Borexino Calibration, Precision Measurement and Seasonal Variations of the ^{7}Be Solar Neutrino Flux

Szymon Manecki
VirginiaTech
on behalf of the Borexino Collaboration

SEASAPS, 2011

Borexino

Location

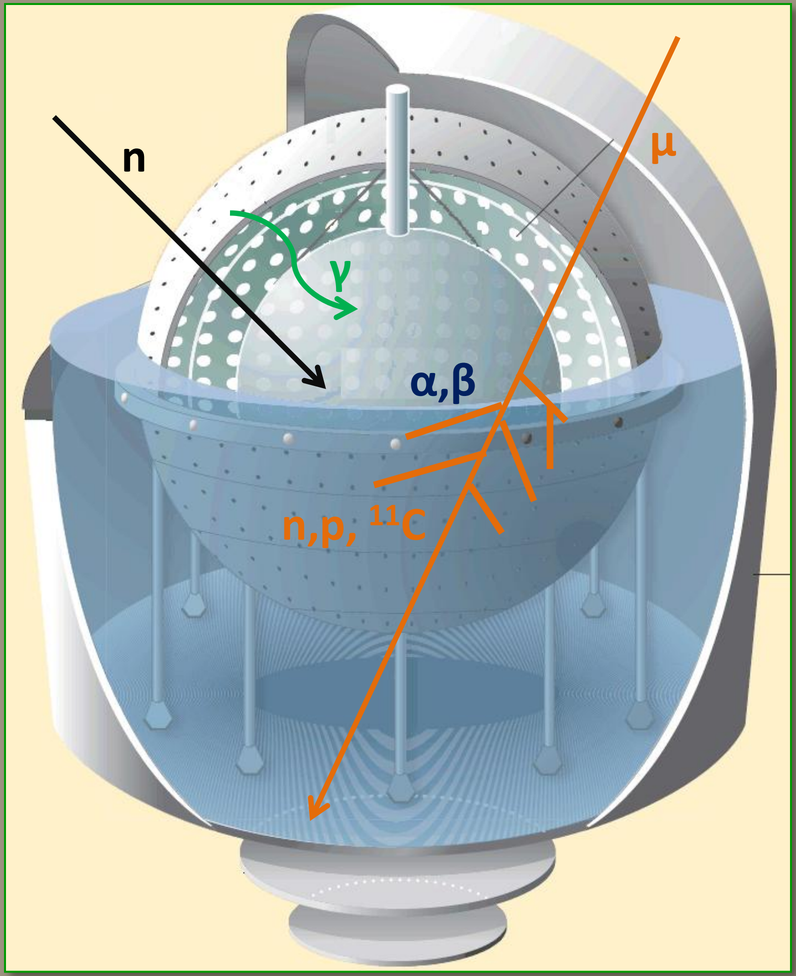
Laboratori Nazionali del Gran Sasso

Borexino detector is located in the Apennine mountains, with an access through one of the longest underground tunnels in the world.

Over a kilometer of limestone rock provide pristine muon shielding for the data

Borexino

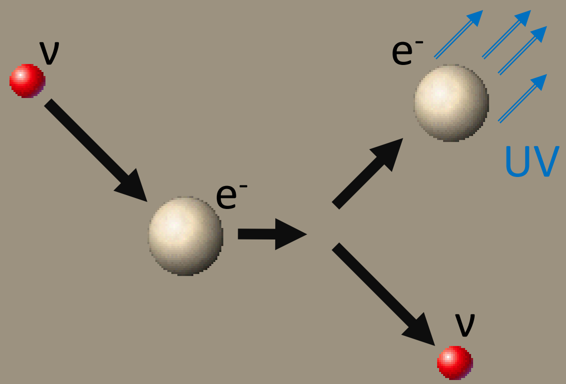
Principles of graded shielding



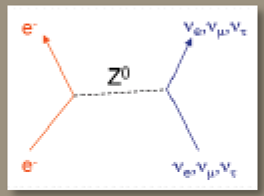
- 3600 m.w.e of rock (μ)
- Cherenkov water detector
- Inner PMTs (Rn emanation)
- Quenched scintillator
- Active scintillator
- Fiducial mass (γ)
- Fast neutrons

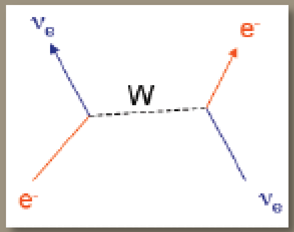
Radio-purity

Interaction



Requirements





Scintillation

- ν-e scattering effect
- Indistinguishable from β/γ backgrounds
- No directional signal

Critical to achieve lowest background levels

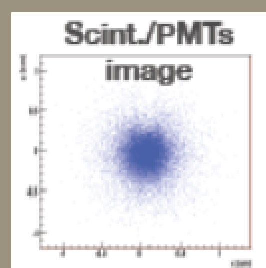
Contamination	Required	Achieved	Technique
$^{14}C/^{12}C$	$<5\cdot10^{-18}$	$2.7\cdot10^{-18}$	Crude oil / underground src
^{238}U	$<10^{-16}$ g/g	$1.6\cdot10^{-17}$ g/g	Water extraction / Distillation
^{232}Th	$<10^{-16}$ g/g	$6.8\cdot10^{-18}$ g/g	Water extraction / Distillation
^{222}Rn	<1 mBq/t	<1 mBq/t	Materials low in ^{226}Ra
^{210}Po	<1 mBq/t	initially ~1 mBq/t	Distillation, Decay(t_H=138 d)
^{85}Kr	<0.1 mBq/t	~3 mBq/t	LAKN sparging

Calibration

- Understanding detector's response: position, energy, α/β discrimination
- Study Trigger Efficiency and PMT timing alignment
- Determine Fiducial Volume

Above all, preserve **radio-purity**

Source location based on CCD cameras



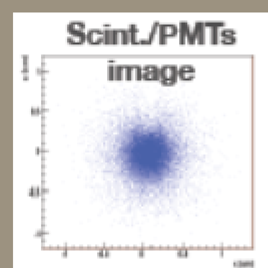
Type	γ								β		α	n		
Src.	^{57}Co	^{139}Ce	^{203}Hg	^{85}Sr	^{54}Mn	^{65}Zn	^{60}Co	^{40}K	^{14}C	^{214}Bi	^{214}Po	n-p	n-^{12}C	n-Fe
MeV	0.122	0.165	0.279	0.514	0.834	1.1	1.1, 1.3	1.4	0.15	3.2	7.69 (0.84)	2.23	4.94	~7.5

Calibration

- Understanding detector's response: position, energy, α/β discrimination
- Study Trigger Efficiency and PMT timing alignment
- Determine Fiducial Volume

Above all, preserve radio-purity

Source location based on CCD cameras



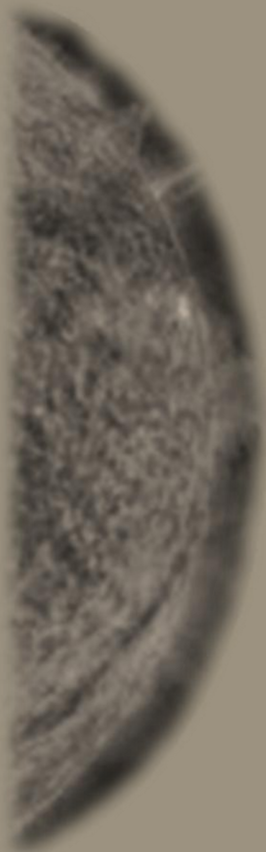
Systematics		
Livetime	0.1%	0.04%
Scintillator ρ	0.2%	0.05%
Event Selection Loss	0.3%	0.1%
Position Reconstruction	6.0%	-1.3% +0.5%
Energy Scale	6.0%	2.7%
TOTAL	8.5%	-3.6% +3.4%

Type	γ								β		α	n		
Src.	^{57}Co	^{139}Ce	^{203}Hg	^{85}Sr	^{54}Mn	^{65}Zn	^{60}Co	^{40}K	^{14}C	^{214}Bi	^{214}Po	n-p	n-^{12}C	n-Fe
MeV	0.122	0.165	0.279	0.514	0.834	1.1	1.1, 1.3	1.4	0.15	3.2	7.69 (0.84)	2.23	4.94	~7.5

Solar neutrinos

Major goal is to measure the ^{7}Be monochromatic line

Total flux of 4.48±0.31 x 10^{9} /cm^{2}/sec



$$p + p \rightarrow {}^{2}H + e^{+} + \upsilon_{e}$$

$$p + e^{-} + p \rightarrow {}^{2}H + \upsilon_{e}$$

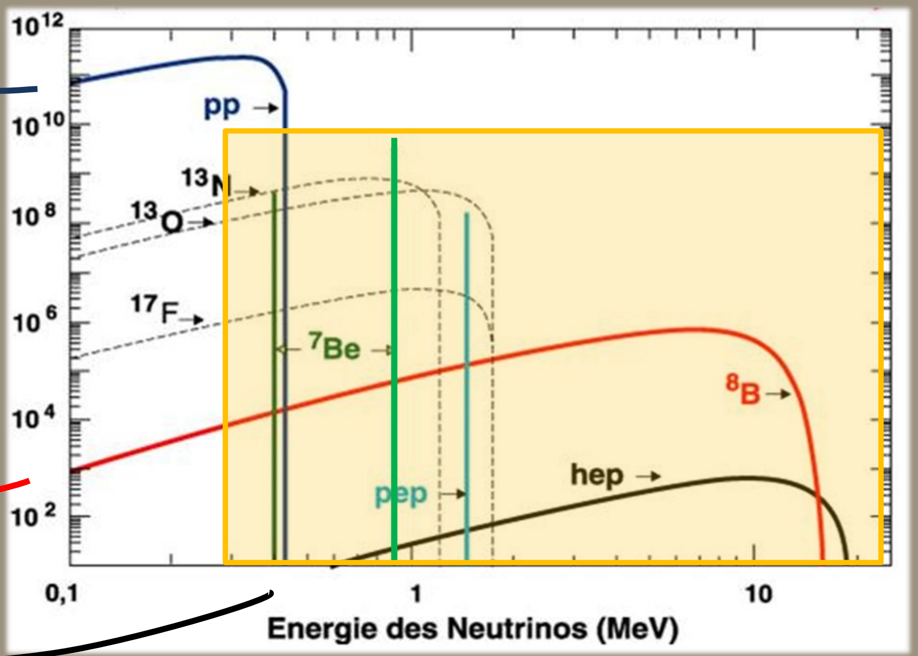
$$^{3}He + {}^{4}He \rightarrow {}^{7}Be + \gamma$$

$$^{7}Be + e^{-} \rightarrow {}^{7}Li + \gamma + \upsilon_{e}$$

$$^{7}Be + p \rightarrow {}^{8}B + \gamma$$

$$^{8}B \rightarrow 2\gamma + e^{+} + \upsilon_{e}$$

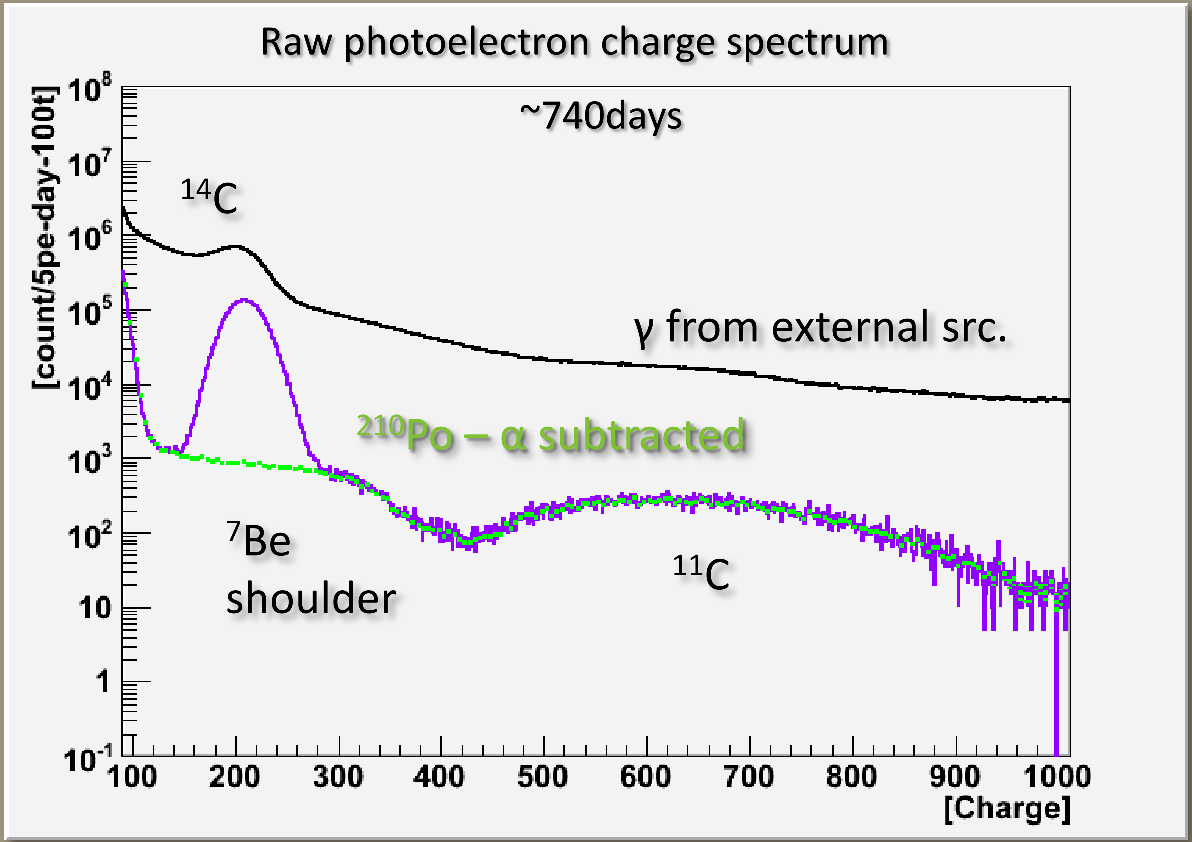
$$^{3}He + p \rightarrow {}^{4}He + e^{+} + \upsilon_{e}$$



Phase II also aims for measurement of the CNO lines

Spectrum

Selection of events



- Major cuts :

1) Muons, and fast cosmogenics,

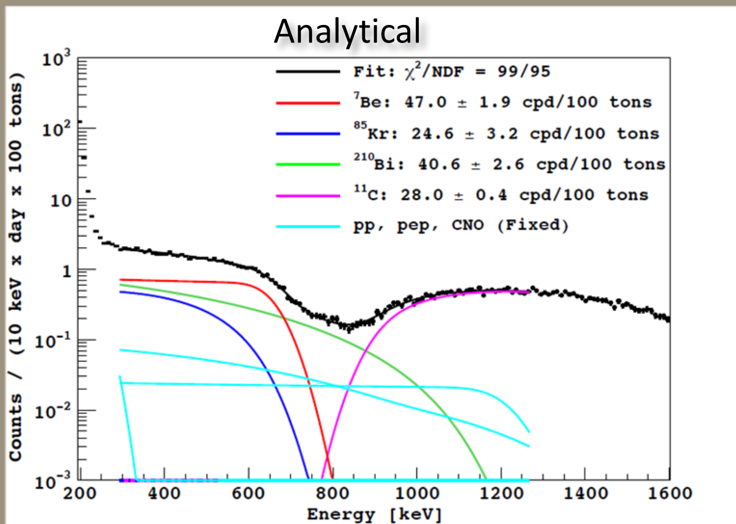
   Electronics noise

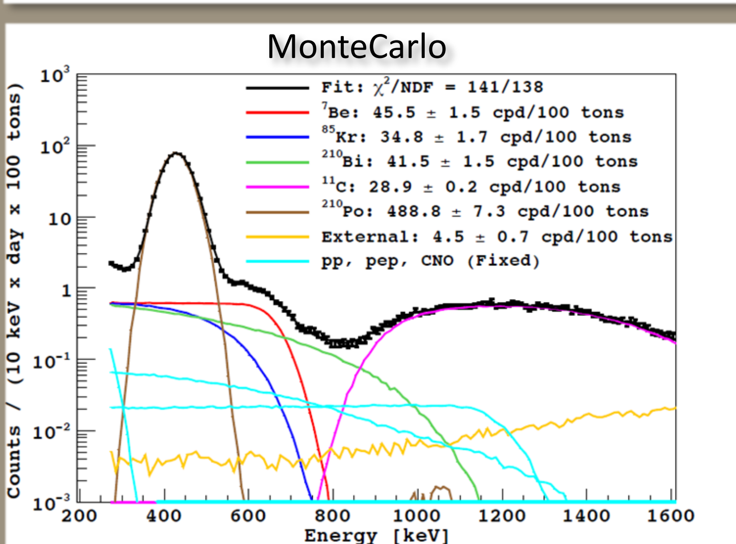
2) Foducial Volume 1/3 active mass

3) α- subtraction (Gatti parameter)

Total of 15 fine cuts remove noise and background events.

^{7}Be Results





Consistent

MonteCarlo and Analytical Fits

Measured Rate:

^{7}Be: $46.0 \pm 1.5_{stat}{}^{+1.5}_{-1.6\,sys}$ cpd/100t

SSM w/ no oscillations, HMetallicity

$74 \pm 5.2_{theor}$

MSW-LMA Prediction

47.5 ± 3.4

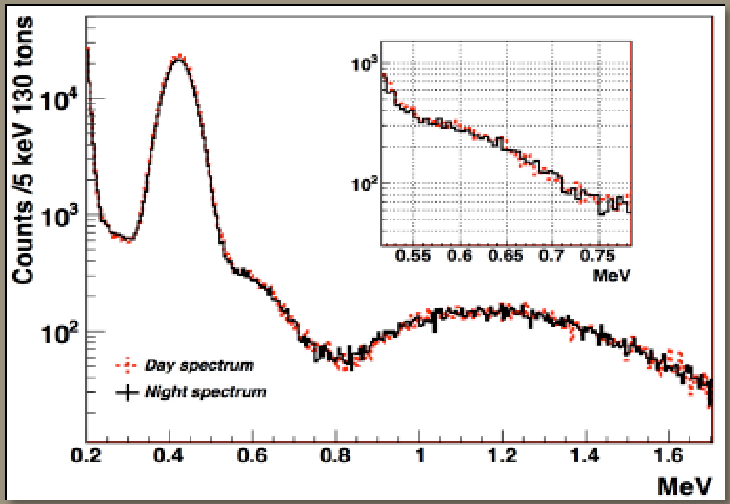
MSW-LMA scenario:

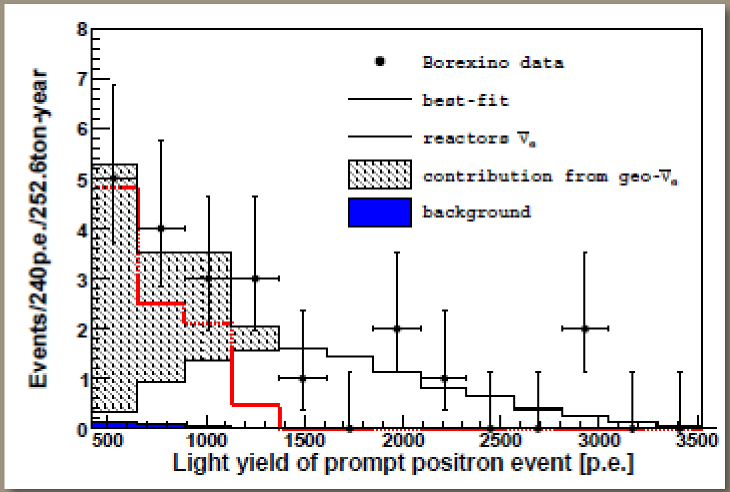
$\Phi(^7Be) = (4.84 \pm 0.24) \times 10^9$ /cm^2/sec

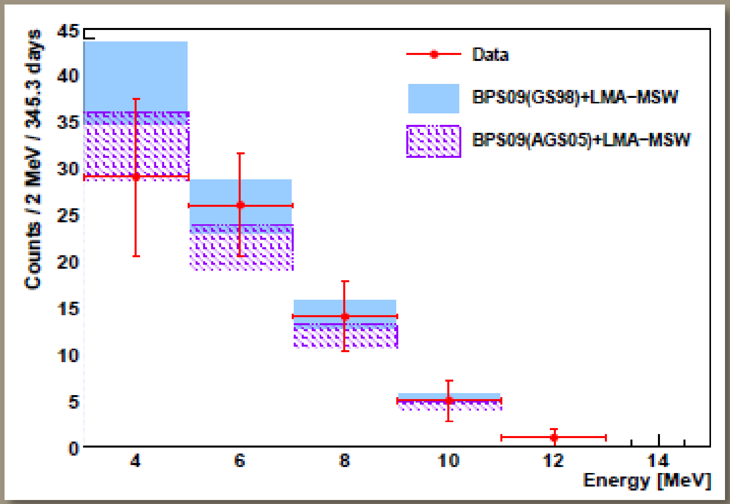
$f_{Be} = 0.97 \pm 0.09$

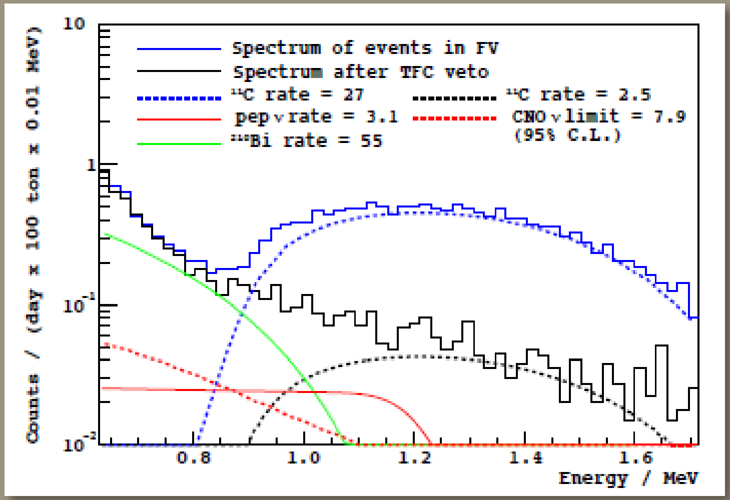
Beyond ^{7}Be

SSM constraints









Beyond ^{7}Be

Day/Night

11% - 80%

LOW

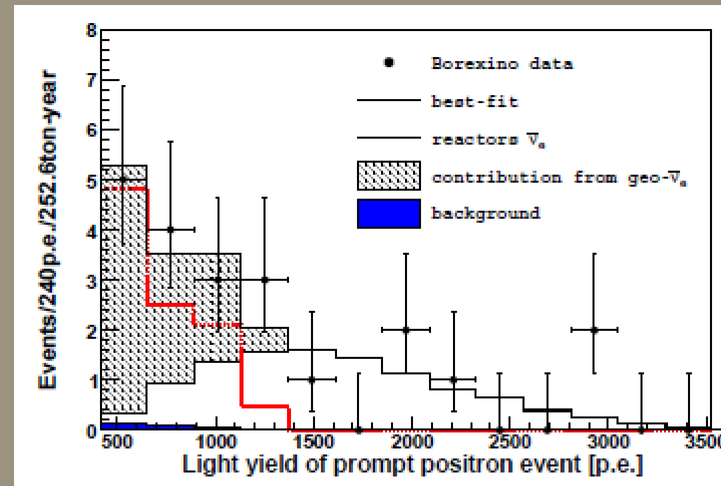
< 0.1%

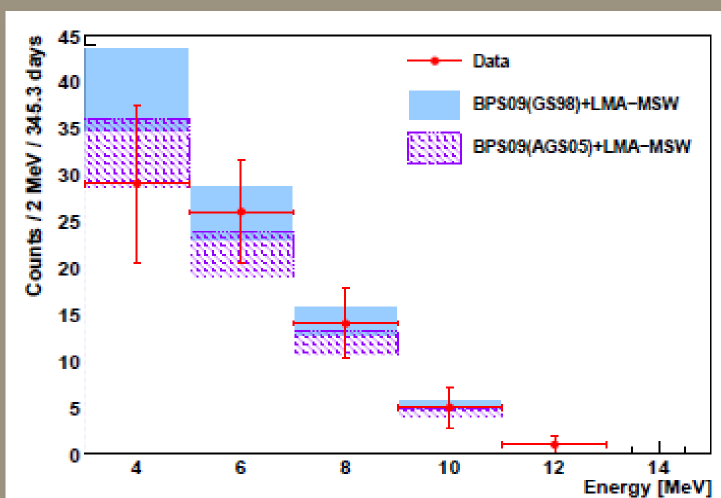
LMA

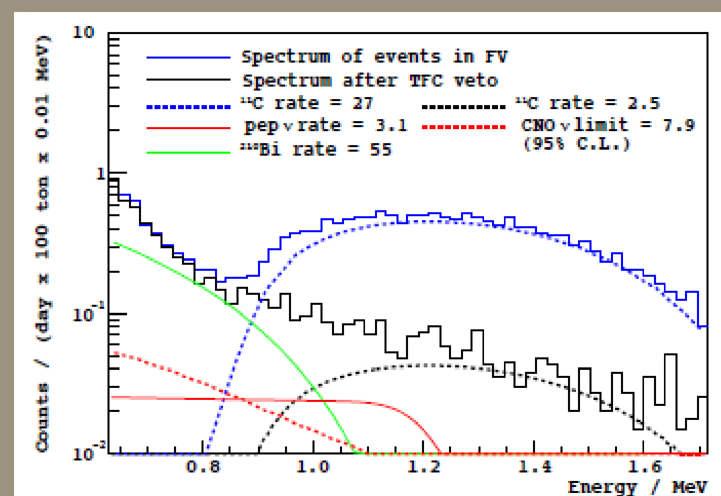
$$A_{dn} = 2 \times \frac{R_N - R_D}{R_N + R_D}$$

$A_{nd} = 0.007 \pm 0.073_{stat}$

$A_{nd} = 0.001 \pm 0.012_{stat} \pm 0.007_{sys}$







Beyond ^{7}Be

Day/Night

REJECTED

11% - 80%

LOW

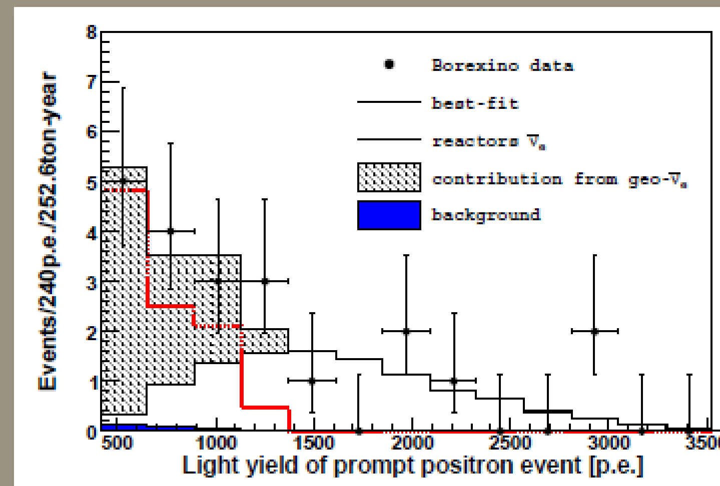
< 0.1%

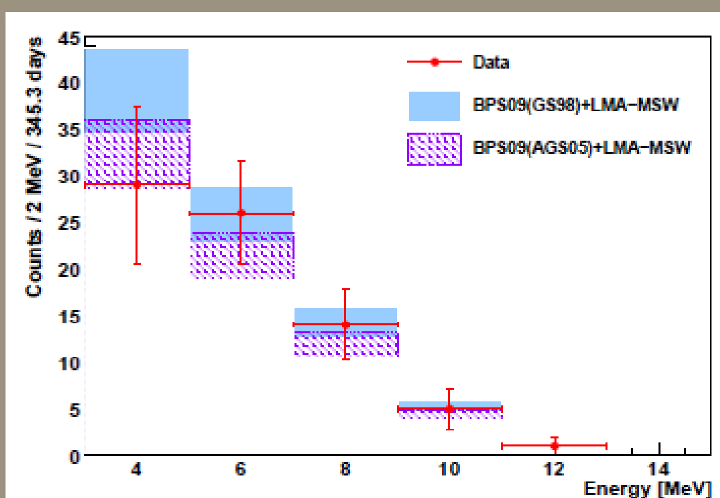
LMA

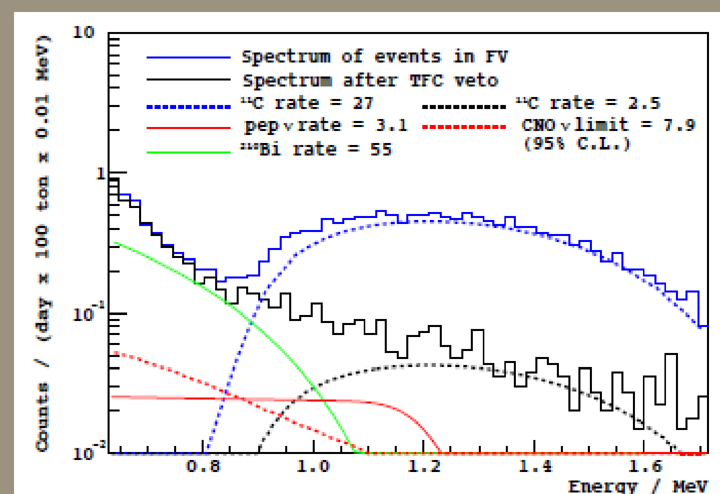
$$A_{dn} = 2 \times \frac{R_N - R_D}{R_N + R_D}$$

$A_{nd} = 0.007 \pm 0.073_{stat}$

$A_{nd} = 0.001 \pm 0.012_{stat} \pm 0.007_{sys}$







Beyond ^{7}Be

^{8}B

11% - 80%

REJECTED

LOW

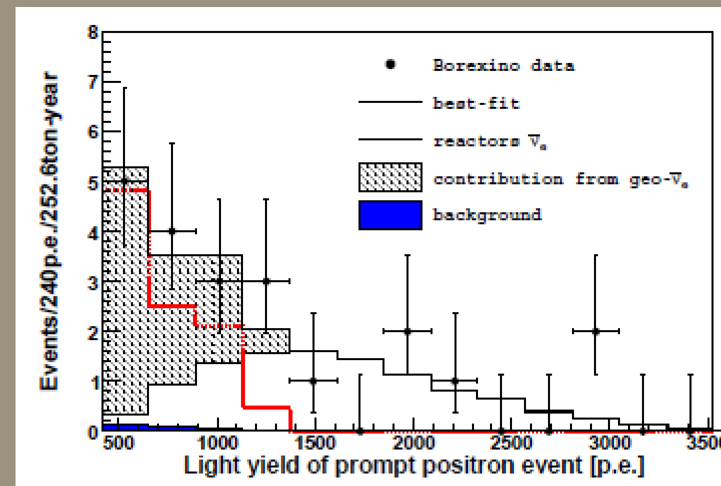
$<$ 0.1%

LMA

$$A_{dn} = 2 \times \frac{R_N - R_D}{R_N + R_D}$$

$A_{nd} = 0.007 \pm 0.073_{stat}$

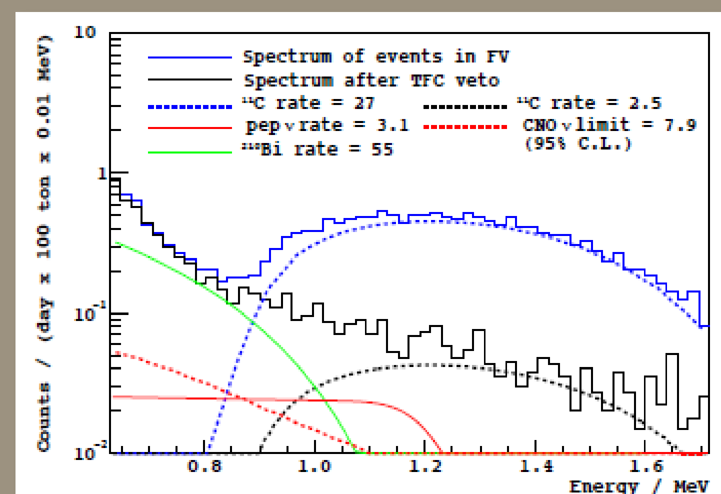
$A_{nd} = 0.001 \pm 0.012_{stat} \pm 0.007_{sys}$



The first ^{8}B to be measured with a Liquid Scintillator Detector

Lowest threshold of 3 MeV

	3.0–16.3 MeV	5.0–16.3 MeV
Rate [cpd/100 t]	$0.22 \pm 0.04 \pm 0.01$	$0.13 \pm 0.02 \pm 0.01$
Φ^{ES}_{exp} [10^6 cm^{-2} s^{-1}]	$2.4 \pm 0.4 \pm 0.1$	$2.7 \pm 0.4 \pm 0.2$
$\Phi^{ES}_{exp}/\Phi^{ES}_{th}$	0.88 ± 0.19	1.08 ± 0.23



Beyond ^{7}Be

Geo-ν

11% - 80%

REJECTED

LOW

< 0.1%

LMA

$$A_{dn} = 2 \times \frac{R_N - R_D}{R_N + R_D}$$

$A_{nd} = 0.007 \pm 0.073_{stat}$

$A_{nd} = 0.001 \pm 0.012_{stat} \pm 0.007_{sys}$

For the first time in Borexino

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

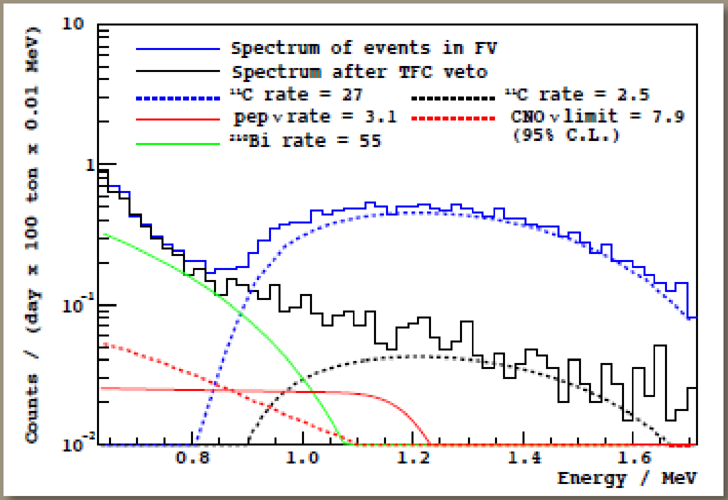
Prompt, Delayed Event

Source	Geo–$\bar{\nu}_e$ Rate [events/(100 ton·yr)]
Borexino	$3.9^{+1.6}_{-1.3}$
BSE [16]	$2.5^{+0.3}_{-0.5}$
BSE [5]	3.6
Max. Radiogenic Earth	3.9
Min. Radiogenic Earth	1.6

The first ^{8}B to be measured with a Liquid Scintillator Detector

Lowest threshold of 3 MeV

	3.0–16.3 MeV	5.0–16.3 MeV
Rate [cpd/100 t]	0.22 ± 0.04 ± 0.01	0.13 ± 0.02 ± 0.01
Φ^{ES}_{exp} [10^6 cm^{-2} s^{-1}]	2.4 ± 0.4 ± 0.1	2.7 ± 0.4 ± 0.2
$\Phi^{ES}_{exp}/\Phi^{ES}_{th}$	0.88 ± 0.19	1.08 ± 0.23



Beyond ^{7}Be

PEP

~~11% - 80%~~ REJECTED | < 0.1%

LOW | LMA

$$A_{dn} = 2 \times \frac{R_N - R_D}{R_N + R_D}$$

$A_{nd} = 0.007 \pm 0.073_{stat}$

$A_{nd} = 0.001 \pm 0.012_{stat} \pm 0.007_{sys}$

For the first time in Borexino

$$\bar{\upsilon}_e + p \rightarrow e^+ + n$$

Prompt, Delayed Event

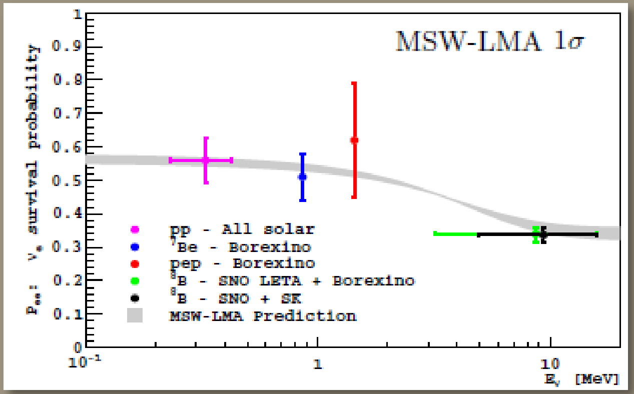
Source	Geo–$\bar{\nu}_e$ Rate [events/(100 ton·yr)]
Borexino	$3.9^{+1.6}_{-1.3}$
BSE [16]	$2.5^{+0.3}_{-0.5}$
BSE [5]	3.6
Max. Radiogenic Earth	3.9
Min. Radiogenic Earth	1.6

The first ^{8}B to be measured with a Liquid Scintillator Detector

Lowest threshold of 3 MeV

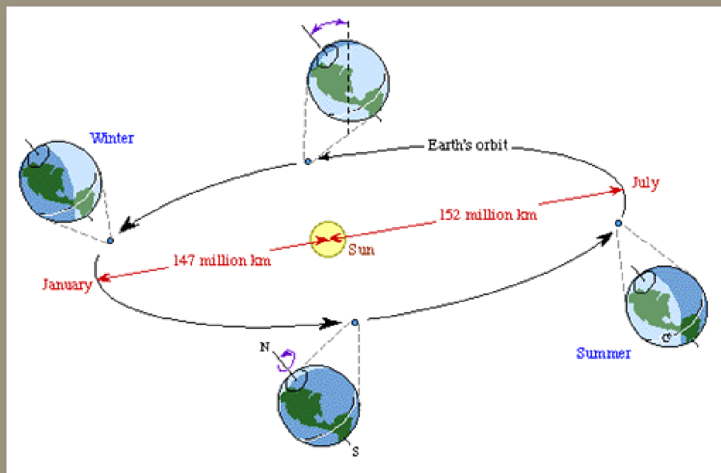
	3.0–16.3 MeV	5.0–16.3 MeV
Rate [cpd/100 t]	$0.22 \pm 0.04 \pm 0.01$	$0.13 \pm 0.02 \pm 0.01$
Φ^{ES}_{exp} [10^6 cm^{-2} s^{-1}]	$2.4 \pm 0.4 \pm 0.1$	$2.7 \pm 0.4 \pm 0.2$
$\Phi^{ES}_{exp}/\Phi^{ES}_{th}$	0.88 ± 0.19	1.08 ± 0.23

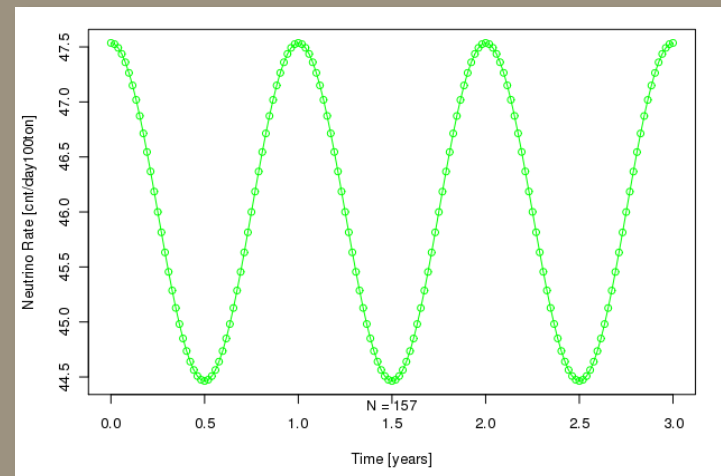
Completed the transition region



Seasonal Modulation

Astronomy





An ellipse of (current) ε = 0.0167

$$r(\theta) = \frac{\beta}{1 - \epsilon \sin(\theta - \theta_0)};$$

"Normal" oscillations:
MSW : ~1/r^2

"Anomalous" oscillations:
Vacuum : ~~~1/r^2~~

P-to-P 7% amplitude modulation

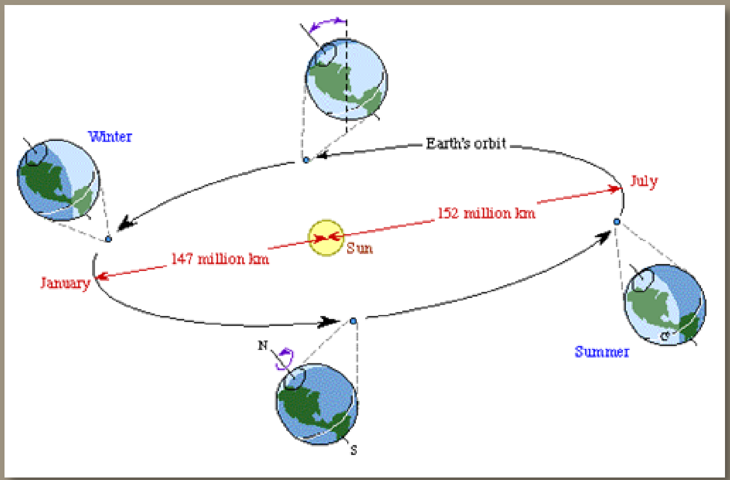
$$R(t) = \left(\frac{\bar{r}_0}{r(t)}\right)^2 = \bar{R}\left[1 + 2\epsilon \cos\left(\frac{2\pi t}{T}\right)\right];$$

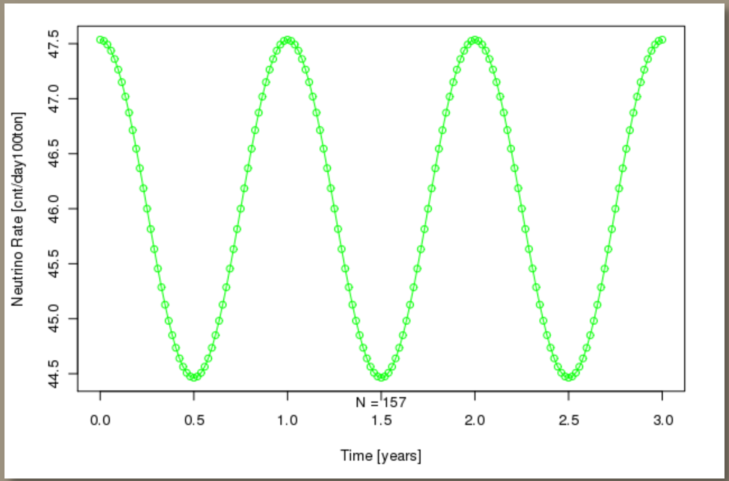
Super-Kamiokande (^{8}B):
ε = 0.0252±0.0072

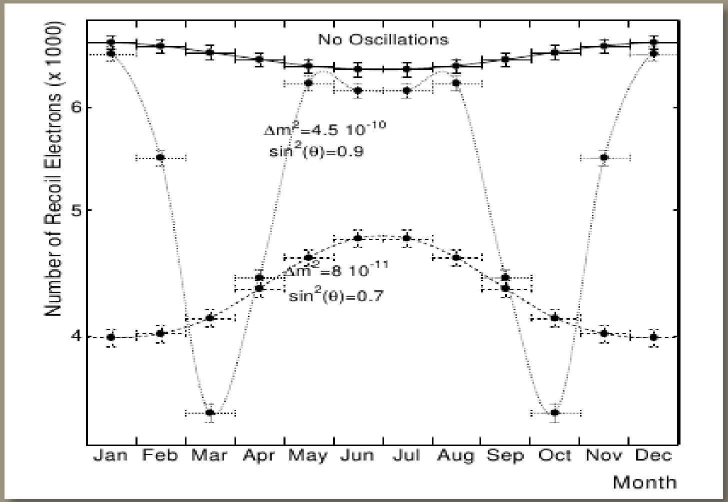
SNO Collaboration (^{8}B):
ε = 0.0143±0.0086

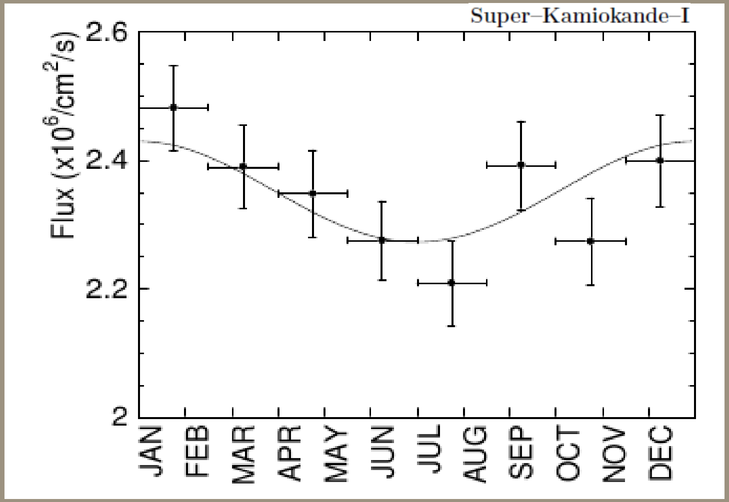
Seasonal Modulation

Astrophysics





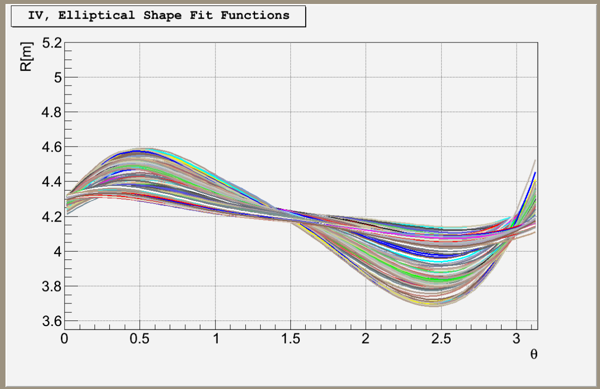




Future

• Borexino detector underwent a vast purification campaign during 2011, that resulted in a significant reduction of the ^{85}Kr and ^{210}Bi backgrounds. As a result, it is believed that the next three years, of phase II, will deliver pristine quality of data for further PEP/CNO study, as well as the seasonal variation analysis.

• Precision determination of the nylon vessel position in Borexino will allow up to 100% increase in the available statistics, improving the signal count rate with stable background.



• The ultimate goal of Borexino it is to measure the ^{7}B line with a lower than 3% precision, that will be required for the calibration of the future LENS solar neutrino detector.

• Borexino is also part of the “SuperNova Early Warning System” (SNEWS) (~90% duty cycle)

The End

Astroparticle and Cosmology Laboratory – Paris, France

INFN Laboratori Nazionali del Gran Sasso – Assergi, Italy

INFN e Dipartimento di Fisica dell’Università – Genova, Italy

INFN e Dipartimento di Fisica dell’Università– Milano, Italy

INFN e Dipartimento di Chimica dell’Università – Perugia, Italy

Institute for Nuclear Research – Gatchina, Russia

Institute of Physics, Jagellonian University – Cracow, Poland

Joint Institute for Nuclear Research – Dubna, Russia

Kurchatov Institute – Moscow, Russia

Max-Planck Institute fuer Kernphysik – Heidelberg, Germany

Princeton University – Princeton, NJ, USA

Technische Universität – Muenchen, Germany

University of Massachusetts at Amherst, MA, USA

University of Moscow – Moscow, Russia

Virginia Tech – Blacksburg, VA, USA