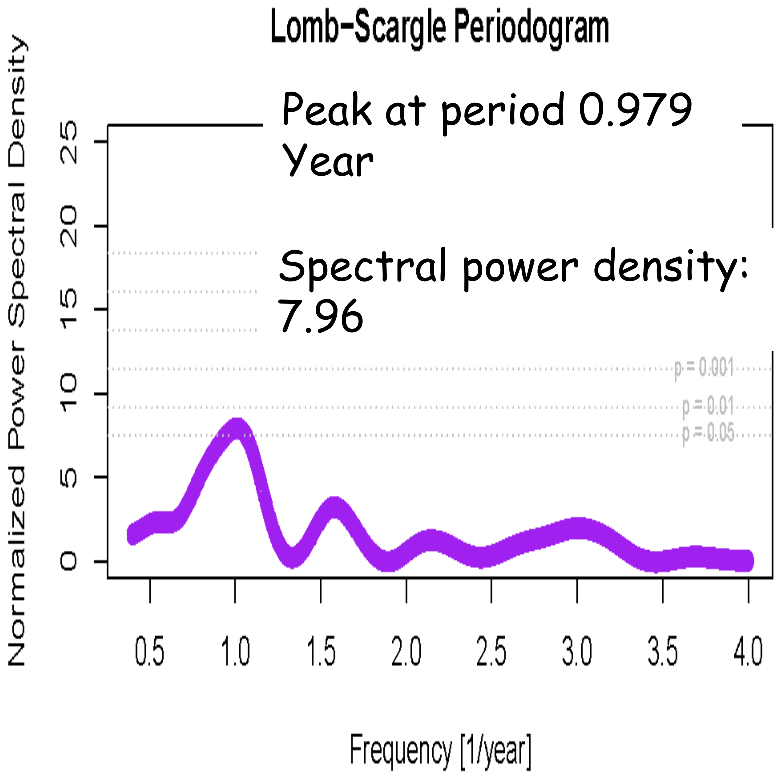
Results:
T=1.01 +- 0.07 y
ε=0.0398 +-0.0102

$\Delta\chi^2$ profile



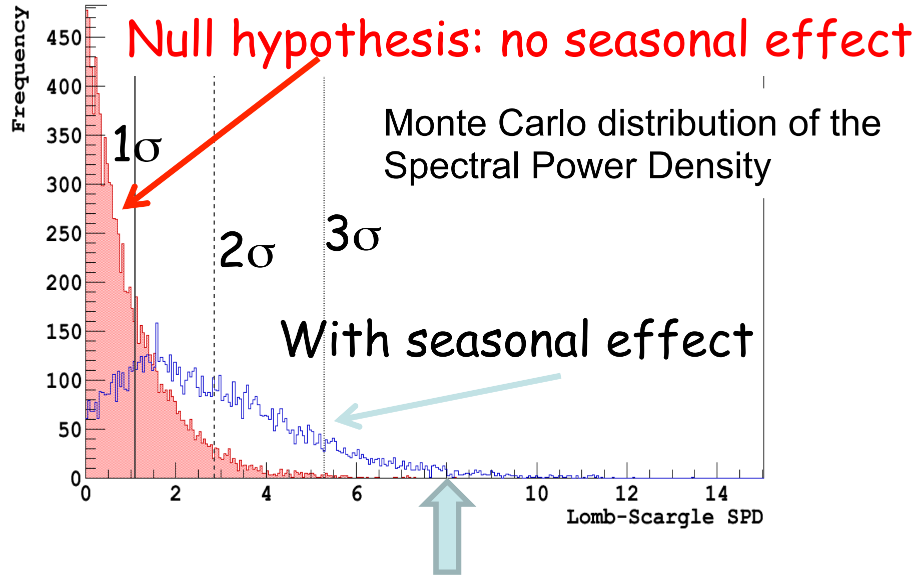
expected values are within the 2 σ contour

Annual modulation of the ν signal (PHASE 1): Lomb Scargle analysis



Monte-Carlo simulation:

- Signal and backgrounds assumed as in the data
- 10^4 simulations, for each calculate LS SPD at 1 year and plot
  Signal (Blue) & Background (Red)

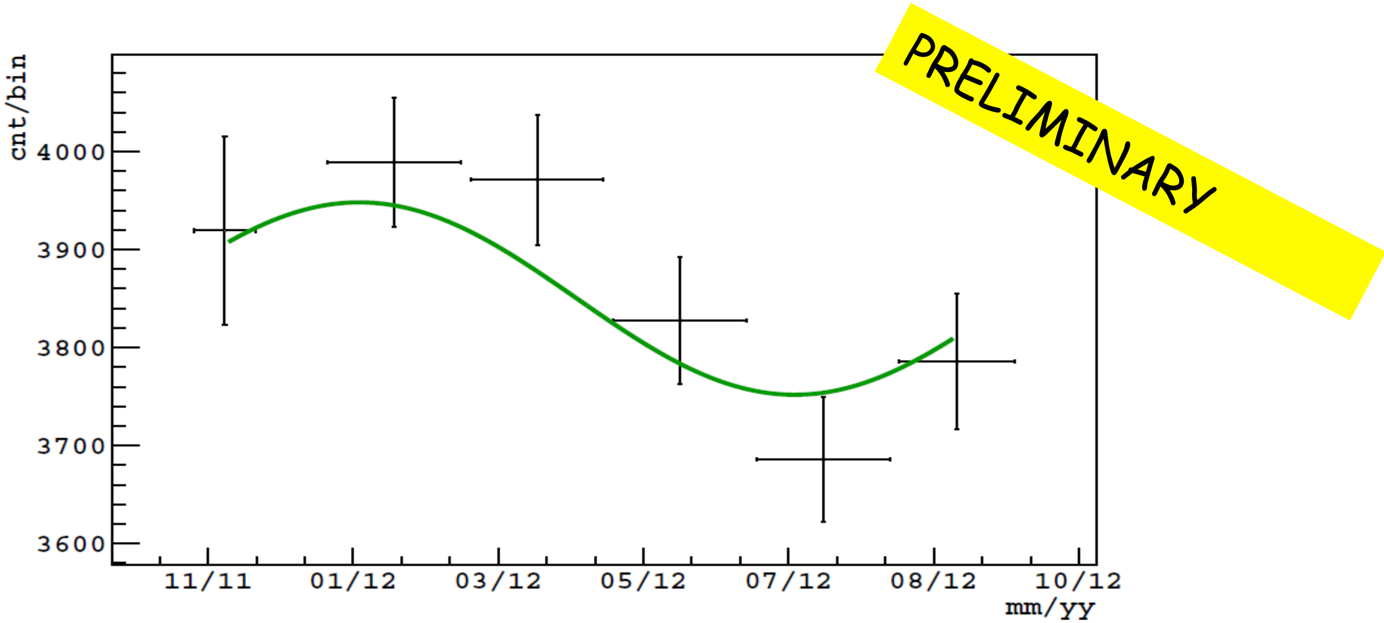


No seasonal effect: excluded at more than 3 σ

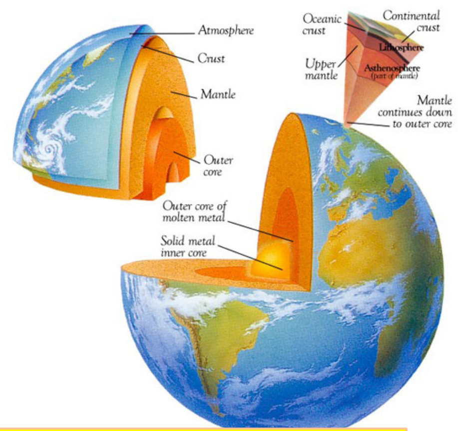
- From the annual flux modulation study, no indication of anomalous oscillation pattern (in agreement with the MSW-LMA scenario)

annual modulation of the ν signal (PHASE 2): counts vs time

results after the scintillator purification

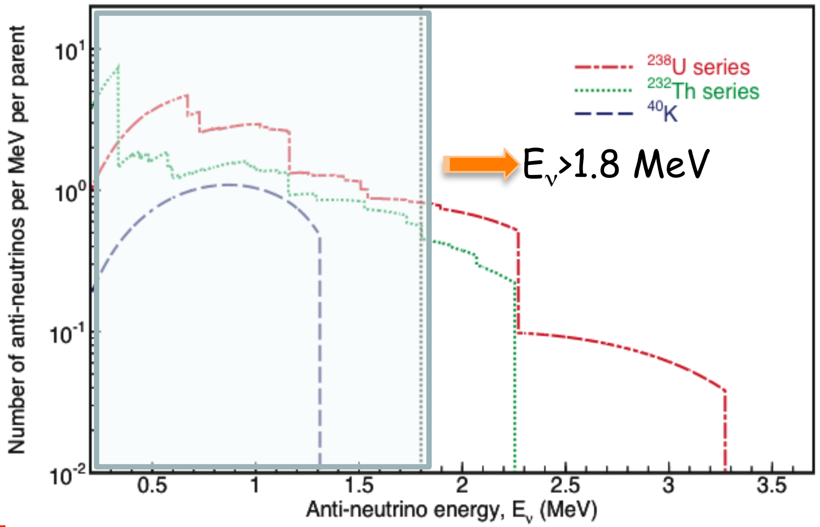


Geo ν: new Borexino results



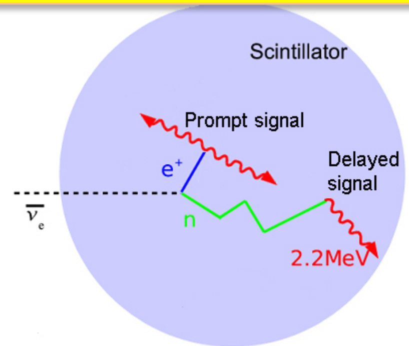
Previous Borexino result: G. Bellini et al., (Borexino Coll.) Phys. Lett. B 687 (2010) 299
Kamland: T. Araki et al., (Kamland Coll.) Nature 436 (2005) 499;
A. Gando et al. (Kamland Coll.) Nature Geoscience 4 (2011) 574

Energy spectrum of geoν neutrinos



$$\bar{\nu} + p \rightarrow n + e^+ \qquad E_\nu > 1.8 \text{ MeV}$$

- "prompt signal"
  e^+: energy loss + annihilation
  (2 γ 511 KeV each)
- "delayed signal"
  n capture after thermalization 2.2 γ



- Low flux: 3 order of magnitude less than ^{7}Be solar ν !
- Geo ν: they probe the U,Th content of the Earth (no K)
- Multidisciplinary research: particle physics&geophysics

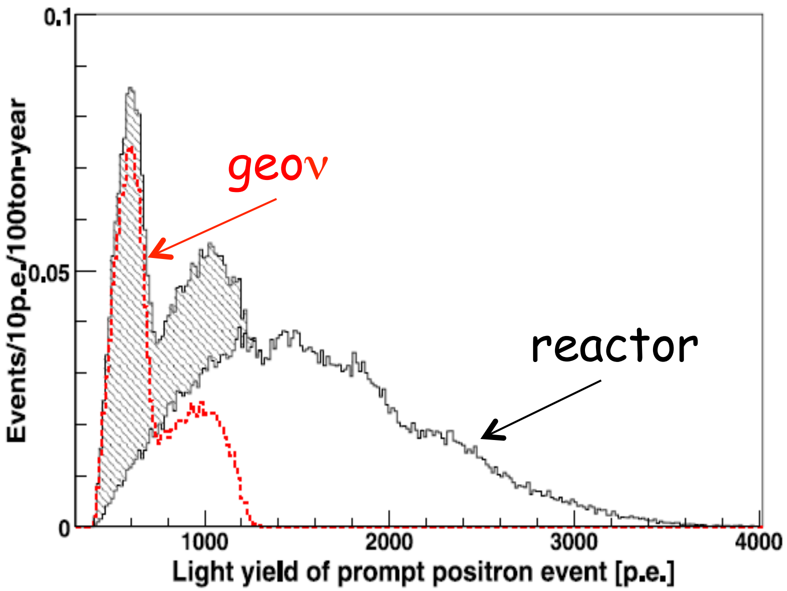
Previous data	Dec 2007-Dec2009	252.6 ton year
New data (2.4 X)	Dec 2007-Aug2012	613.0 ton year
		(3.69 ± 0.16) 10^{31} proton year

Geo ν: signal and background

Main background: anti ν from reactor

$$N_{react} = \sum_{r=1}^{R} \sum_{m=1}^{M} \frac{\eta_m}{4\pi L_r^2} P_{rm} \times$$
$$\times \int dE_{\bar{\nu}_e} \sum_{i=1}^{4} \frac{f_i}{E_i} \phi_i(E_{\bar{\nu}_e}) \sigma(E_{\bar{\nu}_e}) P_{ee}(E_{\bar{\nu}_e}; \hat{\theta}, L_r),$$

Monte Carlo simulation
of the geoν and reactor signal



1MeV≈ 500 p.e.

Source	Error [%]
$\phi(E_{\bar{\nu}})$	3.5
Fuel composition	3.2
θ_{12}	2.3
P_{rm}	2.0
Long–lived isotopes	1.0
E_i	0.6
θ_{13}	0.5
L_r	0.4
$\sigma_{\bar{\nu}p}$	0.4
δm^2	0.03
Total	5.8

446 reactors
Data from IAEA

Background source	Events
^{9}Li–^{8}He	0.25±0.18
Fast n's (μ's in WT)	<0.007
Fast n's (μ's in rock)	<0.28
Untagged muons	0.080±0.007
Accidental coincidences	0.206±0.004
Time corr. background	0.005±0.012
(γ,n)	<0.04
Spontaneous fission in PMTs	0.022±0.002
(α,n) in scintillator	0.13±0.01
(α,n) in the buffer	<0.43
Total	0.70 ± 0.18

Background not due to reactors is very small
0.70 ±0.18 events

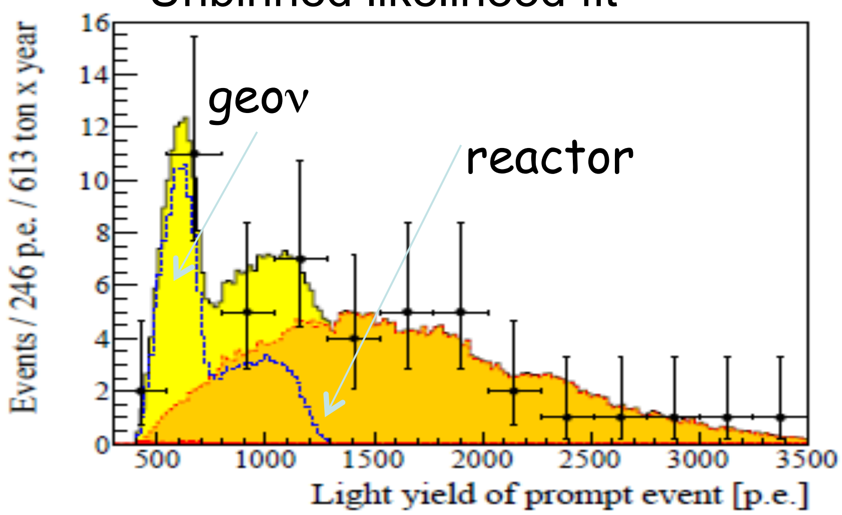
Geo ν results: evidence of the signal

Exposure: 613±26 ton year – 46 Candidates

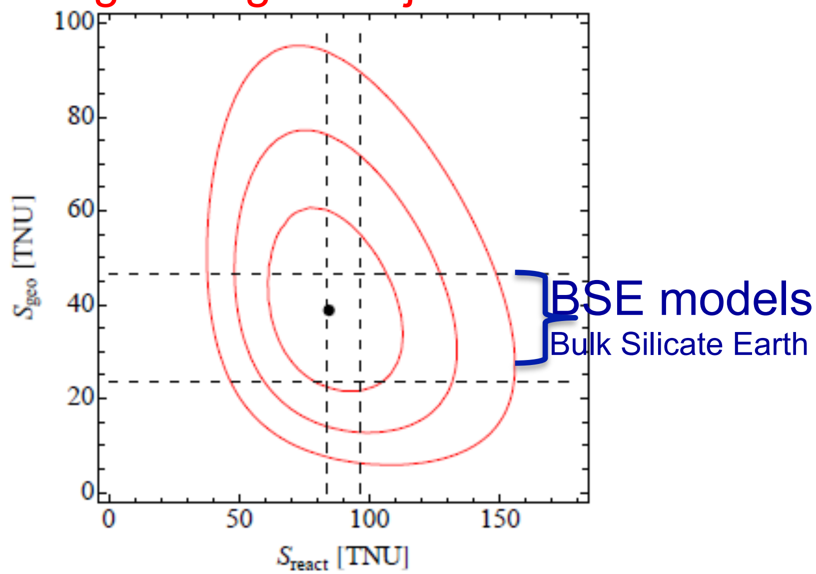
TNU= terrestrial ν units= 1/ev/y/10^{32} protons

$N_{reactor}$ Expected with osc.	$N_{reactor}$ Expected no osc.	Others back.	N_{geo} measured	$N_{reactor}$ measured	N_{geo} measured	$N_{reactor}$ measured
events	Events	events	events	events	TNU	TNU
33.3±2.4	60.4±2.4	0.70±0.18	14.3±4.4	$31.2_{-6.1}^{+7}$	38.8±12.0	$84.5^{+19.3}_{-16.9}$

Unbinned likelihood fit

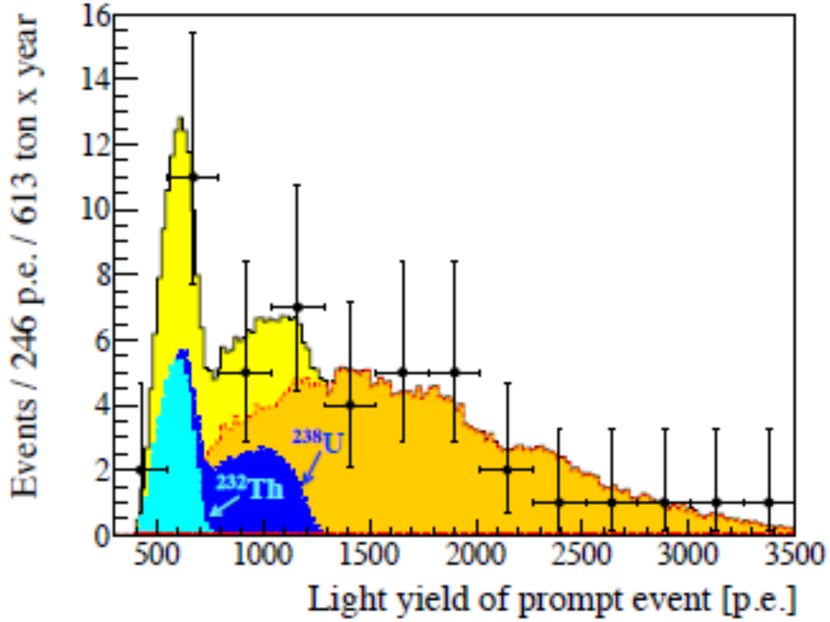


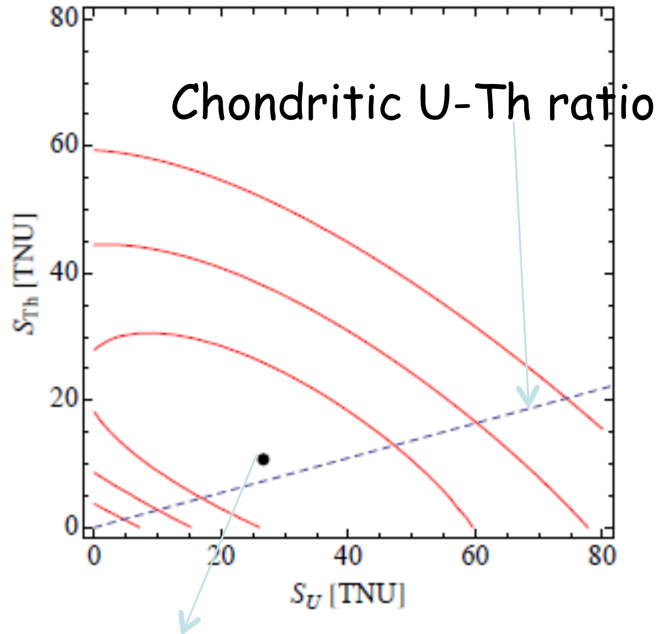
No geoν signal: rejected at 4.5 σ C.L.



Th/U=3.9 mass ratio fixed to chondritic value

geoν results: U and Th separation





For the first time fit with weight of ^{238}U and ^{232}Th spectral contribution free

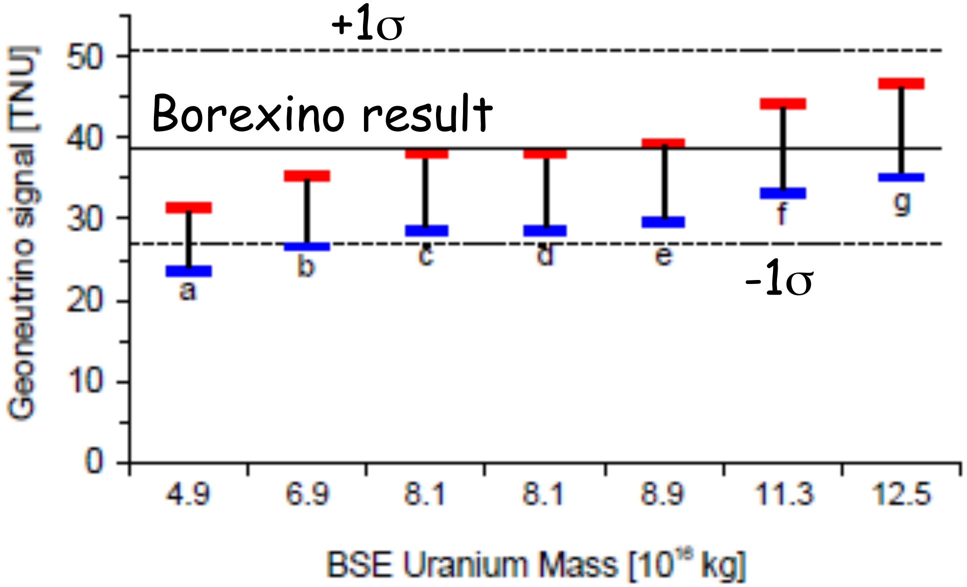
Best fit

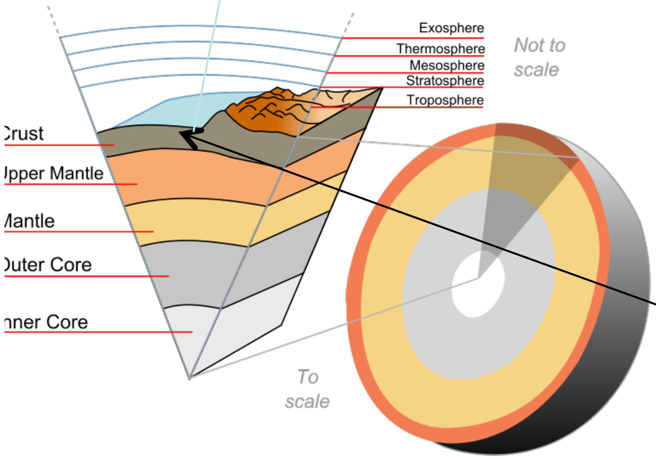
$S(^{238}U) = 26.5 \pm 19.5$ TNU

$S(^{232}T) = 10.6 \pm 12.7$ TNU

geoν results: comparison with expectation

- Borexino result compared with various BSE models (see our paper for details)
- Result consistent with expectation
- We cannot yet discriminate between different models

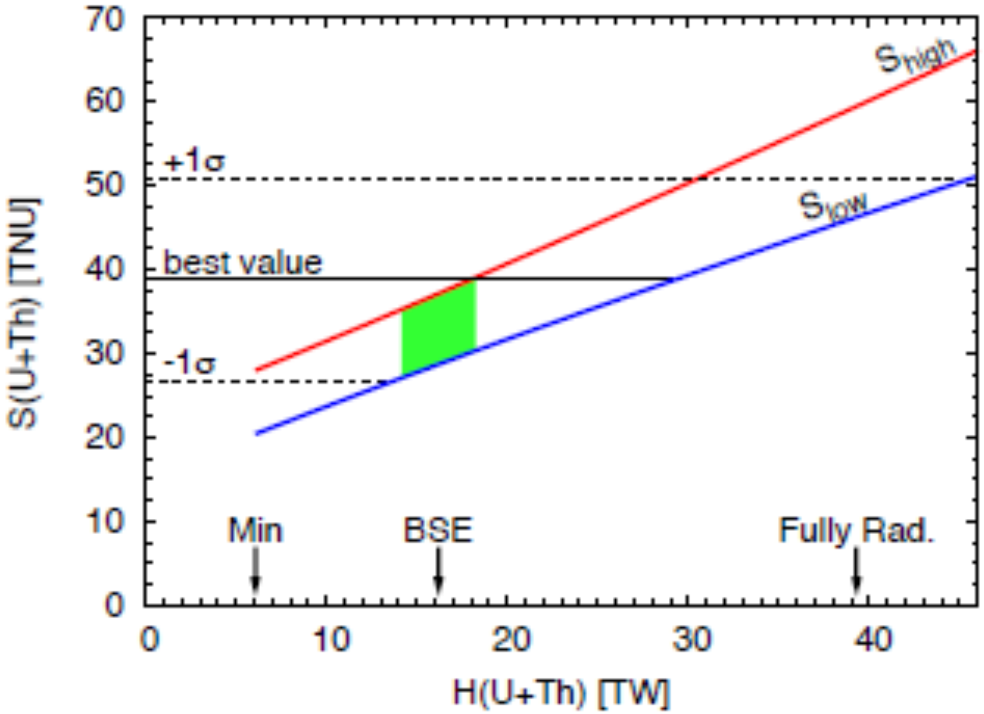




Crust contribution: from local geolog.
Mantle contribution:

Borexino+Kamland : S(Mantle) 14.1 ± 8.1 TNU
After subtracting the crust contribution from the two measurement

geoν results: radiogenic heat



- Contribution of the radioacative decays of ^{238}U and ^{232}Th to the total radiogenic heat?
- Generated heat – within the possible BSE models – explainable by the observed geo ν.
- Errors on the geoν flux still large
- Kamland and Borexino results very similar (two different places)

Toward the Borexino PHASE 2 and more

After the purification of the scintillator

- Krypton: strongly reduced: consistent with zero cpd/100t from spectral fit
- ^{210}Bi : from ~70 cpd/100tons to 20 cpd/100tons) ;
- ^{238}U (from ^{214}Bi-Po tagging) $< 9.7\ 10^{-19}$ g/g at 95% C.L.
- ^{232}Th $< 2.9\ 10^{-18}$ g/g at 95% C.L.
- ^{210}Po
- It may be possible to estimate the ^{210}Bi content from ^{210}Po evolution in time;

Physics goals on PHASE 2

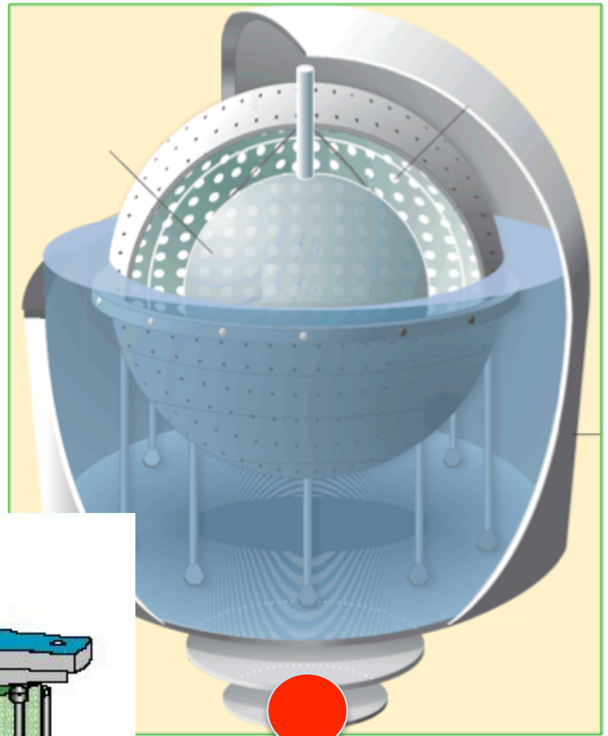
- Improve limit on CNO (observation?); (^{210}Bi suppression required);
- Improve significance of pep signal (3s or more) ^{210}Bi suppression required;
- Search for pp neutrinos (^{85}Kr suppression helps);
- Improve precision on ^{7}Be neutrinos (^{210}Bi and ^{85}Kr suppression required);

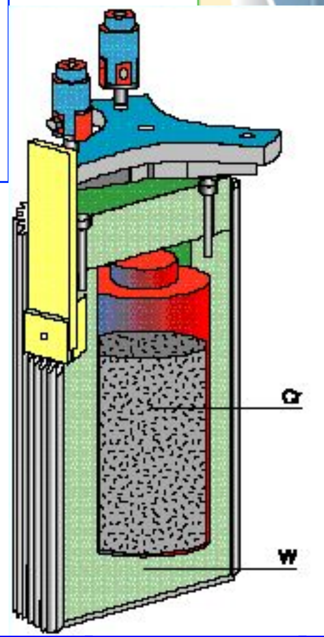
SOX: *A Short Baseline neutrino oscillation experiment with Borexino*
see "Seminario di Dipartimento"

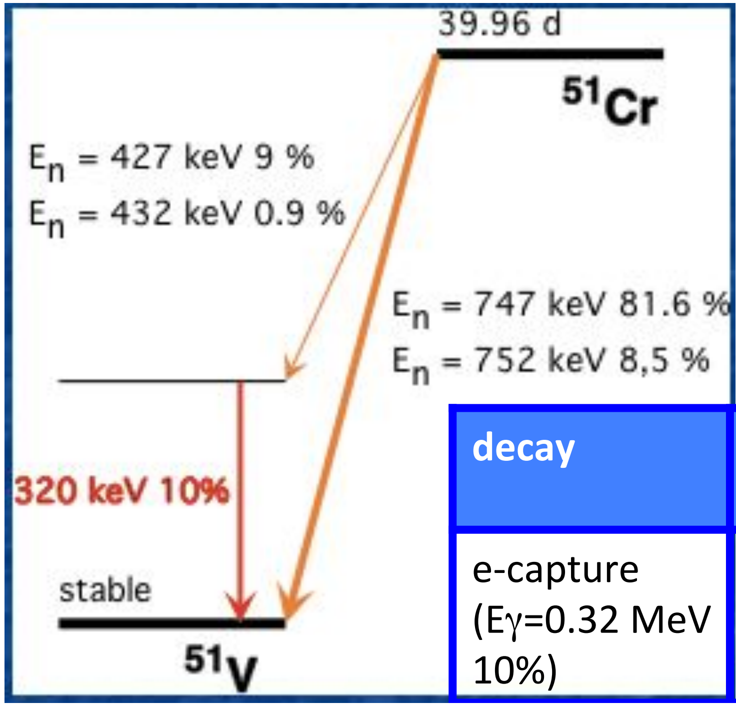
Borexino

con sorgente esterna di ^{51}Cr di ν

- Neutrino magnetic moment
- Neutrino-electron non standard interactions
- Probe ν_e- e weak couplings at 1 MeV scale
- Probe sterile neutrinos at 1eV scale
- Probe neutrino vs anti-neutrino oscillations on 10m scale







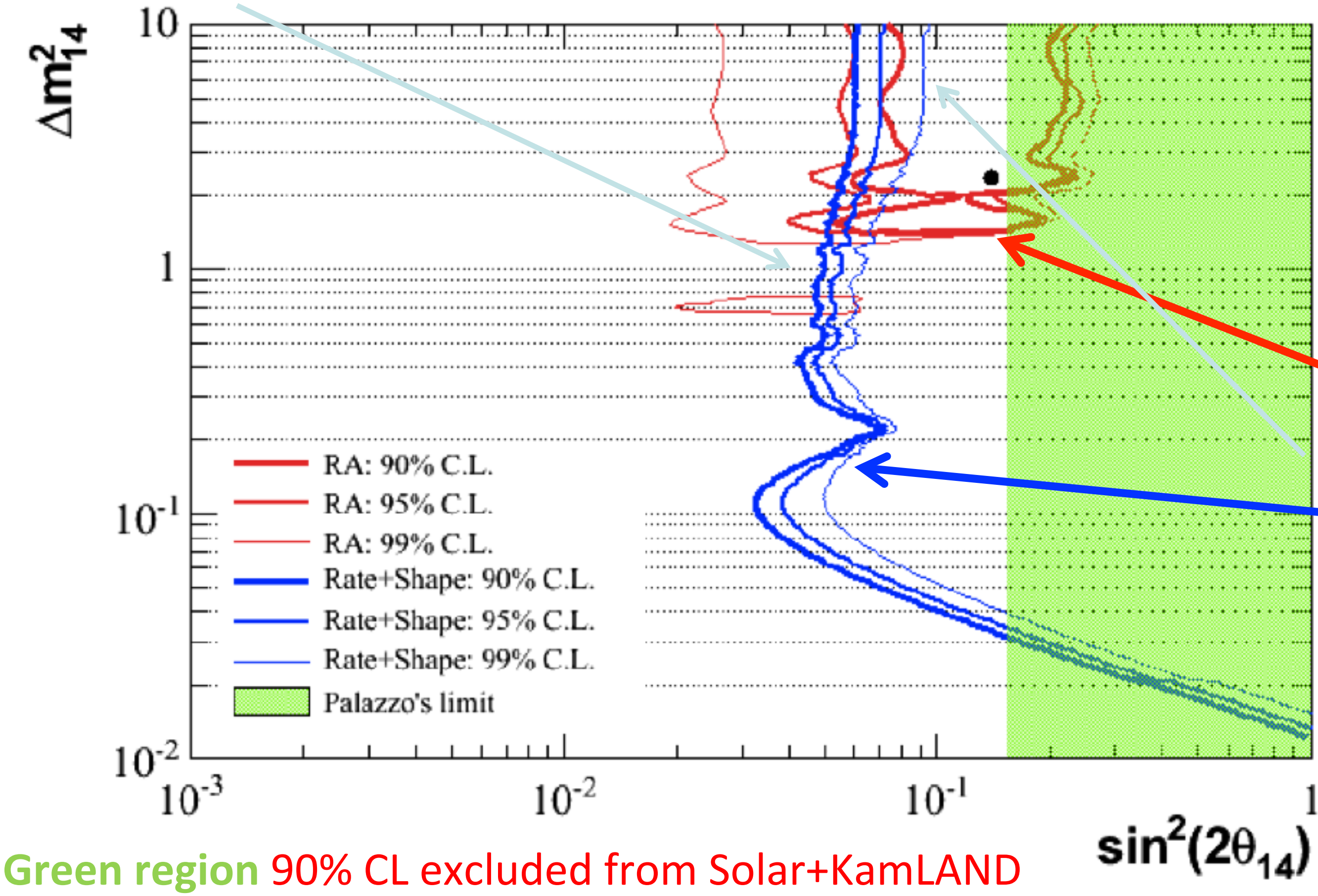
decay	τ (days)	Energy MeV	Kg/MCi	W/kCi
e-capture ($E\gamma$=0.32 MeV 10%)	40	0.746 81%	0.011	0.19

Reach of the sterile neutrino search with the ^{51}Cr source

χ^2 analysis of the ^{51}Cr source outside BX

Rate + shape + additional handle: time decay of the source event rate to better discriminate against the background

Sensitivity to the rate + wave shape



- activity=10MCi;
- Error on activity=1%;
- Error on FV=1%;

Reactor anomaly

Sensitivity to the rate only

Exclusion contours

Green region 90% CL excluded from Solar+KamLAND constraints accounting for the $\theta_{13} \neq 0$ value

A. Palazzo - Phys. Rev. D 85, 077301 (2012)

FV error better than 1% already achieved in BX (calibration)

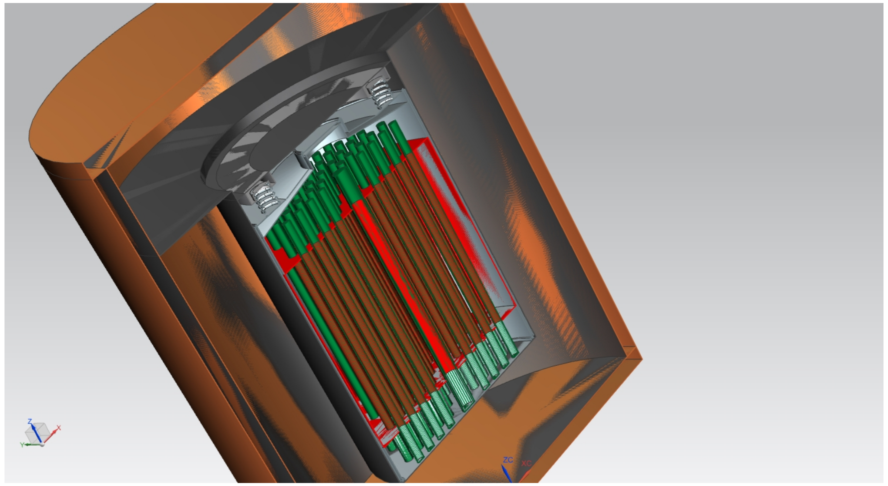
Error of 1% on the source intensity is agressive – important effort to achieve it

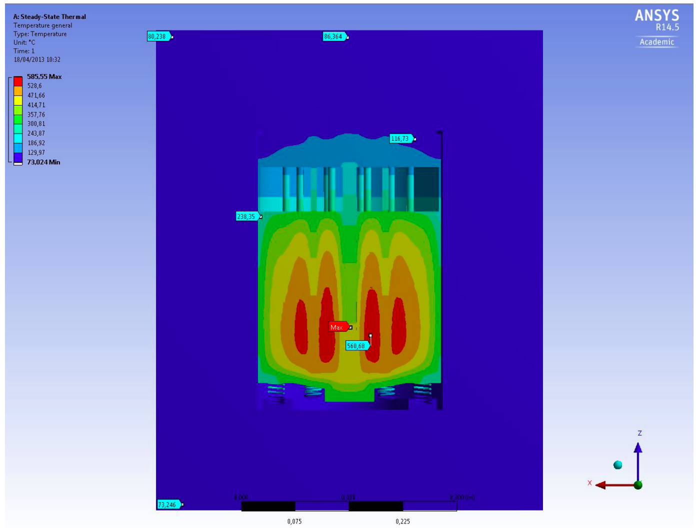
Analisi termica e meccanica della sorgente

con il servizio progettazione meccanica

- Scopo dello studio:
  - definire il progetto meccanico
  - definire in maniera controllata la distribuzione di temperatura nei vari componenti della sorgente (il materiale stesso nonché lo schermo di tungsteno), tenendo conto della generazione di calore causata dal decadimento del Cr51 generato dall'irraggiamento al reattore.

- E' importante che
  - non venga superata la temperatura a cui il Cromo sinterizza (700 gradi)
  - la temperatura esterna del tungsteno sia non eccessiva, 80-90 gradi, anche per questioni di sicurezza, prevedendo allo scopo un'opportuna alettatura.
  - Inoltre la distribuzione superficiale di temperatura deve essere la più uniforme possibile per garantire la misura precisa dell'intensità della sorgente stessa, tramite un calorimetro ad-hoc in cui verrà inserita





Composizione del Gruppo di Milano

	Altro	Borex		Altro	Borex
G. Bellini			L. Miramonti	Auger	40%
B. Caccianiga	Auger	40%	G. Ranucci	CTF-RD-DS	30%
D. D'Angelo	CTF	60%	A. Re (A.R)		100%
M.Giammarchi	AEGIS	40%	A. Brigatti	CTF-RD-DS	80%
P. Lombardi	CTF-RD-DS	60%	S. Parmeggiano	CTF-RD-DS	80%
L. Ludhova		Art.INFN	P. Saggese	CTF-RD-DS	80%
E. Meroni	CTF-RD-DS	70%			

Richieste 2014
In linea con quanto chiesto per il 2013

Attività prevista per il 2013/14

✘ **Astenerci dal fare operazioni sul rivelatore**

- Continuare l'analisi dei dati raccolti prima della purificazione mediante "water extraction" per la determinazione del rate dei ν solari da pp e per la modulazione annuale dei ν solari da ^{7}Be.
- Analisi dei dati che saranno raccolti dopo la ripurificazione allo scopo di verificare la possibilità ridurre ulteriormente gli errori sui flussi misurati.
- Sorgenti:
  - studiare la fattibilità di realizzare sorgenti di ν e anti-ν per lo studio di oscillazioni di neutrini a breve distanza.
  - Recuperare la sorgente da Saclay
  - Studio per l'irraggiamento presso reattori europei