Recent results of the Borexino experiment

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(on behalf of the Borexino collaboration)

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Borexino Collaboration

Genova

Milano

APC Paris

Princeton University

Perugia

Virginia Tech. University

Dubna JINR (Russia)

RRC "Kurchatov Institute" (Russia)

Jagiellonian U. Cracow (Poland)

Heidelberg (Germany)

Munich (Germany)

Borexino Physics

- Solar program:
  - ^{7}Be neutrinos (E = 0.862 MeV);
  - ^{8}B neutrinos (E < 14.06 MeV);
  - Possibly *pp*-, *pep*- and CNO-neutrinos.
- Study of geo-neutrinos;
- Reactor antineutrinos;
- Supernovae (SNEWS);
- Beyond SM…

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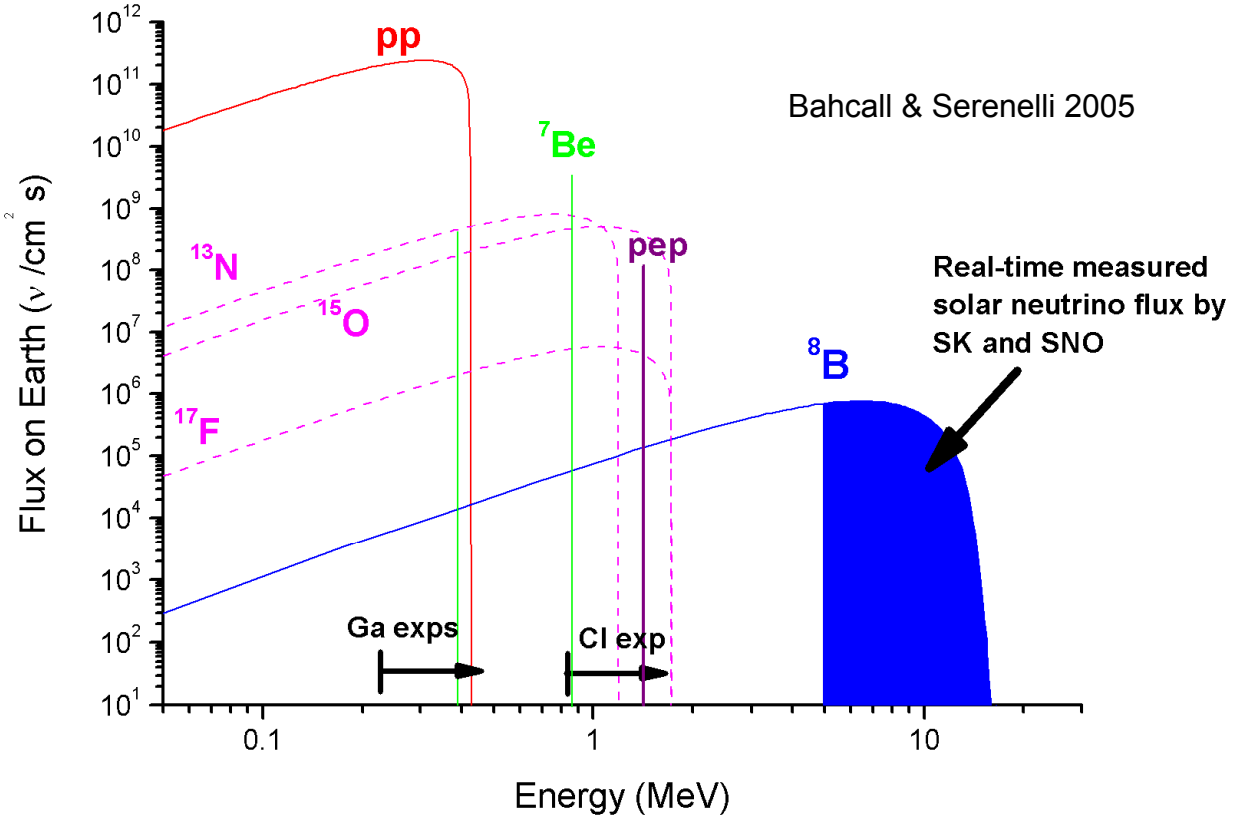
Solar neutrinos energy spectrum



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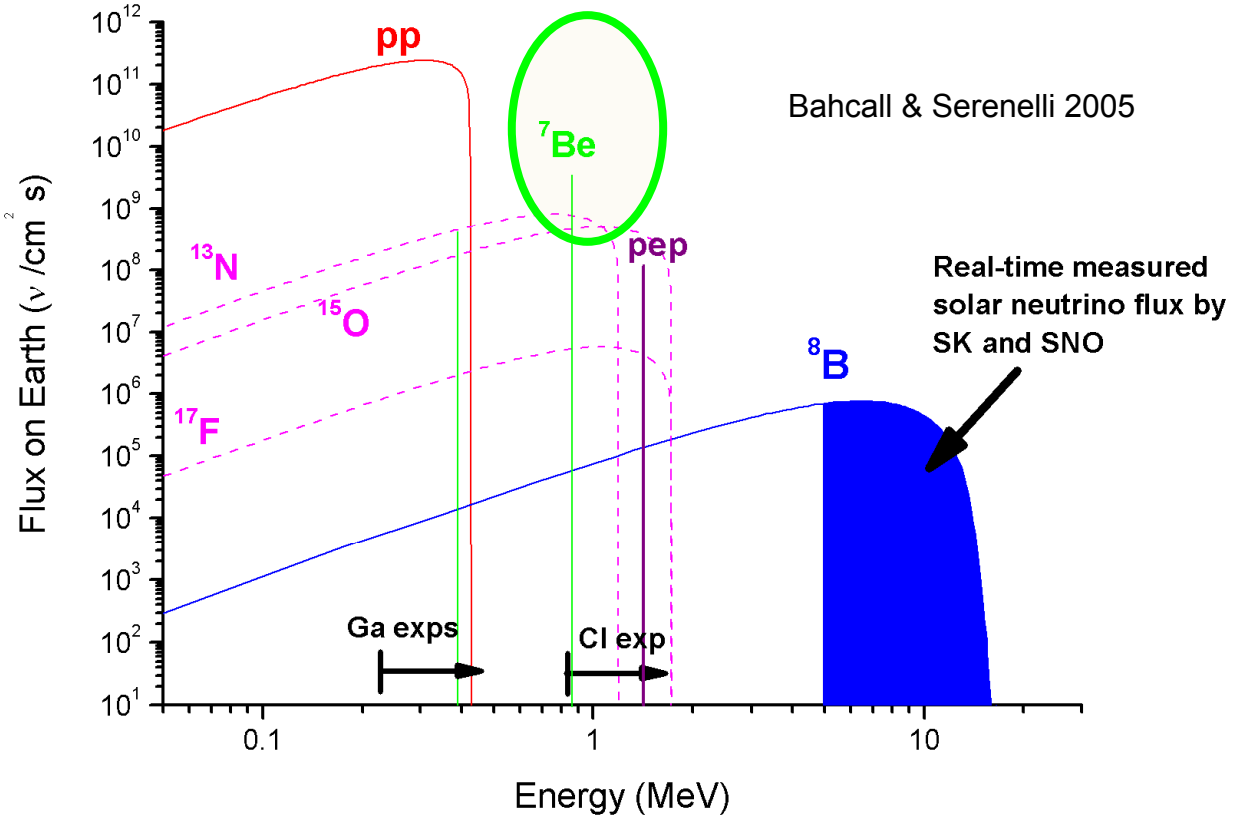

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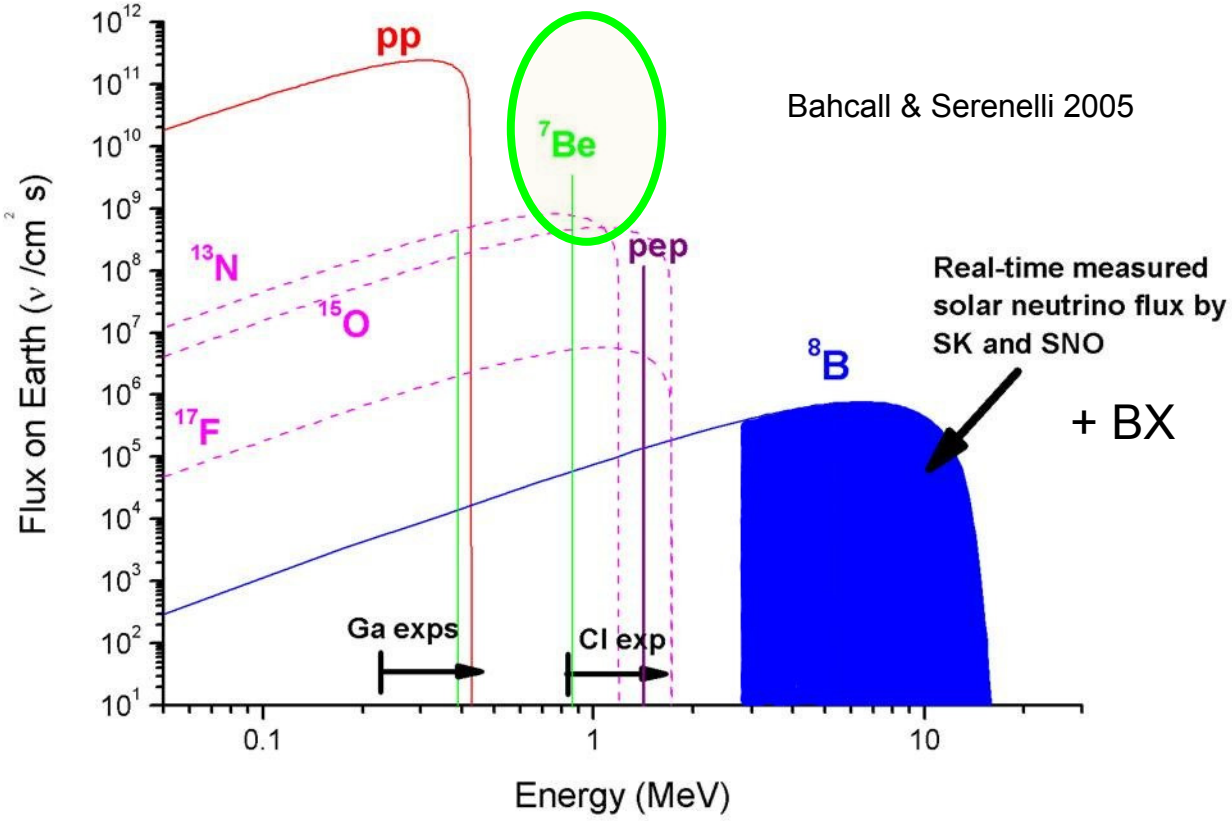


Borexino detector

- …located at the Gran Sasso underground laboratory (3800 m.w.e.), central Italy.
- Detection principle is neutrino-electron elastic scattering in organic liquid scintillator, target mass is 278 tons.
- Energy threshold ~60 keV, counting rate ~30 Hz!
- Energy resolution 6% @ 1 MeV (14% FWHM).
- Spatial resolution 14 cm @ 1 MeV.
- Detector is fully operative since 15 May 2007.

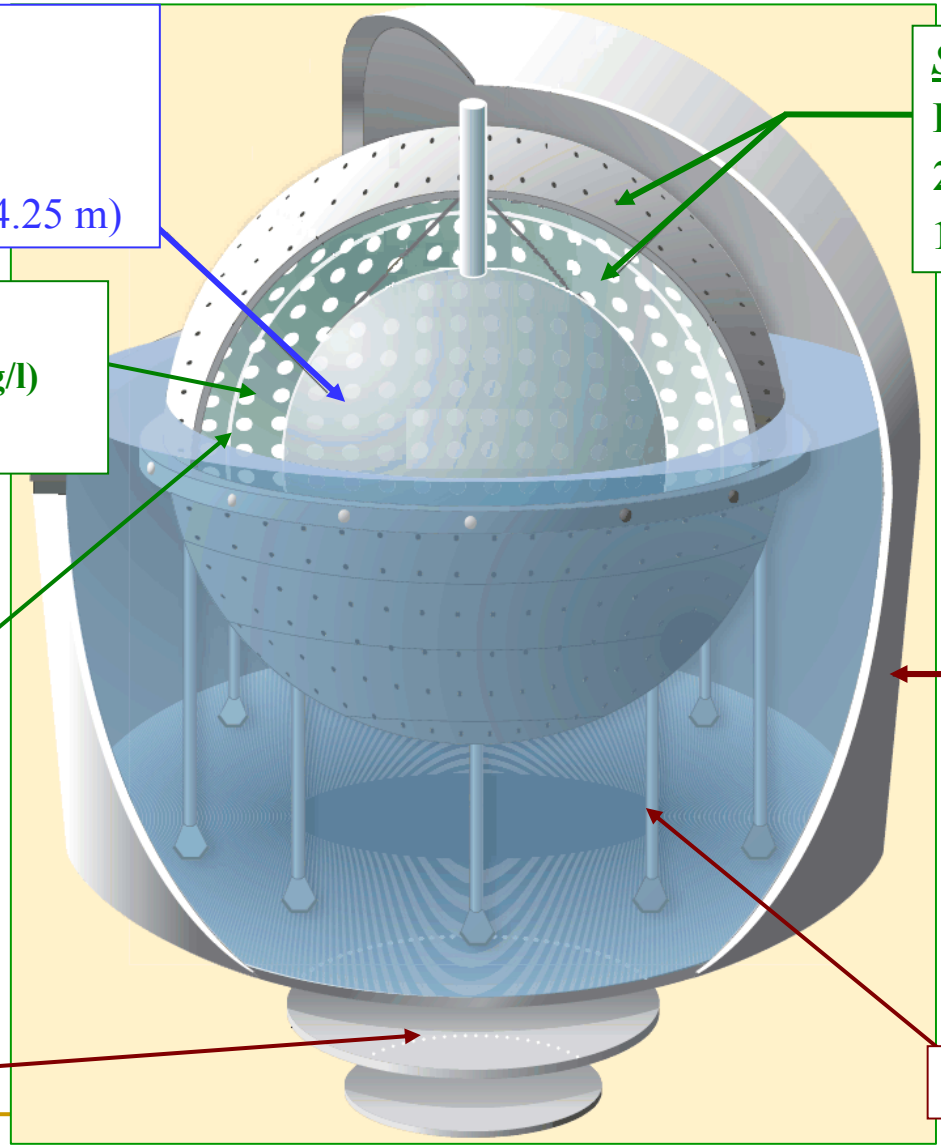
Borexino detector

Scintillator:
278 t PC+PPO (1.5 g/l)
in a 150 μm thick
inner nylon vessel (R = 4.25 m)

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

Outer nylon vessel:
R = 5.50 m
(^{222}Rn barrier)

Carbon steel plates

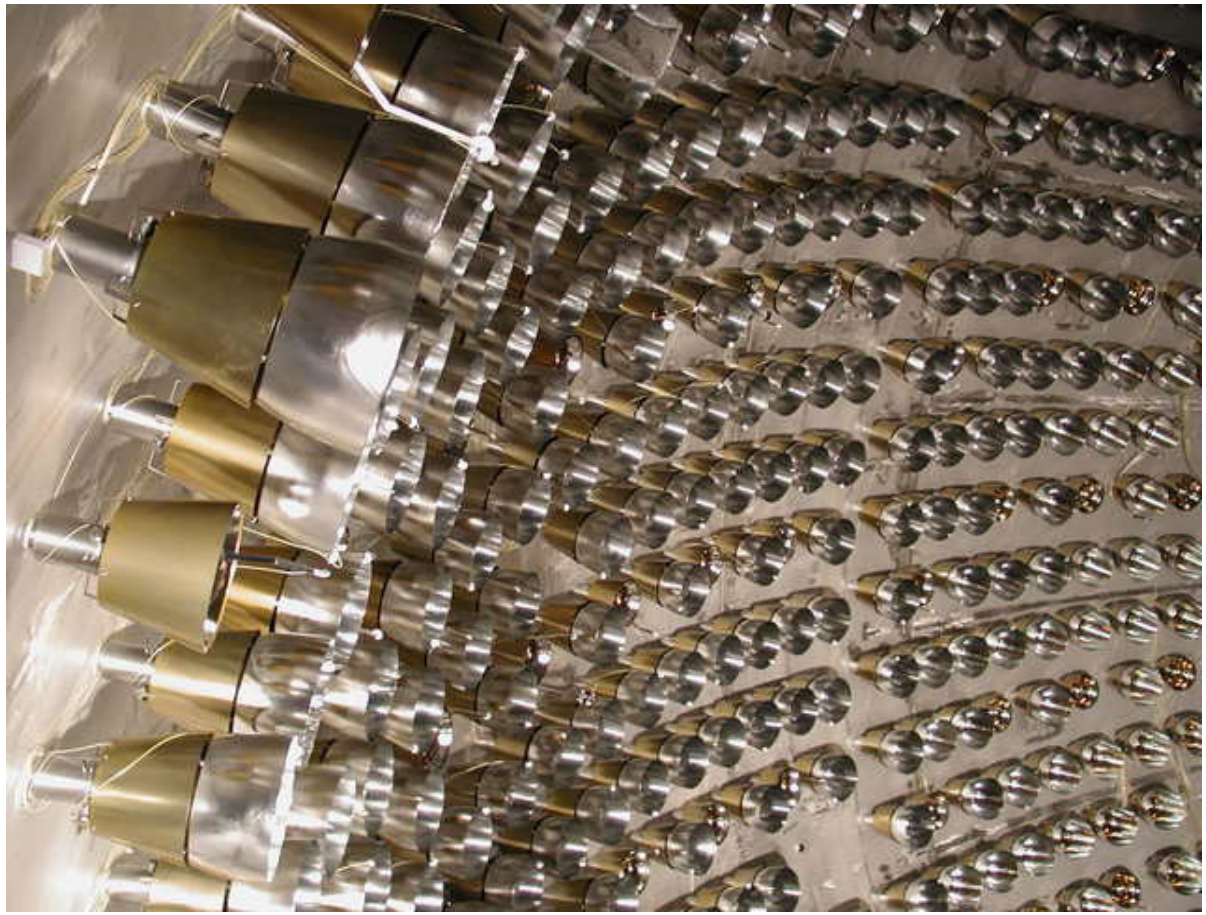


Stainless Steel Sphere:
R = 6.75 m
2212 PMTs
1350 m^3

Water Tank:
γ and n shield
μ water Č detector
208 PMTs in water
2100 m^3

20 steel legs

Borexino detector



…30% optical coverage

Detector radiopurity

Source	Typical abundance	Level achieved
$^{14}C/^{12}C$	10^{-12} (cosmogenic) g/g	$(2.7 \pm 0.6) \cdot 10^{-18}$ g/g
^{238}U (by ^{214}Bi-^{214}Po)	$2 \cdot 10^{-5}$ (dust) g/g	$(1.6 \pm 0.1) \cdot 10^{-17}$ g/g
^{232}Th (by ^{212}Bi-^{212}Po)	$2 \cdot 10^{-5}$ (dust) g/g	$(6.8 \pm 1.5) \cdot 10^{-18}$ g/g
^{222}Rn (by ^{214}Bi-^{214}Po)	100 atoms/cm^3 (air) emanation from materials	~ 10^{-17} g/g (~1 cpd/100 tons)
^{210}Po	Surface contamination	May 07: 70 cpd/ton Sep 08: 7 cpd/ton
^{40}K	$2 \cdot 10^{-6}$ (dust) g/g	$< 3 \cdot 10^{-18}$ (90%) g/g
^{85}Kr	1 Bq/m^3 (air)	(28 ± 7) cpd/100 tons
^{39}Ar	17 mBq/m^3 (air)	<< ^{85}Kr

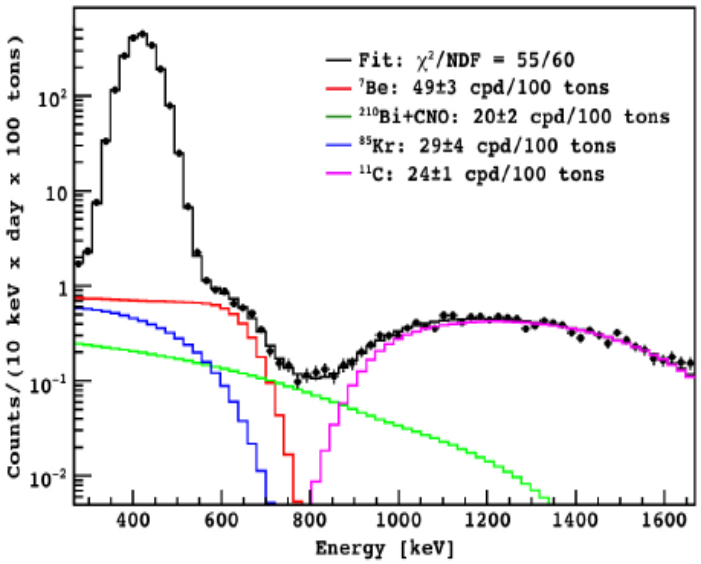
…is a result of more than 15 years of work!

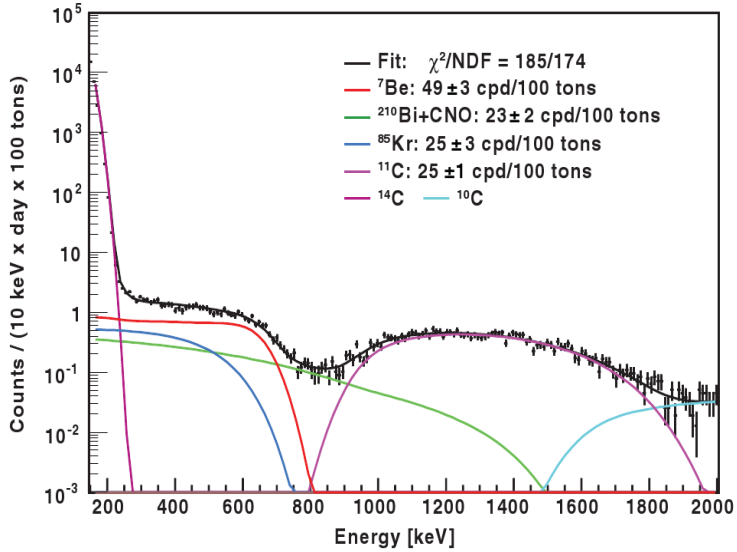
Solar ^{7}Be neutrinos

C. Arpesella *et al*. (Borexino Collab.), Direct measurement of the ^{7}Be solar neutrino flux with 192 days of Borexino data, Phys. Rev. Lett. **101**, 091302 (2008).

Measured rate is:

$R(^{7}\mathrm{Be}) = 49 \pm 3(\mathrm{stat}) \pm 4(\mathrm{sys})$ cpd/100 t





	Expected rate (cpd/100 t)
No oscillation	78 ± 5
High-Z SSM	48 ± 4
Low-Z SSM	44 ± 4

Solar ^{7}Be neutrinos flux measured

- No oscillation:
  - $\Phi(^{7}Be) = (2.74 \pm 0.27) \cdot 10^{9}\ cm^{-2}\ s^{-1}$
- MSW-LMA:
  - $\Phi(^{7}Be) = (5.18 \pm 0.51) \cdot 10^{9}\ cm^{-2}\ s^{-1}$

SSM prediction:

- High-Z:
  - $\Phi(^{7}Be) = (5.07 \pm 0.31) \cdot 10^{9}\ cm^{-2}\ s^{-1}$
- Low-Z:
  - $\Phi(^{7}Be) = (4.55 \pm 0.27) \cdot 10^{9}\ cm^{-2}\ s^{-1}$

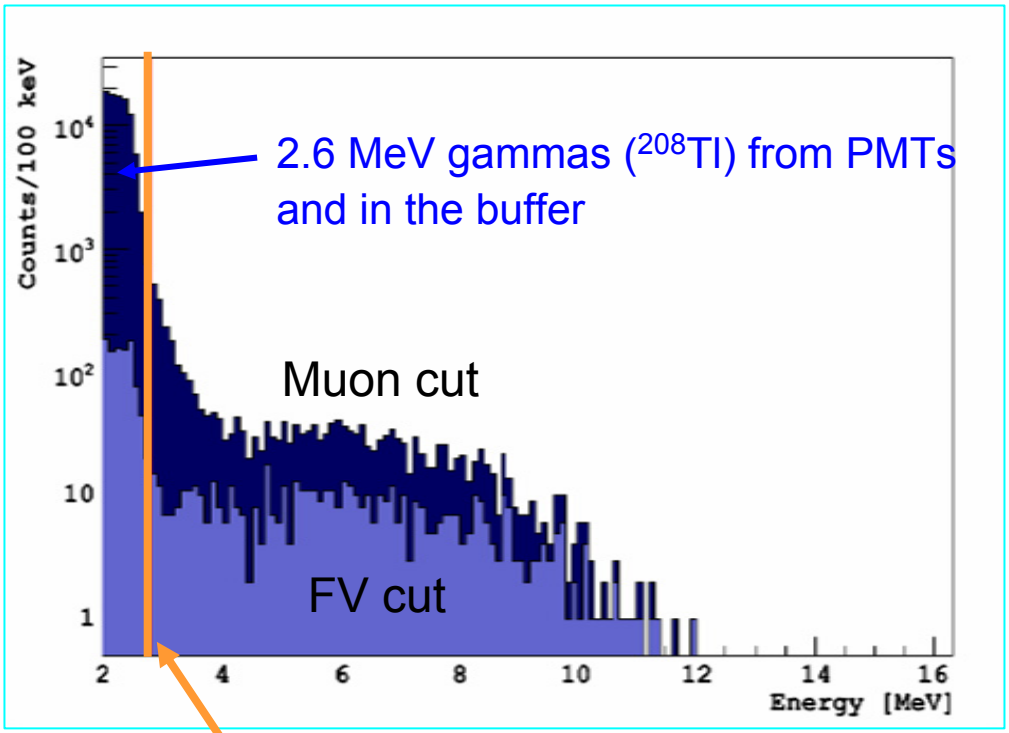
Systematic uncertainties (%)

Total Scintillator Mass	0.2	Fiducial Mass Ratio	6.0
Live Time	0.1	Detector Resp. Function	6.0
Efficiency of Cuts	0.3		
Total Systematic Error			8.5

Calibration program is in progress, see below…

Solar ^{8}B neutrinos

Energy spectrum before cosmogenic cut (5 s after each muon):



E_{thr} = 2.8 MeV > 5σ distant from the 2.6 MeV gamma peak

MSW-LMA prediction:
expected ^{8}B neutrinos rate in 100 tons fiducial volume of BX scintillator above 2.8 MeV:

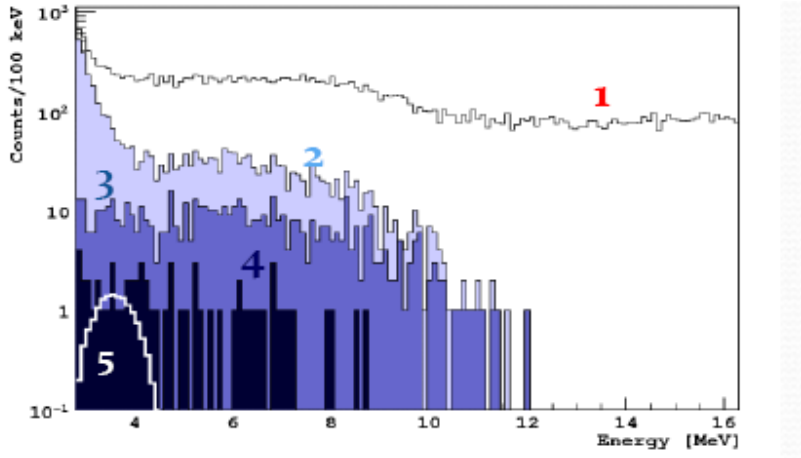
$R(^{8}B)$ = 0.27 ± 0.03 cpd

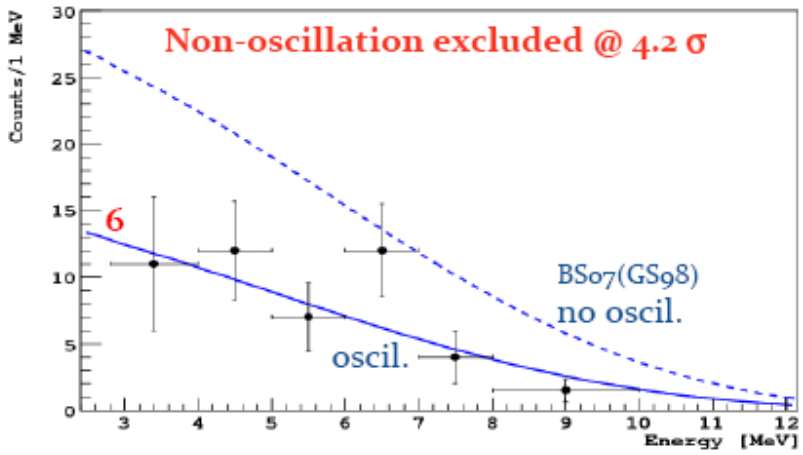
Measured rate in 100 tons fiducial volume:
$R(^{8}B)$ = 0.26 ± 0.04 ± 0.02 cpd

astro-ph > arXiv:0808.2868

Solar ^{8}B neutrinos

Cut	Counts 2.8-16.3 MeV	Counts 5.0-16.3 MeV	Indx
None	20449	14304	1
Muon cut	3363	1135	2
Neutron cut	3280	1114	
FV cut	567	372	3
Cosmogenic cut	71	26	
^{10}C removal	65	26	
^{214}Bi removal	62	26	4
Expected ^{208}Tl	14 ± 3	0	5
Measured ^{8}B-ν	48 ± 8	26 ± 5	6
BS07(GS98) ^{8}B-ν	50 ± 5	25 ± 3	
BS07(AGS05) ^{8}B-ν	40 ± 4	20 ± 2	





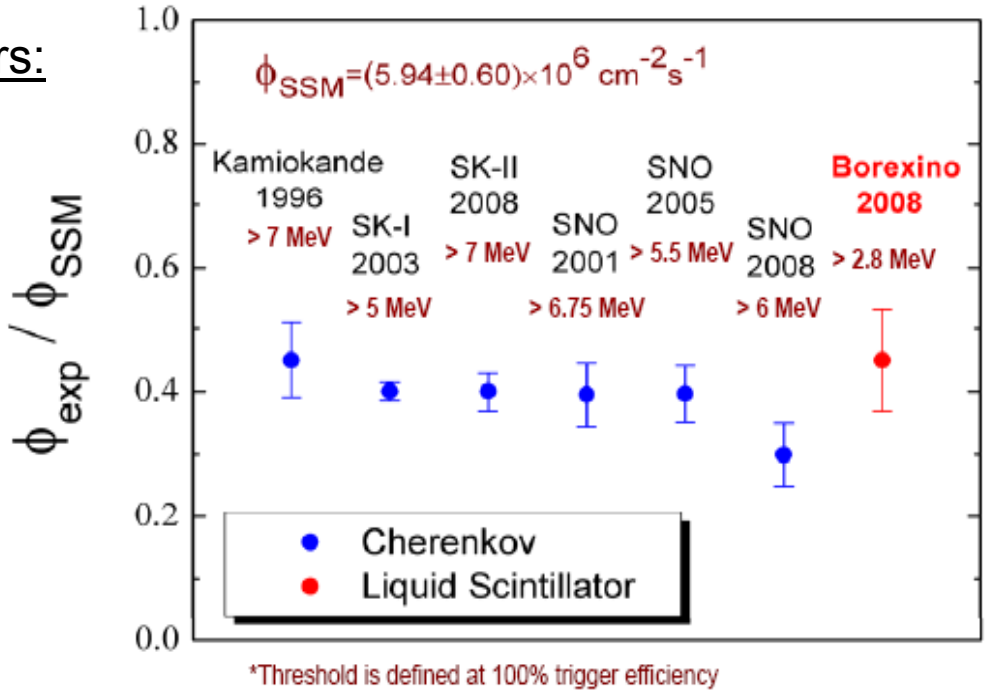
Solar ^{8}B neutrinos flux

$$\Phi(^8B) = (2.65 \pm 0.44 \pm 0.18) \cdot 10^6 \text{ cm}^{-2} \text{ s}^{-1}$$

(from the 2.8 MeV threshold)

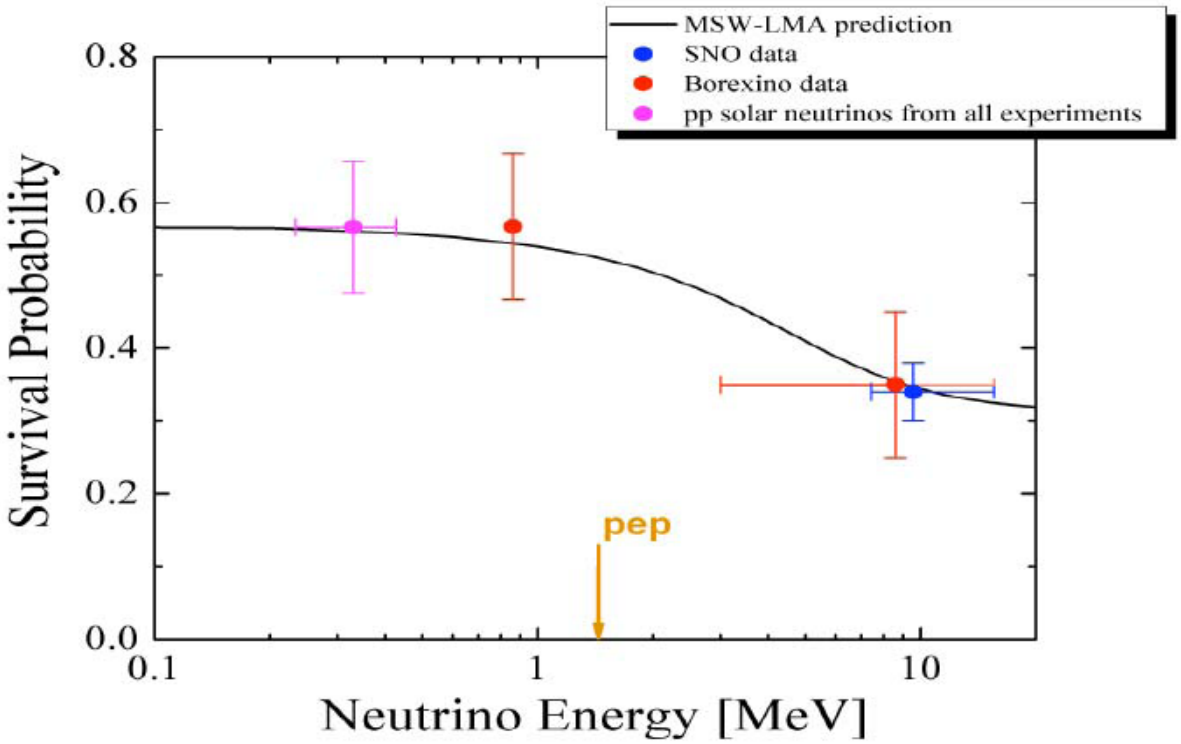
Main sources of systematic errors:

- 6% from the determination of the 100 tons fiducial mass
- 3% uncertainty in the ^{8}B rate above 2.8 MeV from the determination of the detector energy response



Electron neutrino survival probability

Borexino has performed first simultaneous spectral measurements both in vacuum-dominated (^{7}Be) and matter-enhanced (^{8}B) neutrino oscillation (LMA) regions.

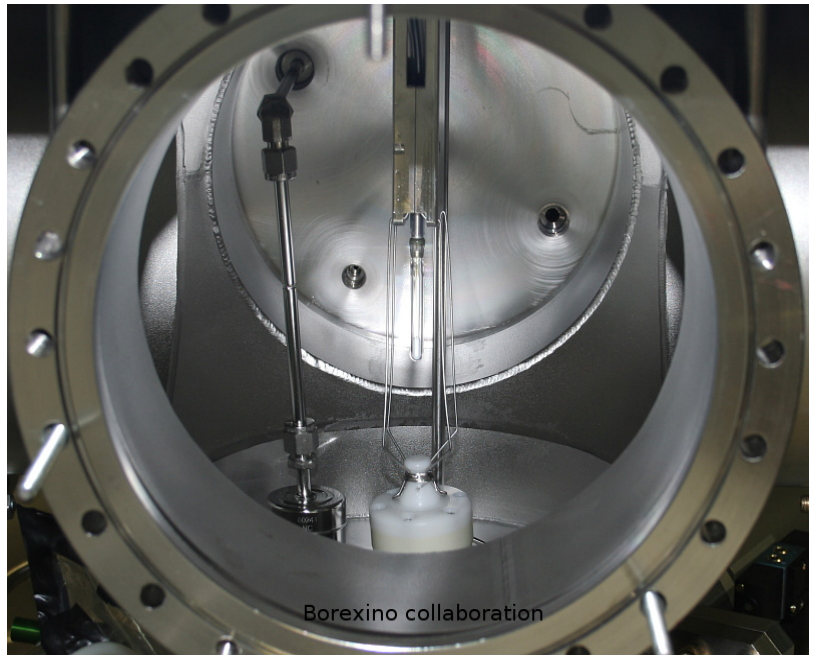


Borexino calibration

- We plan to achieve 5% error in determination of ^{7}Be solar neutrino flux.
- Several calibration campaigns (on- and off-axis) have been performed starting from October 2008. Radioactive source position inside the Borexino is known within 2 cm error. Calibrations are completed by July 2009.
- Study of alpha-, gamma- and proton quenching in the Borexino liquid scintillator. Analysis of calibration data are in progress.

Borexino calibration

Am-Be source inside the cross above Borexino:



Borexino calibration

Several gamma sources used:

- ^{57}Co (122 keV)
- ^{139}Ce (166 keV)
- ^{203}Hg (279 keV)
- ^{85}Sr (514 keV)
- ^{54}Mn (835 keV)
- ^{65}Zn (1115 keV)
- ^{60}Co (1173 + 1332 keV)
- ^{40}K (1461 keV)

Alpha source ^{222}Rn
Neutron source ^{241}Am-^{9}Be

Data analysis are in progress!

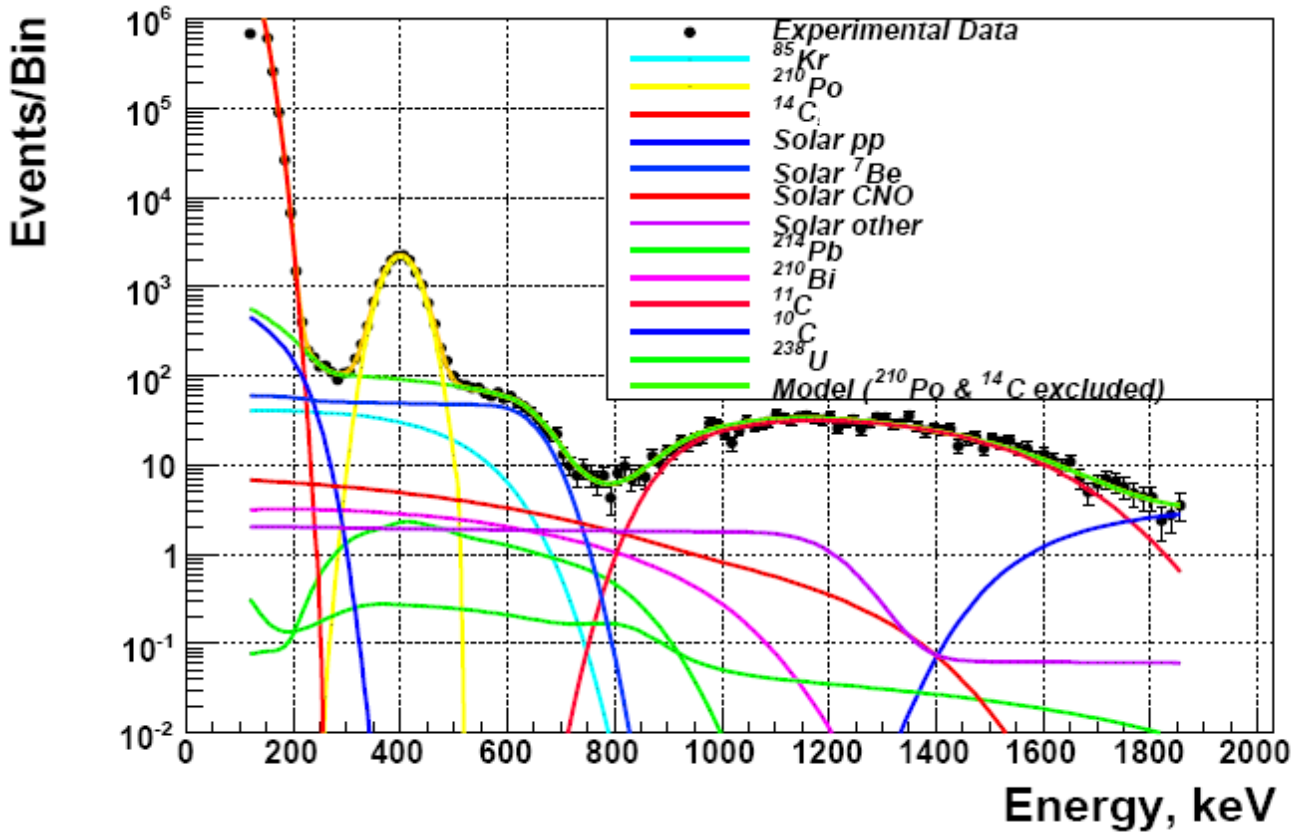
Conclusions

- Borexino has performed first real-time measurement of ^{7}Be solar neutrinos flux.
- Direct measurement of ^{8}B solar neutrinos flux with the lowest threshold ever achieved by real-time detector (2.8 MeV) was done.
- Simultaneous spectral measurement in vacuum-dominated (^{7}Be-neutrinos) and matter-enhanced (^{8}B-neutrinos) oscillation (LMA) regions was done for the first time by single detector.
- More results are coming…

Bonus

$$R = \int_{T_e > T_0} dT_e \int_{E_\nu > E_0} dE_\nu \left(\overline{P}_{ee} \cdot \frac{d\sigma_e}{dT_e}(E_\nu, T_e) + (1 - \overline{P}_{ee}) \cdot \frac{d\sigma_{\mu\text{-}\tau}}{dT_e}(E_\nu, T_e) \right) N_e \cdot \frac{d\Phi_e}{dE_\nu}(E_\nu)$$

Bonus


Events/Bin
Energy, keV
Experimental Data
^{85}Kr
^{210}Po
^{14}C
Solar pp
Solar ^{7}Be
Solar CNO
Solar other
^{214}Pb
^{210}Bi
^{11}C
^{10}C
^{238}U
Model (^{210}Po & ^{14}C excluded)

Bonus

- ^{14}C free (with fixed shape factor);
- ^{85}Kr free; in principle can be bounded (correlated with ^{7}Be)
- ^{210}Po; free (in another approach removed by statistical α/β subtraction)
- ^{214}Pb fixed at the value found for the number of ^{222}Rn events
- ^{210}Bi; free
- ^{7}Be; free normalization for MSW(LMA) parameters
- ^{11}C; free
- CNO fixed @ SSM+MSW(LMA) (highly correlated with ^{210}Bi);
- fix pp and other solar neutrino contributions @ SSM+MSW(LMA)
- Other contributions (still not completely excluded ^{40}K; isotopes from ^{238}U and ^{232}Th decay chains in secular equilibrium) are found to be negligible
- Light yield + one energy resolution parameter are free;
- Birks' quenching model with parameter k_B fixed at the (best-fit) value found with CTF