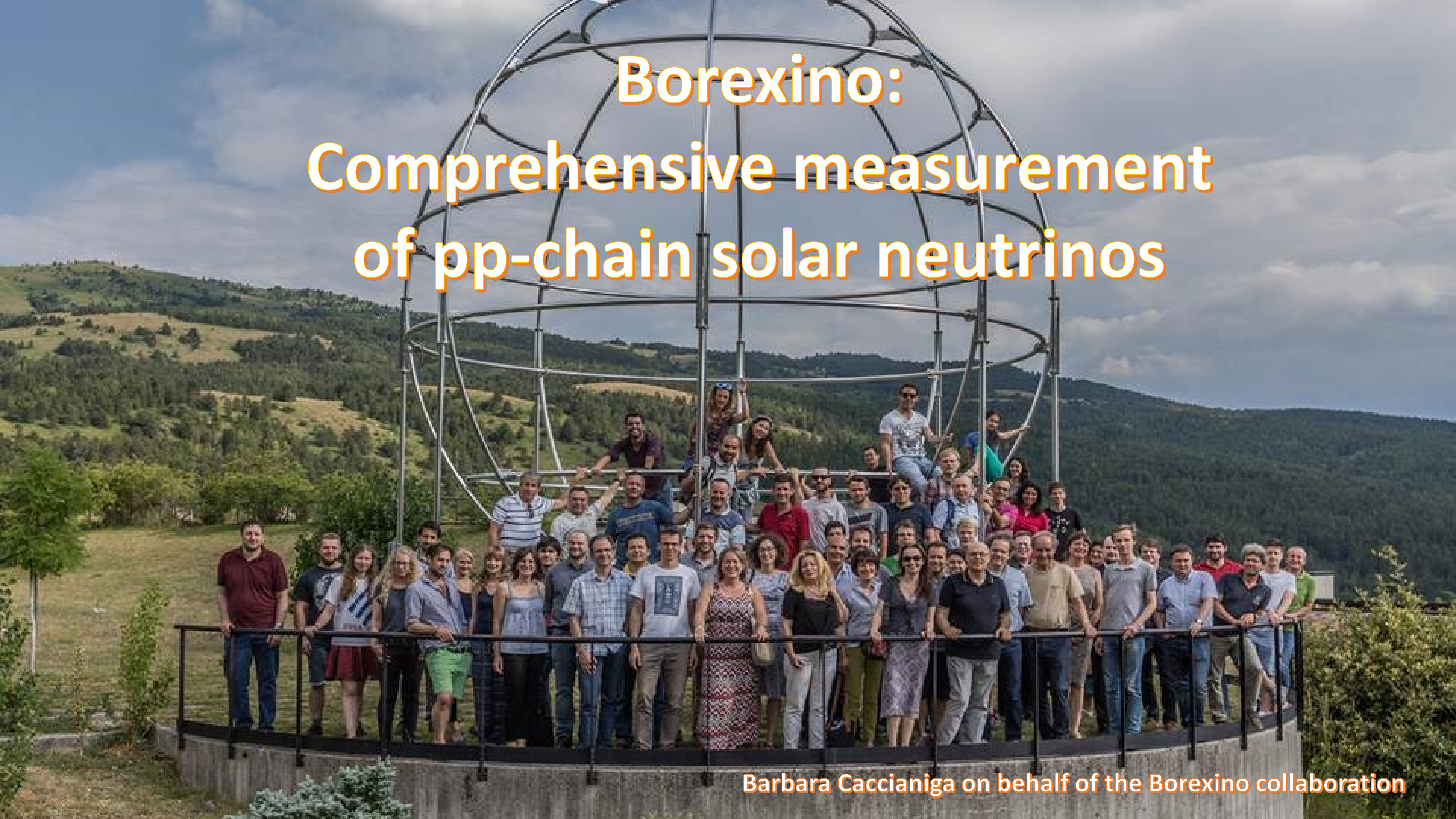
Borexino: Comprehensive measurement of pp-chain solar neutrinos



Barbara Caccianiga on behalf of the Borexino collaboration

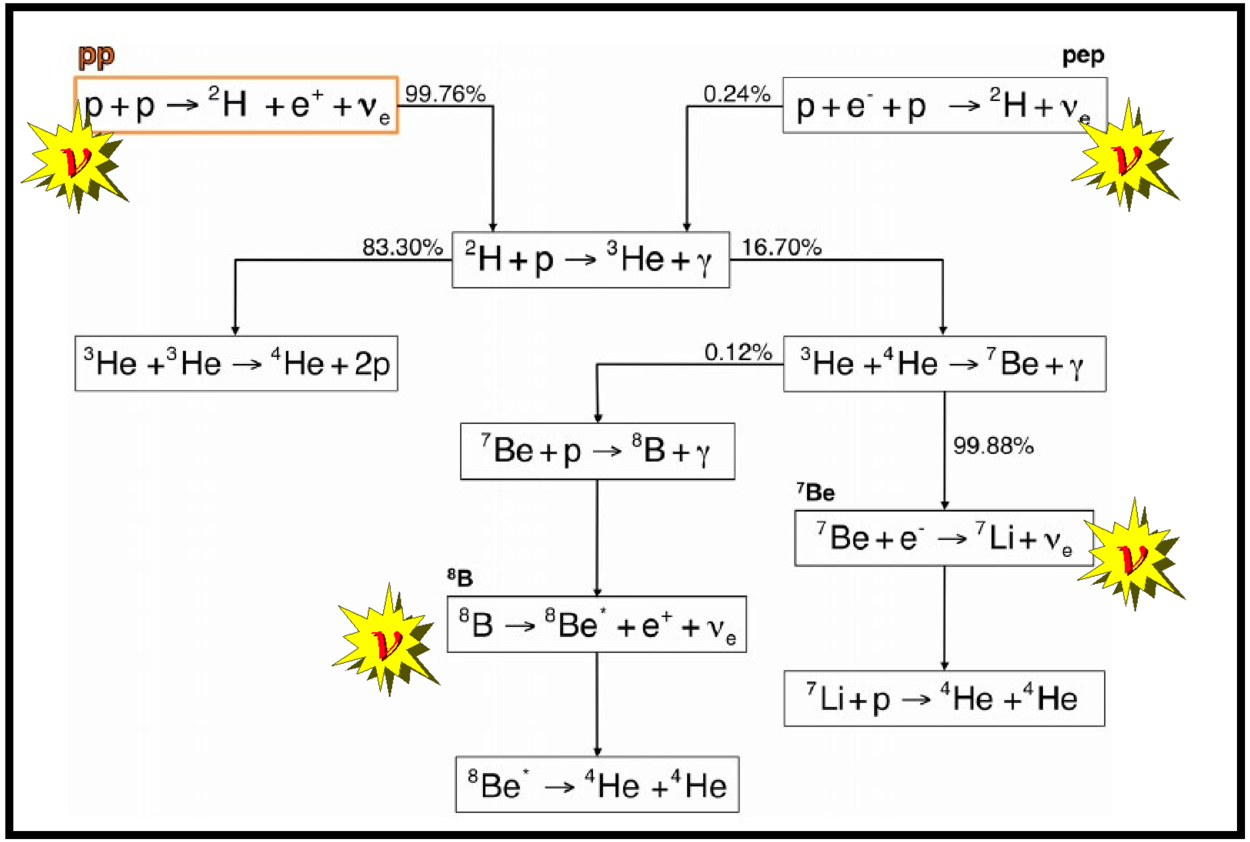
Studying solar neutrinos

Studying Solar Neutrinos

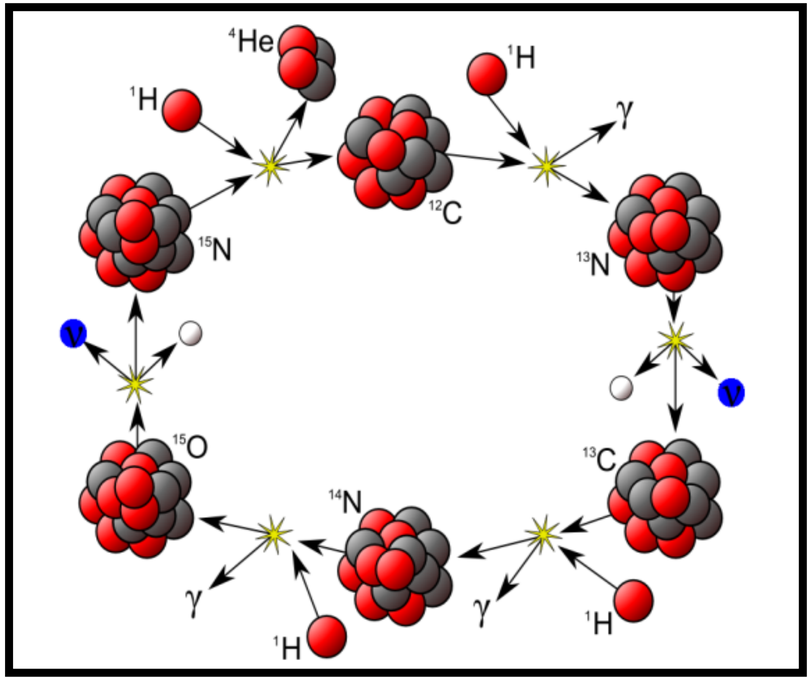
Neutrinos are emitted by fusion reactions occurring in the Sun

$4\,p \rightarrow \alpha + 2\,e^{+} + 2\nu$ (E released ~ 26 MeV)

pp CHAIN: ~99% of the Sun energy



CNO cycle: ~1% of the Sun energy



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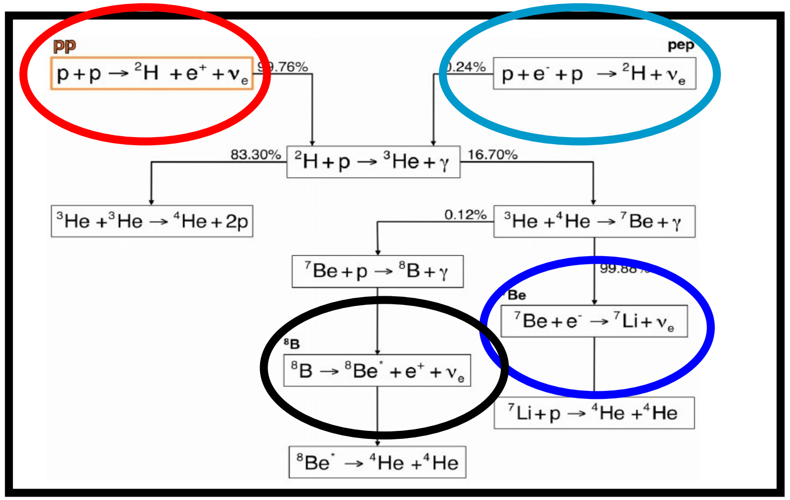
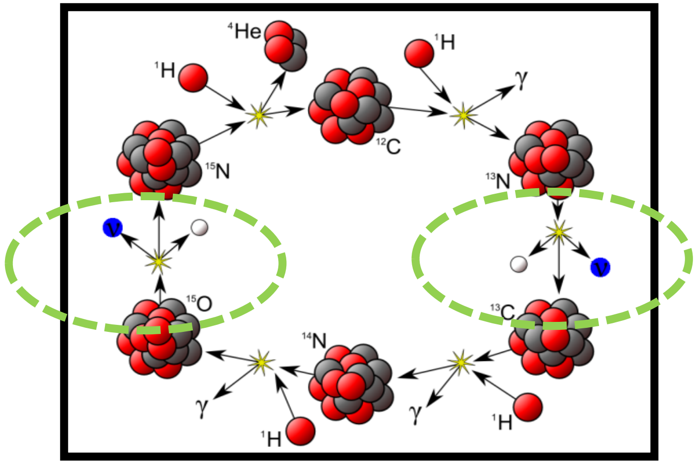
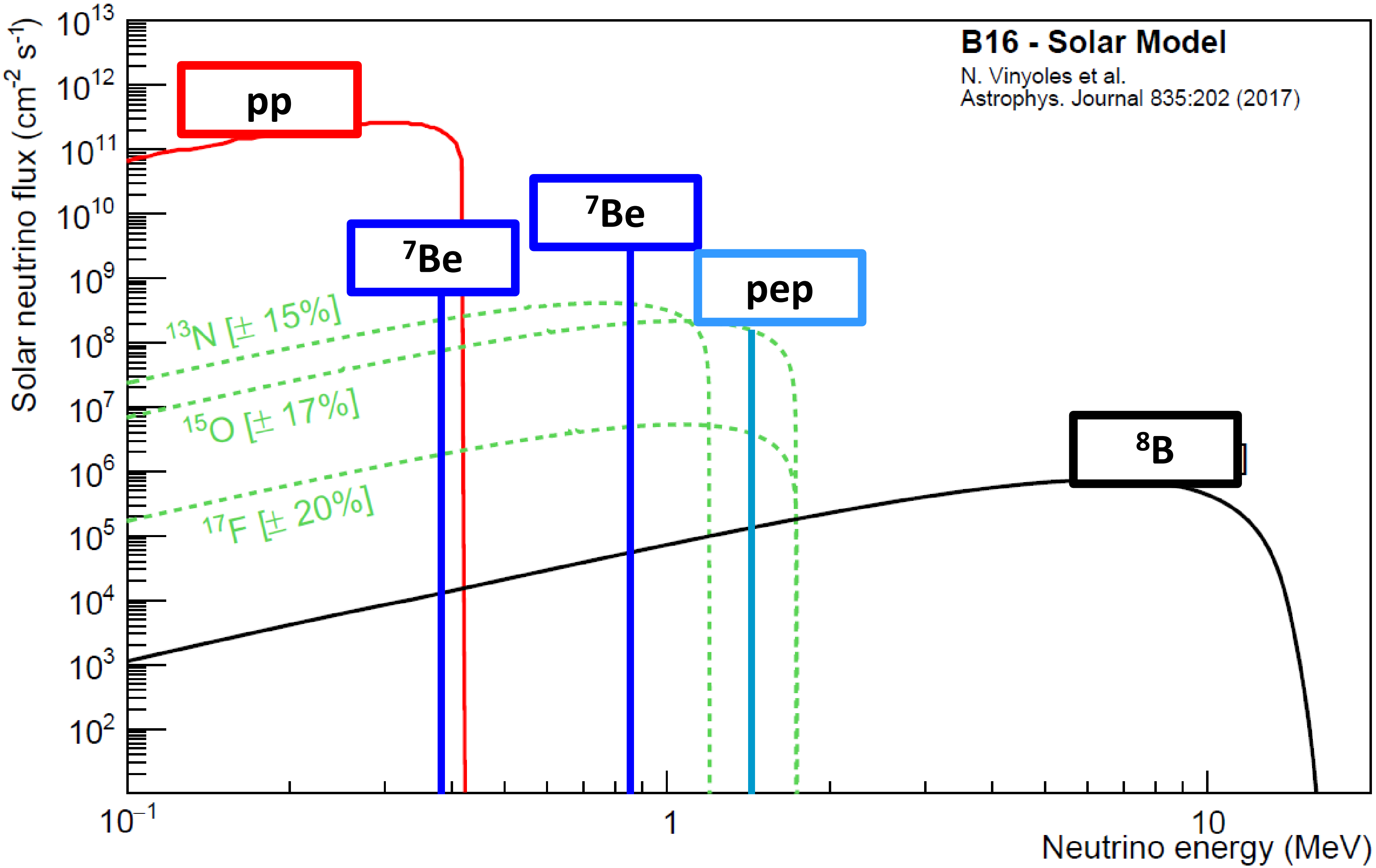
Studying Solar Neutrinos







Barbara Caccianiga (BX collaboration) ``Borexino: comprehensive measurement of pp-chain solar neutrinos''

Studying Solar Neutrinos

The glorious past

Astrophysics

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

→ **Solar neutrino problem**

↓

Particle physics

Breakthrough! The solar neutrino problem provided one of the first hints towards the discovery of neutrino oscillations;

← **Study of the details of ν flux**

↑

Studying Solar Neutrinos

The challenging present

Astrophysics

Still open issues on our Sun;

- **Metallicity problem**
- **CNO neutrinos**

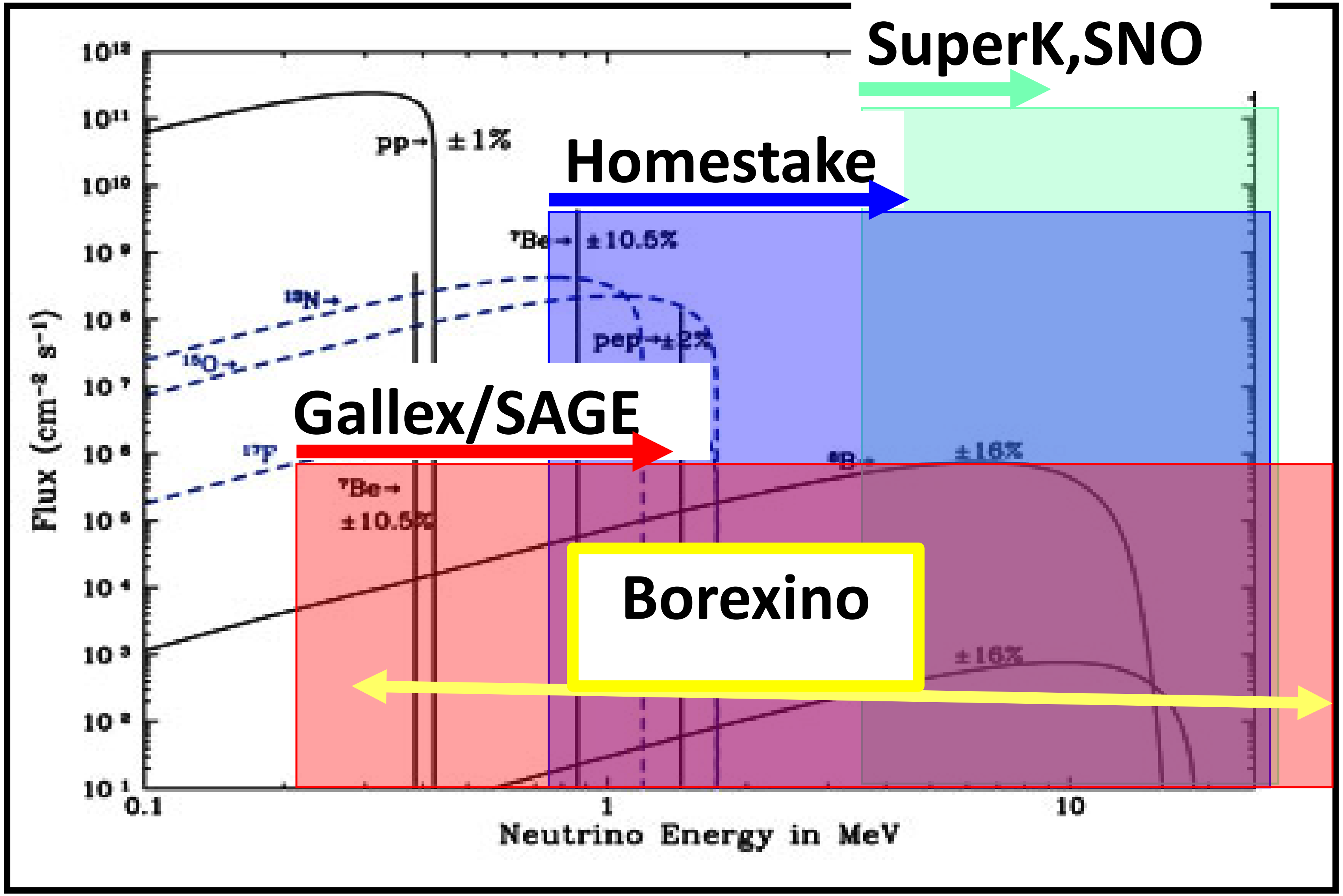
Particle physics

open issues on neutrino oscillations;

- **Non Standard Interactions of neutrinos**

Both astrophysics and particle physics can greatly profit from a detailed knowledge of the solar neutrino spectrum

Studying Solar Neutrinos



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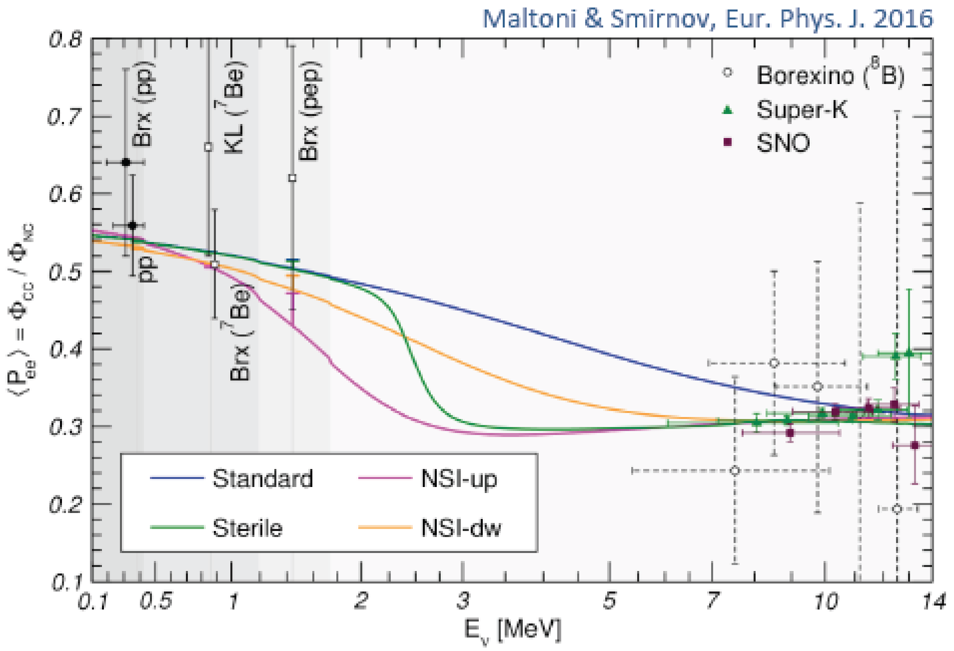
Studying Solar Neutrinos

Astrophysics: metallicity puzzle

- The metallicity determines the opacity of solar plasma and, as a cosequence, regulates the central T of the Sun and the Branching Ratios of the reactions:
- Measuring with high precision the flux of ^{7}Be, ^{8}B or CNO neutrinos could provide an experimental answer to the 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)	3.261±0.18)	38.3%



Particle physics: NSI

- Study of the Pee at different energies;
- Study of the shape of recoil e$^-$ after interaction with neutrinos;

Borexino

Borexino

@ Laboratori Nazionali del Gran Sasso (LNGS)

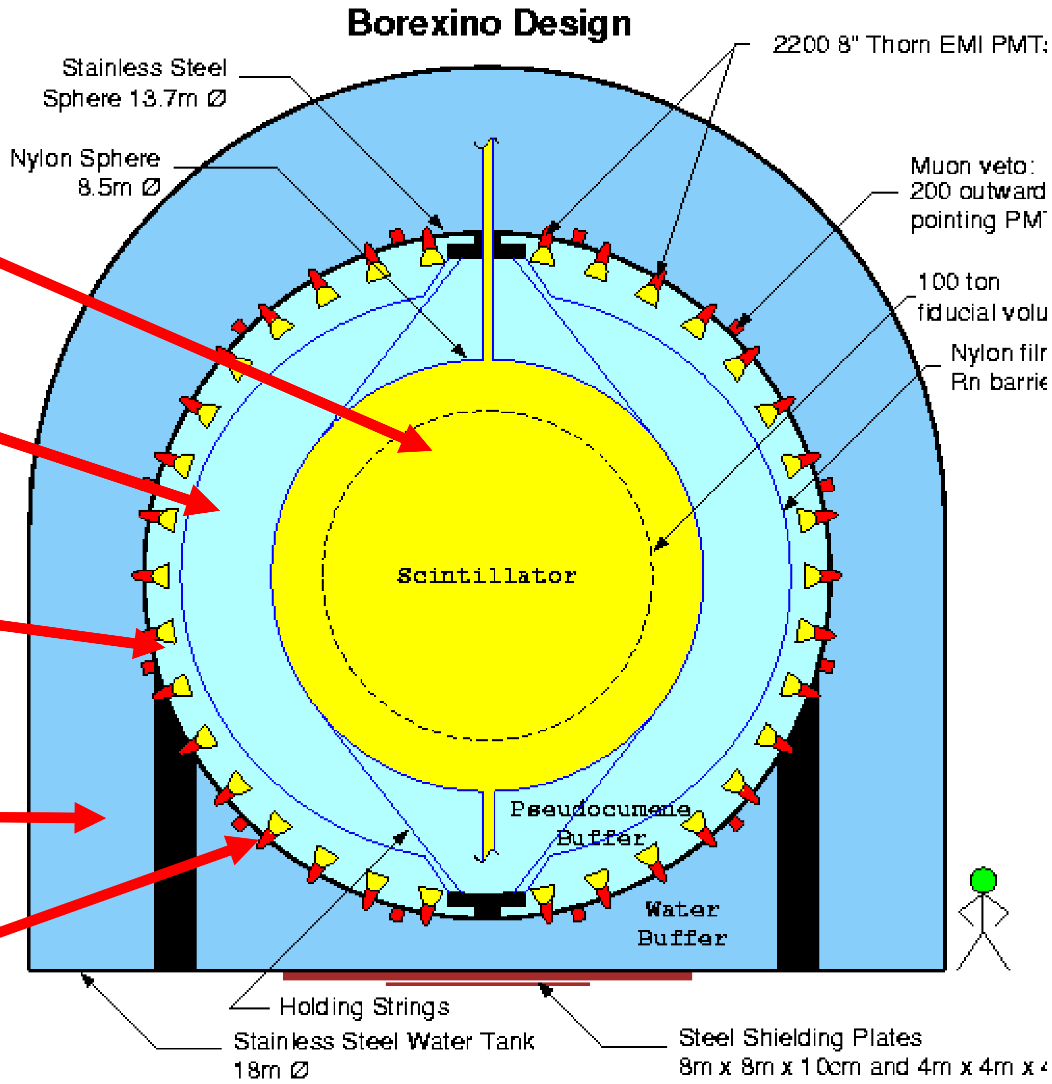
Core of the detector: 300 tons of liquid scintillator (PC+PPO) contained in a nylon vessel of 4.25 m radius;

1st shield: 1000 tons of ultra-pure buffer liquid (pure PC) contained in a stainless steel sphere of 7 m radius;

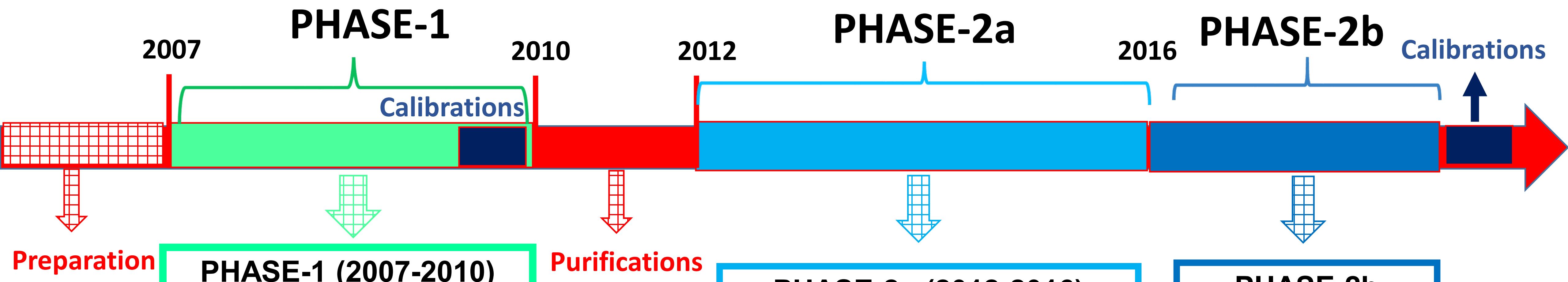
2214 photomultiplier tubes pointing towards the center to view the light emitted by the scintillator;

2nd shield: 2000 tons of ultra-pure water contained in a cylindrical dome;

200 PMTs mounted on the SSS pointing outwards to detect light emitted in the water by muons crossing the detector;



Borexino: the long story..



PHASE-1 (2007-2010)

<u>Solar neutrinos</u>

• ^{7}Be ν : 1st observation+ precise measurement; Day/Night asymmetry;
•pep ν: 1st observation;
• ^{8}B ν with low treshold;
•CNO ν: best limit;

<u>Other</u>

•geo-ν Evidence > 4.5σ
•Limit on rare processes
•Study on cosmogenics

6 cycles of water extraction

PHASE-2a (2012-2016)

<u>Solar neutrinos</u>

- pp neutrinos (Nature 2014)
- seasonal modul. (2017)

- **<u>NEW RESULTS (this talk)</u>**

``Comprehensive measurement of pp-chain solar neutrinos" (Nature 2018)

PHASE-2b

The detector has been stabilized in temperature;

→ Attempt to search for CNO neutrinos in progress

Borexino: essential ingredients

For each scintillation event, we record

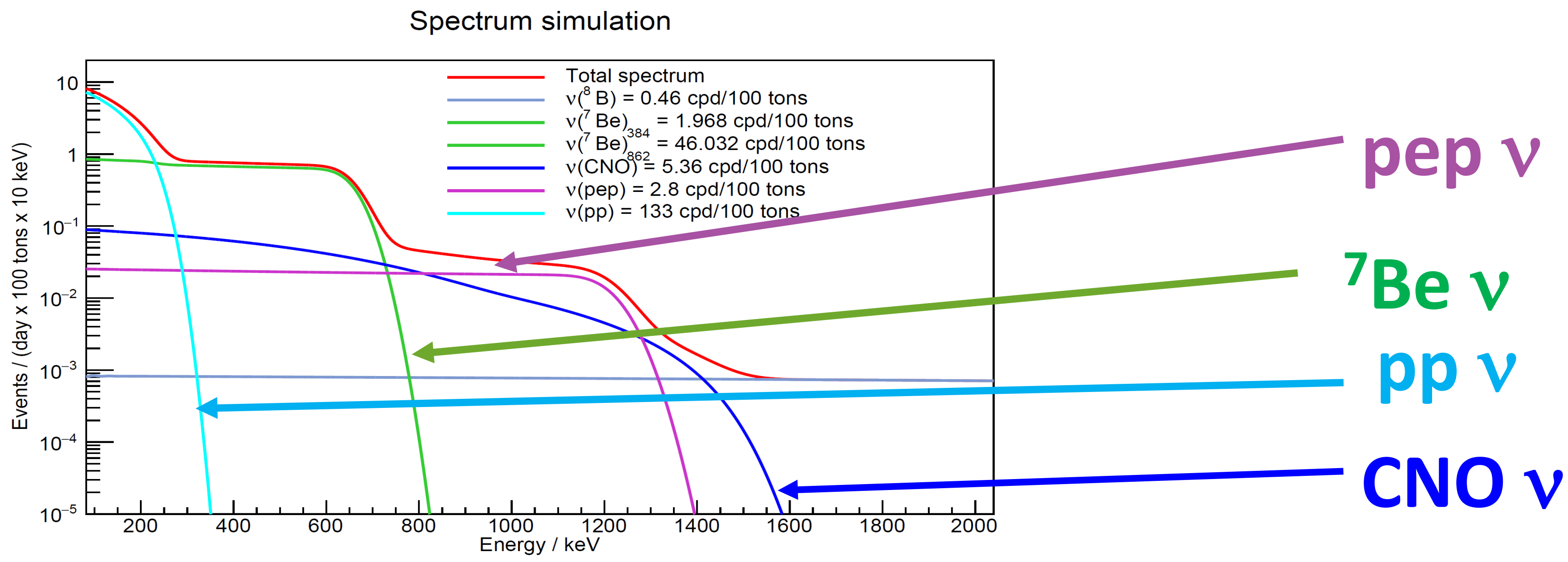
- Number of photons → Energy (approx 500 p.e./MeV)
- Time of arrival of photons → position reconstruction

σ_E /E~ 5% /sqrt(E)

σ_x ~ 12 cm/sqrt(E)

Borexino detects neutrinos through scattering on electrons

- $\nu_x + e^- \rightarrow \nu_x + e^-$
- So what we see is the energy carried away by the electron NOT the neutrino energy



Barbara Caccianiga (BX collaboration) ``Borexino: comprehensive measurement of pp-chain solar neutrinos''

Borexino: the quest for the radiopurity Grail

Requirements: since the neutrino signal is virtually indistinguishable from background, radiopurity is a MUST

- **The expected rate of solar ν in BX (in the energy window considered) is at most ~ 50 counts/day/100t which corresponds to ~ $5\ 10^{-9}$ Bq/Kg;**
- Just for comparison:
  - Natural water is ~ 10 Bq/Kg in ^{238}U, ^{232}Th and ^{40}K
  - Air is ~ 10 Bq/m^3 in ^{39}Ar, ^{85}Kr and ^{222}Rn
  - Typical rock is ~ 100-1000 Bq/m^3 in ^{238}U, ^{232}Th and ^{40}K

BX scintillator must be 9 order of magnitude less radioactive than anything on Earth!

Borexino: the quest for the radiopurity Grail

15 years of work

- **Internal background: contamination of the scintillator itself (^{238}U, ^{232}Th, ^{40}K, ^{39}Ar, ^{85}Kr, ^{222}Rn)**
  - Solvent purification (pseudocumene): distillation, vacuum stripping with low Argon/Kripton N2 (LAKN);
  - Fluor purification (PPO): water extraction, filtration, distillation, N_2 stripping with LAKN;
  - Leak requirements for all systems and plants < 10^{-8} mbar· liter/sec;
- **External background: γ and neutrons from surrounding materials**
  - Detector design: concentric shells to shield the inner scintillator;
  - Material selection and surface treatement;
  - Clean construction and handling;

Borexino: the quest for the radiopurity Grail

Achievements

Internal background: contamination of the scintillator itself

- Contamination from ^{14}C ~ $2x10^{-18}$ $^{14}C/^{12}C$ **OK!**
- Contamination from ^{238}U chain < $9.4x10^{-20}$g/g and ^{232}Th chain ~$5.7x\times10^{-19}$g/g; More than two orders of magnitude better than specifications! **OK!**
- Contamination from ^{40}K not observed; **OK!**
- Contamination from ^{7}Be (cosmogenic) not observed; **OK!**
- Contamination from ^{39}Ar <<1 cpd/100t **OK!**
- Some backgrounds out of specifications: ^{210}Po, ^{85}Kr, ^{210}Bi, ^{11}C ⟵ **See later**

External background: γ and neutrons from surrounding materials

- Contribution in the relevant energy window ~3 counts/day/100t

Borexino: the quest for the radiopurity Grail

The fight against background is not over...

Even in these high radiopurity conditions, we still have background events contaminating our solar neutrino signal;

- We need to apply software cuts to data, in order to remove as much background as possible;
- Furthermore, we need a fit to separate the signal from the residual background components;

New Borexino Phase-II results

New Phase-II results

Summary of improvements with respect to Phase-I

1. **Improved radiopurity**, because of the purification campaign;
2. **Increased statistics** (x 1.6 exposure of published Phase-I data);
3. **Increased stability** of the detector;
4. **Better comprehension of the details of the energy scale and detector response;**

New Phase-II results

ARTICLE

https://doi.org/10.1038/s41586-018-0624-y

Nature, 496 (2018) 505.

Comprehensive measurement of *pp*-chain solar neutrinos

The Borexino Collaboration*

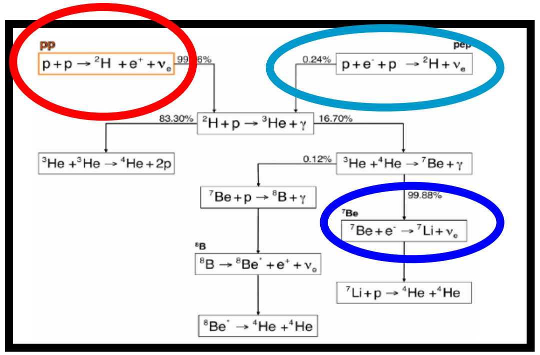
About 99 per cent of solar energy is produced through sequences of nuclear reactions that convert hydrogen into helium, starting from the fusion of two protons (the *pp* chain). The neutrinos emitted by five of these reactions represent a unique probe of the Sun's internal working and, at the same time, offer an intense natural neutrino beam for fundamental physics. Here we report a complete study of the *pp* chain. We measure the neutrino–electron elastic-scattering rates for neutrinos produced by four reactions of the chain: the initial proton–proton fusion, the electron-capture decay of beryllium-7, the three-body proton–electron–proton (*pep*) fusion, here measured with the highest precision so far achieved, and the boron-8 beta decay, measured with the lowest energy threshold. We also set a limit on the neutrino flux produced by the ^{3}He–proton fusion (hep). These measurements provide a direct determination of the relative intensity of the two primary terminations of the *pp* chain (*pp*-I and *pp*-II) and an indication that the temperature profile in the Sun is more compatible with solar models that assume high surface metallicity. We also determine the survival probability of solar electron neutrinos at different energies, thus probing simultaneously and with high precision the neutrino flavour-conversion paradigm, both in vacuum and in matter-dominated regimes.

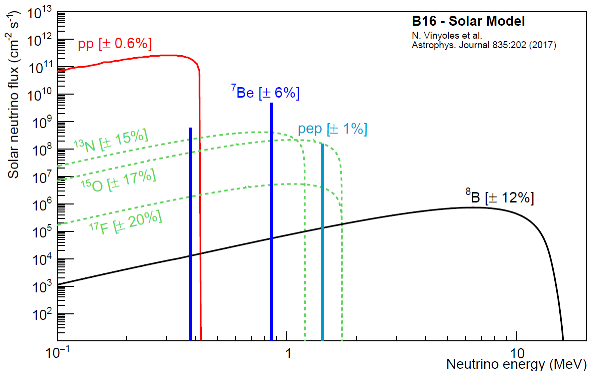
Comprehensive measurement of pp-chain solar neutrinos

Comprehensive analysis performed on two energy ranges

- **LER** (Low Energy Range) between (0.19 – 2.93) MeV (pp, pep and ^{7}Be neutrinos)
- **HER** (High Energy Range) between (2.3 -16) MeV (^{8}B neutrinos)

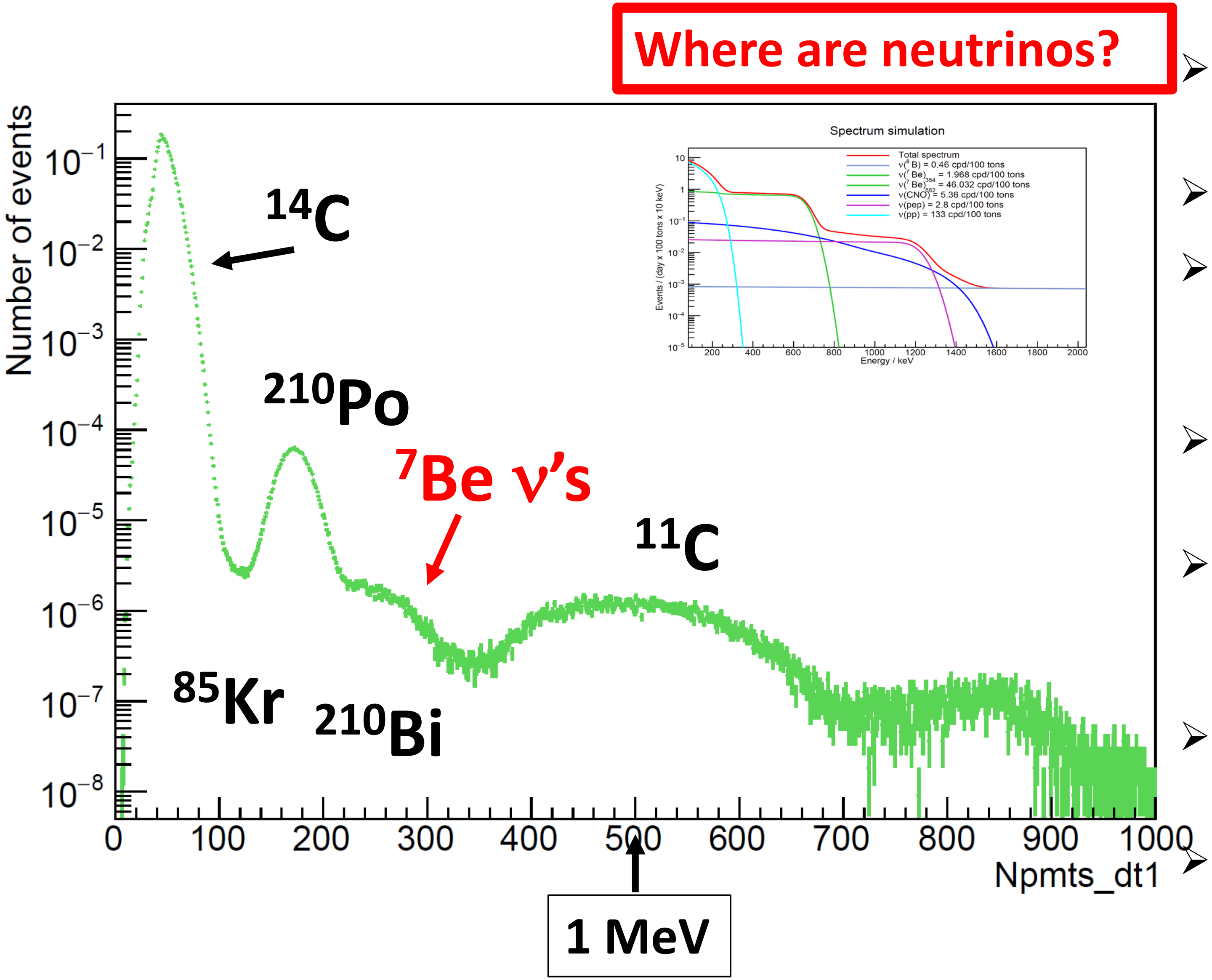
- The analysis follows similar strategies in LER and HER;
- It is optimized differently in the two energy regions to comply with the different backgrounds affecting each specific energy range;





Analysis in the LER (0.19- 2.93) MeV: pp, pep and ^{7}Be neutrinos

Analysis in the LER: pp,^{7}Be and pep neutrinos



- **^{14}C**: irreducible background in an organic scintillator. It decays β^- (Q=156 keV);
- **pile-up** of events (especially ^{14}C);
- **^{210}Po**: belongs to the ^{238}U chain. Not in equilibrium with the ^{238}U chain nor with ^{210}Pb; it decays with its livetime of ~ 200 d
- **^{85}Kr**: present in air. Decays β^- (Q= 687 keV);
- **^{210}Bi**: comes from ^{210}Pb not in equilibrium with ^{238}U chain. It decays β^- (Q= 1160 keV)
- **^{11}C**: produced by μ. It decays in 30 minutes;
- **^{208}Tl** from the PMTs High energy gamma at 2.6 MeV mainly affectig the ^{8}B ν search

Analysis in the LER: pp, ^{7}Be and pep neutrinos

Extracting the neutrino signal from data

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;

A multivariate fit is performed including in the likelihood

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

to improve the fit capability to disentangle ^{11}C

to improve the fit capability to disentangle external background

Analysis in the LER: pp, ^{7}Be and pep neutrinos

The Three-fold Coincidence technique (TFC)

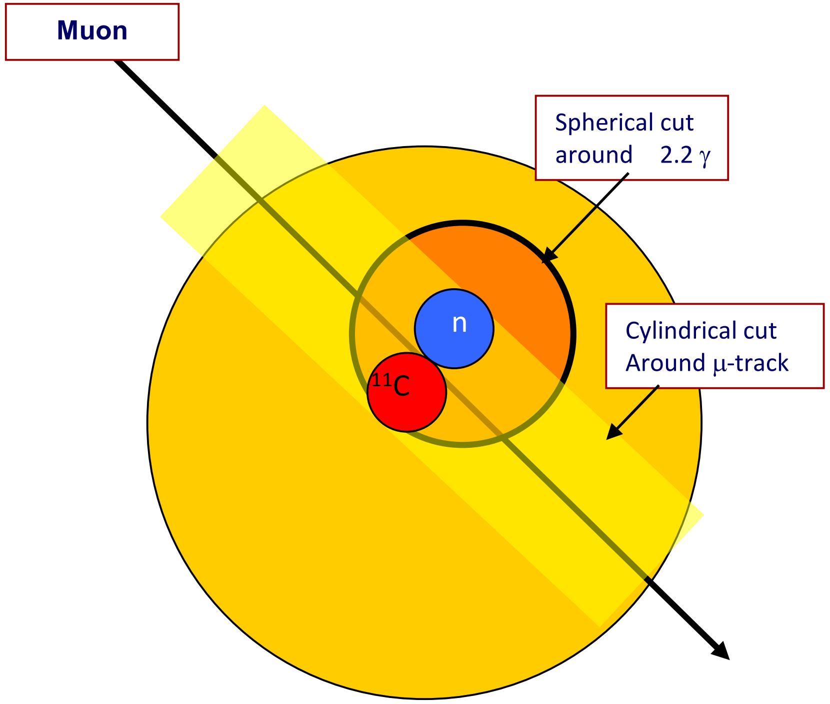
to improve the fit capability to disentangle ^{11}C

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

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

${}^{11}C \rightarrow {}^{11}B + e^+ + \nu_e$ $\quad$ $t \sim 30 min$

$n + p \rightarrow d + \gamma$ $\quad$ $\tau \sim 260 \mu s$



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;

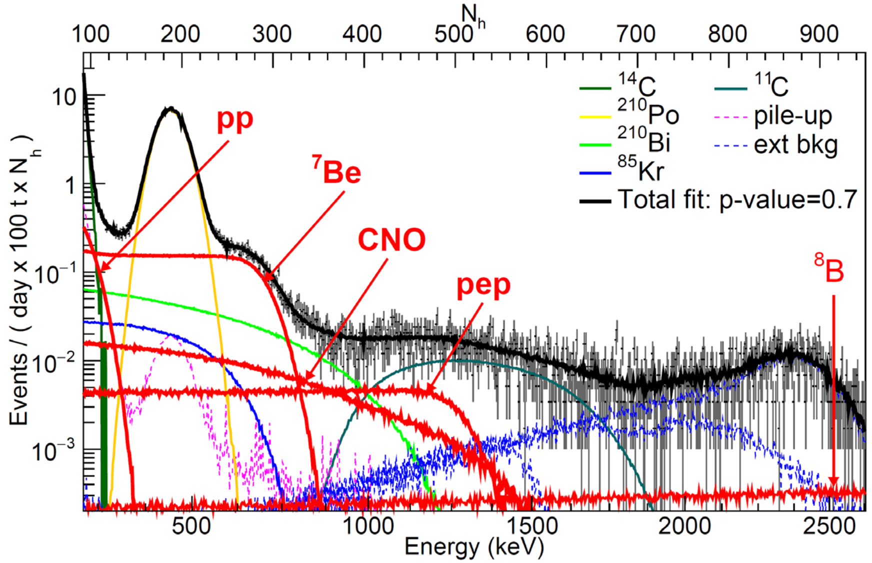
The data-set is divided in two samples: one depleted in ^{11}C (TFC-subtracted) and one enriched in ^{11}C (TFC-tagged) which are simultaneously fit;

Analysis in the LER: pp, ^{7}Be and pep neutrinos

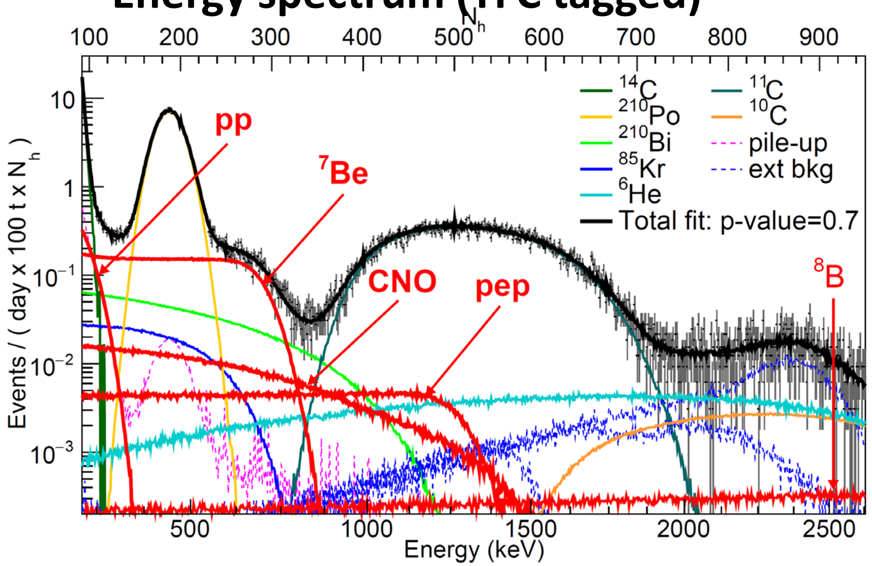
Data-set: Dec 14th 2011- May 21st 2016; **Total exposure**: 1291.51 days x 71.3 tons;

Results on data

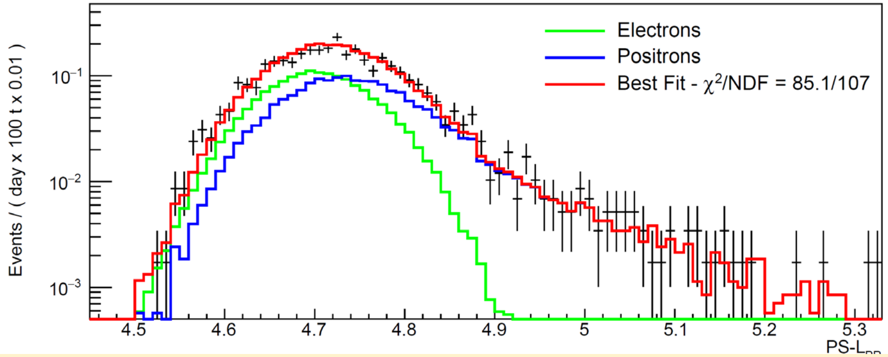
Energy spectrum (TFC subtracted)



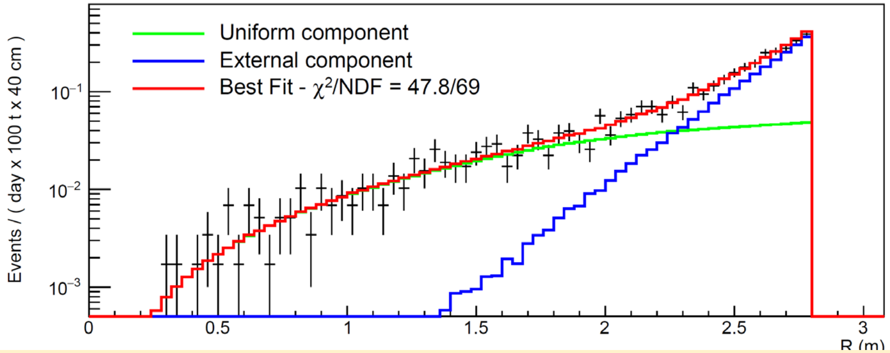
Energy spectrum (TFC tagged)



PS_L_{Pr} distribution



Radial distribution



Analysis in the LER: pp,^{7}Be and pep neutrinos

Systematic errors

Two methods to take into account pile-up:

- Effects of non perfect modelling of the detector response;
- Uncertainty on theoretical input spectra (^{210}Bi);

- ^{85}Kr constrained to be <7.5cpd/100t(95% C.L.) (from Kr-Rb delayed coincidences)

	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

Analysis in the LER: pp,^{7}Be and pep neutrinos

Borexino results and comparison with the theoretical predictions

Neutrino rates

Solar ν	Borexino results Rate [cpd/100 t]
pp	$134 \pm 10 \,^{+6}_{-10}$
^{7}Be	$48.3 \pm 1.1 \,^{+0.4}_{-0.7}$
pep (HZ)	$2.43 \pm 0.36 \,^{+0.15}_{-0.22}$
pep (LZ)	$2.65 \pm 0.36 \,^{+0.15}_{-0.24}$

← Total uncertainty at 2.7% (it was 5%)

← >5σ evidence

Analysis in the LER: pp,^{7}Be and pep neutrinos

Borexino results and comparison with the theoretical predictions

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← Total uncertainty at 2.7% (it was 5%)

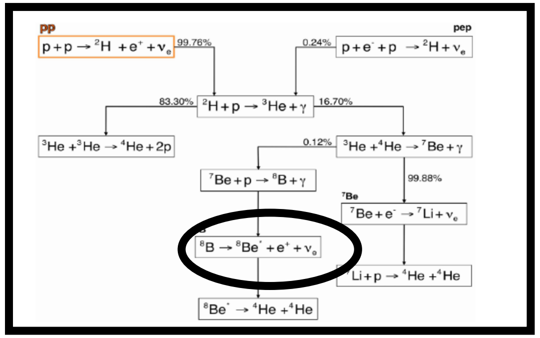
← >5σ evidence

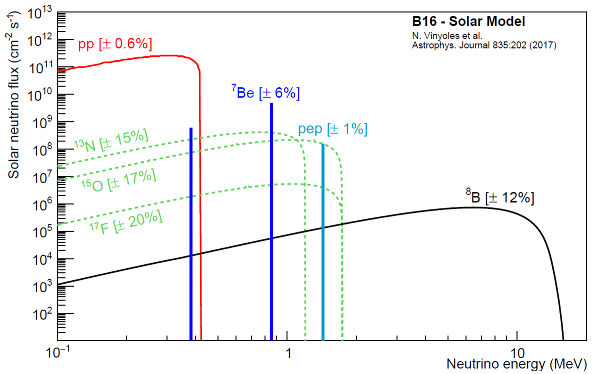
Neutrino fluxes Φ

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

*oscillation parameters from: I.Esteban, *MC.Gonzalez-Concha, M.Maltoni, I.Martinez-Soler and T.Schwetz, Journal of High Energy Physics 01 (2017)*

**neutrino fluxes from: *N.Vinyole,A.Serenelli, F.Villante, S.Basu, J.Bergstrom,M.C.Gonzalez-Garcia, M.Maltoni, C.Pena-Garay, N.Song, Astr.Jour. 835,202 (2017)*





Analysis in the HER (2.3- 16) MeV: ${}^8B$ neutrinos

Barbara Caccianiga (BX collaboration) ``Borexino: comprehensive measurement of pp-chain solar neutrinos''

Analysis in the HER: ^{8}B neutrinos

Extracting the neutrino signal from data

Residual backgrounds affecting this energy region are: ^{208}Tl (emanated from PMTs, from the vessel or internal), cosmogenic isotopes, ^{214}Bi (intl);

- Analysis is performed in two energy window HER-1 (3.2 -5.7 MeV) and HER-2 (5.7-16 MeV);
- A fit to the radial distribution of events is performed, in order to separate the external background contribution from the signal;
- The internal background is estimated and fixed in the fit;

Analysis in the HER: ^8B neutrinos

Results on data

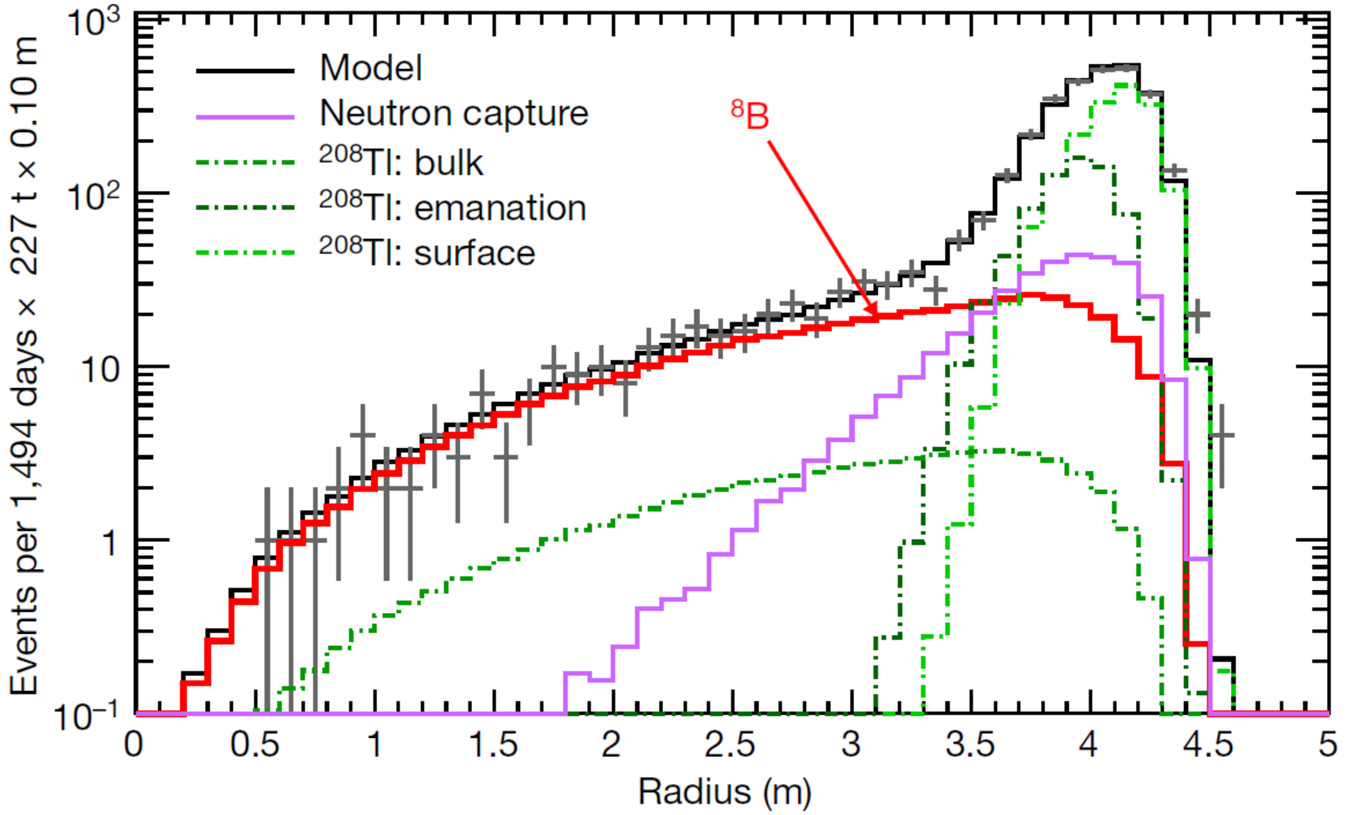
- **Data-set:** Jan 2008- Dec 2016; **Total exposure**: 2062.4 days x 227.8 (266) tons;

Rate = $0.223^{+0.015+0.006}_{-0.016-0.006}$ cpd/100t

Flux = $(5.68^{+0.39+0.03}_{-0.41-0.03}) \times 10^6$ cm^{-2} s^{-1}

Theoretical predictions

Flux= $5.46(1.0\pm0.12)\times10^6$ cm^{-2} s^{-1} (HZ)
$4.50(1.0\pm0.12)\times10^6$ cm^{-2} s^{-1} (LZ)



Analysis in the HER: ^{8}B neutrinos

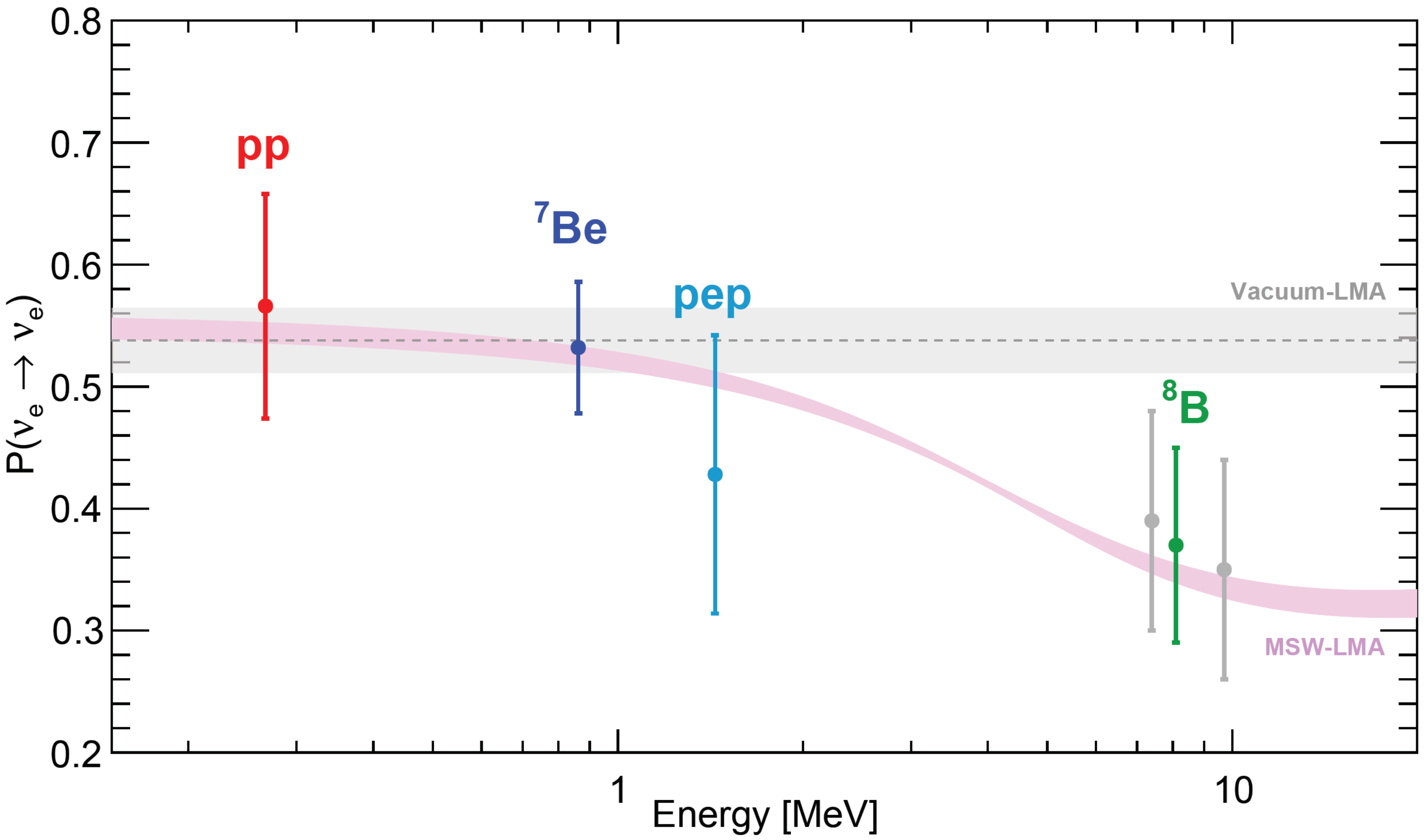
Systematic errors

	HER-I		*HER-II*		*HER* (tot)	
Source of uncertainty	-%	+%	-%	+%	-%	+%
Target mass	-2.0	+2.0	-2.0	+2.0	-2.0	+2.0
Energy scale	-0.5	+0.5	-4.9	+4.9	-1.7	+1.7
z-cut	-0.7	+0.7	0	0	-0.4	+0.4
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
Total systematics (%)	**-2.2**	**+2.2**	**-5.3**	**+5.3**	**-2.7**	**+2.7**

Implications of the new BX results

Implications of the new BX results on particle physics

Implication n.1: survival probability P_{ee}



*oscillation parameters from: I.Esteban, *MC.Gonzalez-Concha, M.Maltoni, I.Martinez-Soler and T.Schwetz, Journal of High Energy Physics 01 (2017)*

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

- P_{ee}(pp)=0.57±0.09
- P_{ee}(^{7}Be)=0.53±0.05
- P_{ee}(pep)=0.43±0.11
- P_{ee}(^{8}B)=0.37±0.08

Data disfavour vacuum-LMA hypothesis at 98.2% C.L.

Implications of the new BX results on astrophysics

Implication n.2: solar luminosity

- Neutrinos are detected on Earth only 8 minutes after they have been produced in the core of the Sun → They provide a real-time picture of the core of the Sun;
- Using only Borexino results we can calculate the solar luminosity

$$L = (3.89^{+0.35}_{-0.42}) \times 10^{33} \text{ erg s}^{-1}$$

which is found to be in agreement with the well measured photon output

$$L = (3.846 \pm 0.015) \times 10^{33} \text{ erg s}^{-1}$$

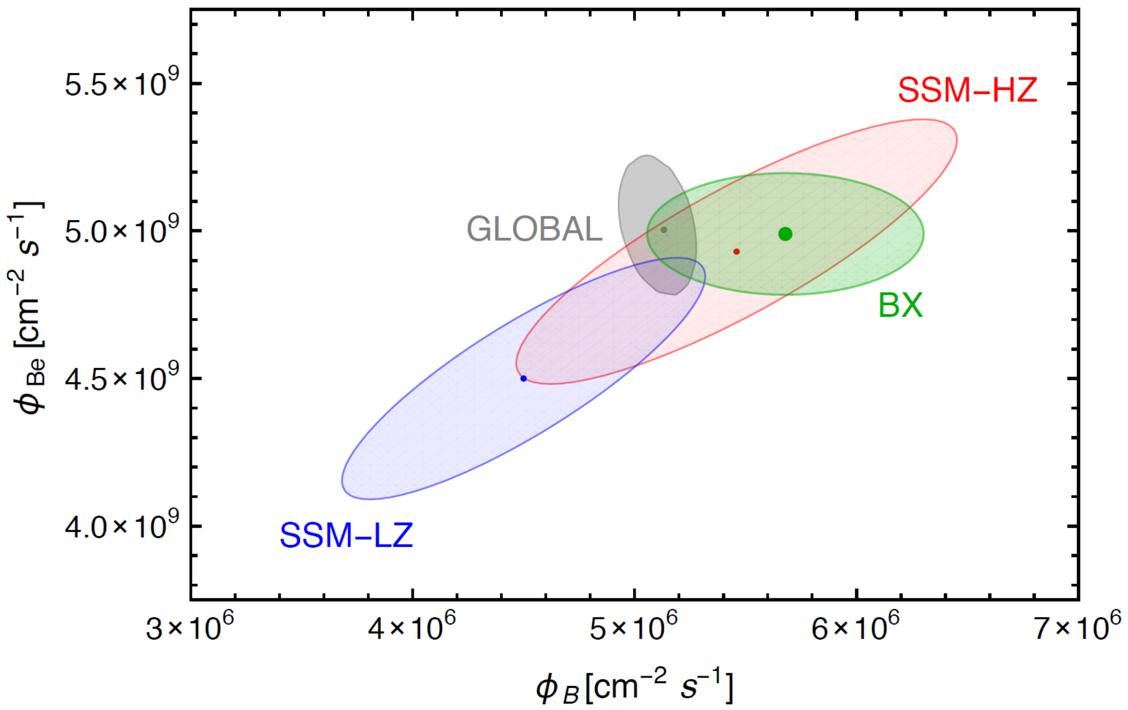
- This confirms the nuclear origin of the solar power;
- It proves that the Sun has been in thermodynamic equilibrium over 10^5 years (the time required fro radiation to flow from the center to the surface of the Sun)

Implications of the new BX results on astrophysics

Implication n.3: metallicity issue

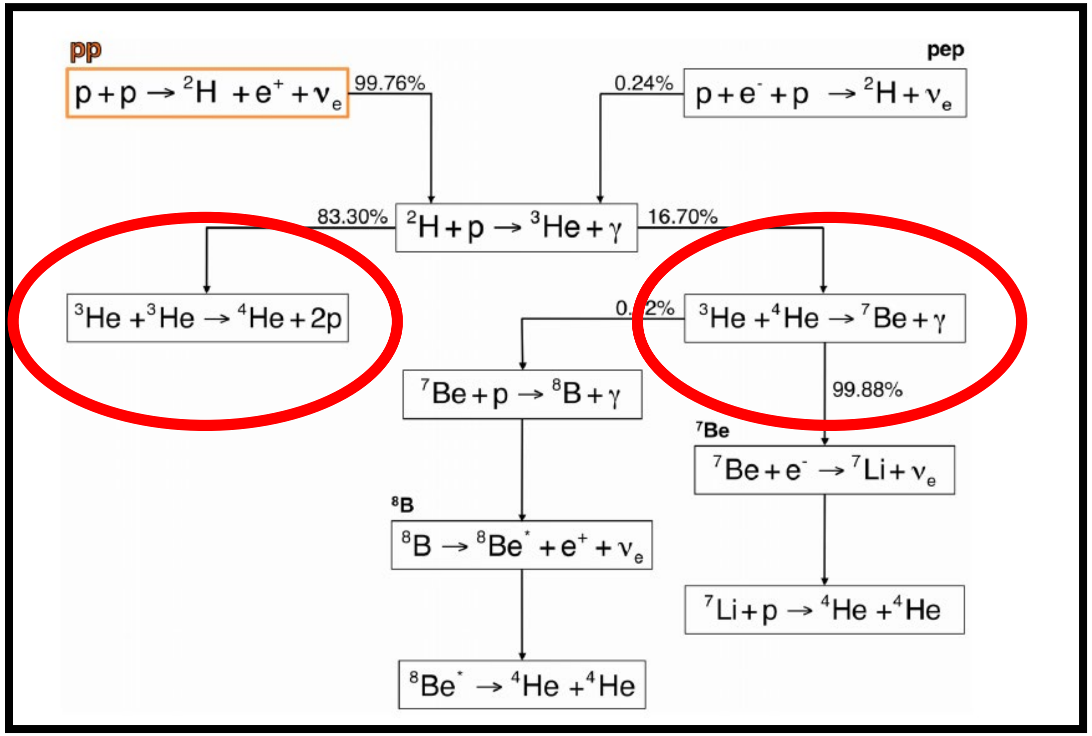
The metallicity determines the opacity of solar plasma and, as a cosequence, regulates the central T of the Sun and the Branching Ratios of the different pp-chain terminations;

- Combining the BX results on ^{7}Be and ^{8}B in a likelihood-ratio test we obtain a small hint towards High Metallicity;
- Assuming HZ, we disfavours LZ at 96.6% C.L.;
- Note: we are now largely dominated by the theoretical error;



Implications of the new BX results on astrophysics

Implication n.4: probing solar fusion



From the pp and ^{7}Be flux new measurement

$$\mathbb{R} = 0.178^{+0.027}_{-0.023}$$

- From the pp and ^{7}Be flux measurements it is possible to determine the ratio $\mathbb{R}$ between the rate of ^{3}He-^{3}He e ^{4}He-^{3}He;

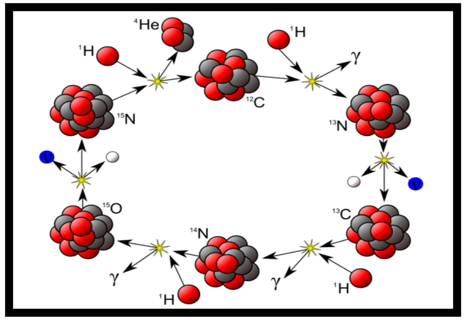
$$R \equiv \frac{<^3\text{ He} +^4\text{ He}>}{<^3\text{ He} +^3\text{ He}>} = \frac{2\phi(^7\text{Be})}{\phi(\text{pp}) - \phi(^7\text{Be})}$$

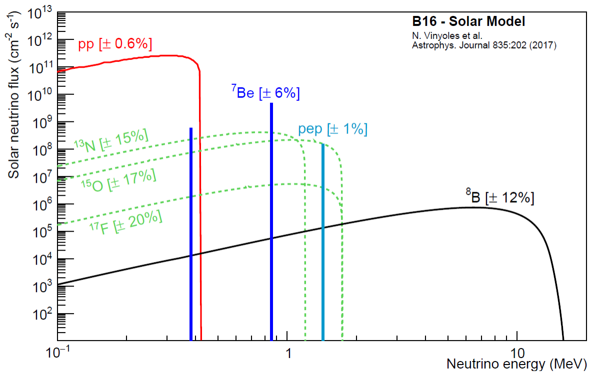
- It is an important experimental test of the solar fusion

- Theoretical predictions

$\mathbb{R}$(HZ)= 0.180 ± 0.011

$\mathbb{R}$(LZ)= 0.161 ± 0.010

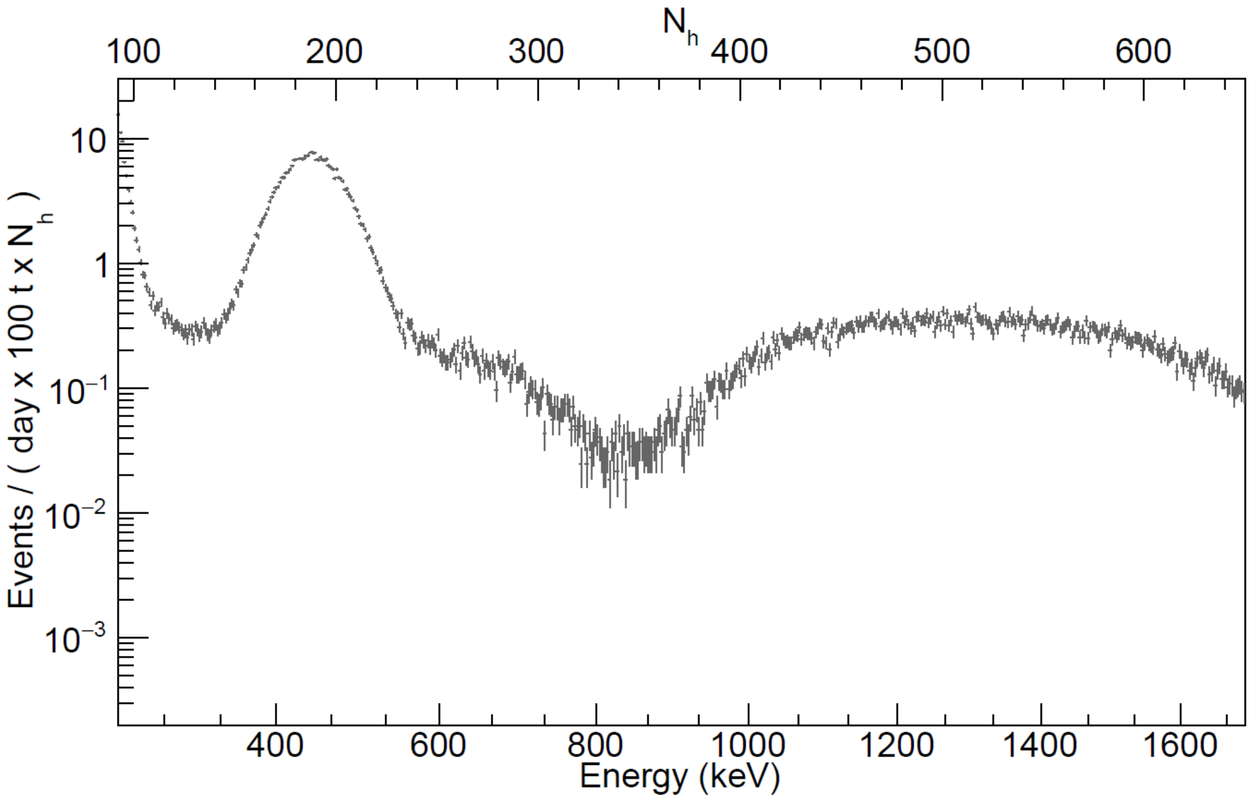




What about CNO neutrinos?

What about CNO neutrinos?

Difficulties to extract the CNO rate



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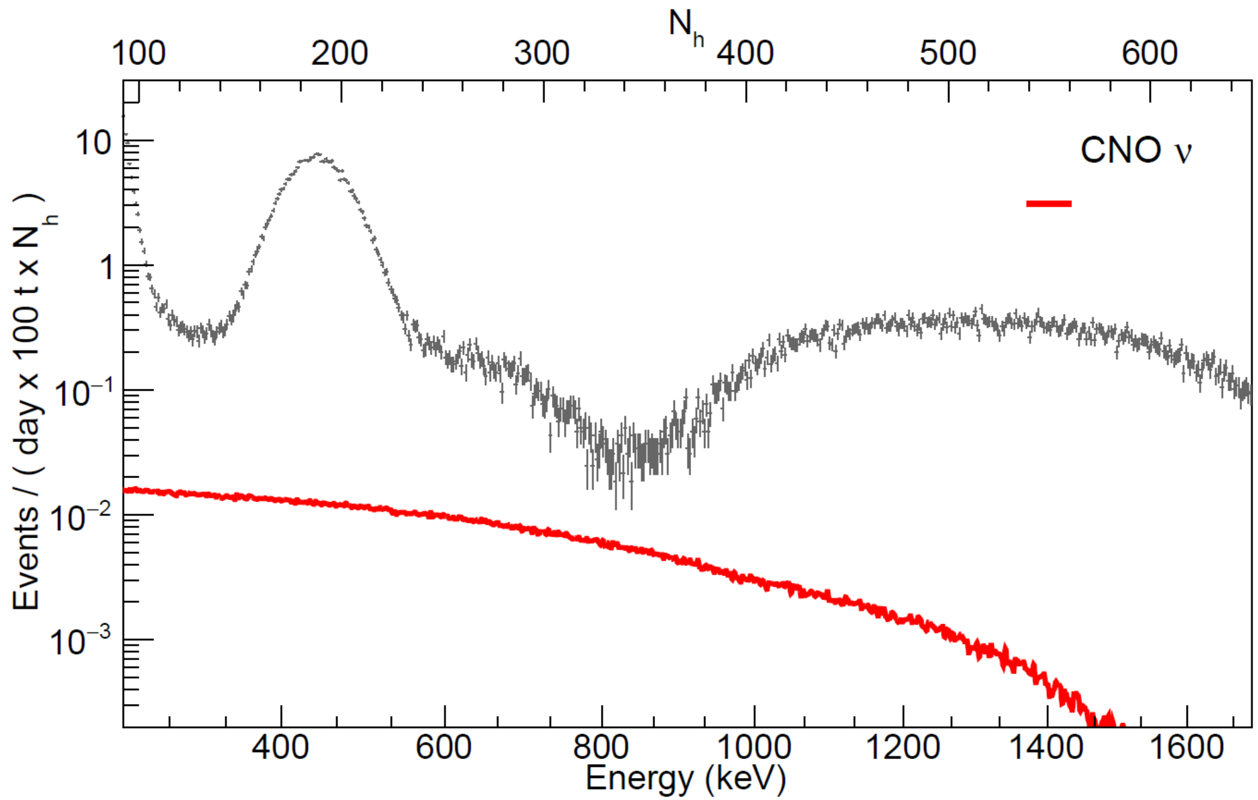
Difficulties to extract the CNO rate



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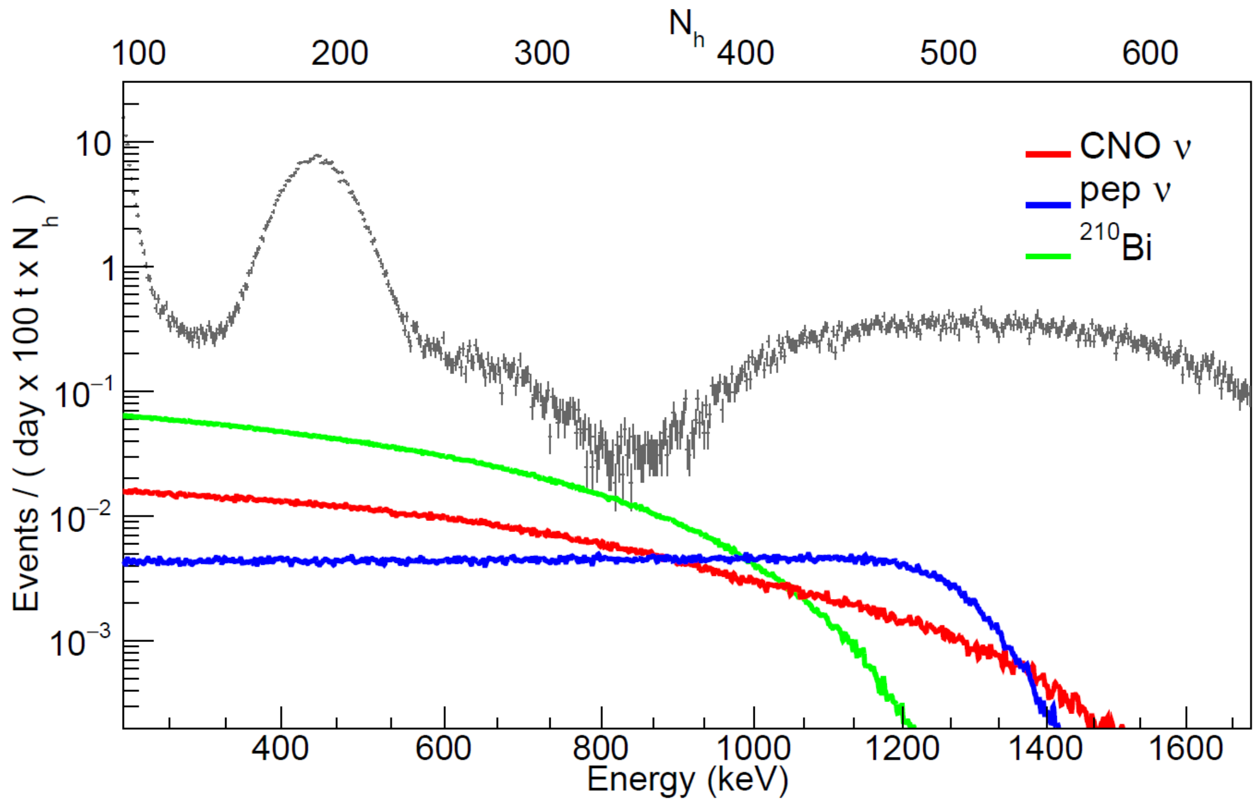
Difficulties to extract the CNO rate



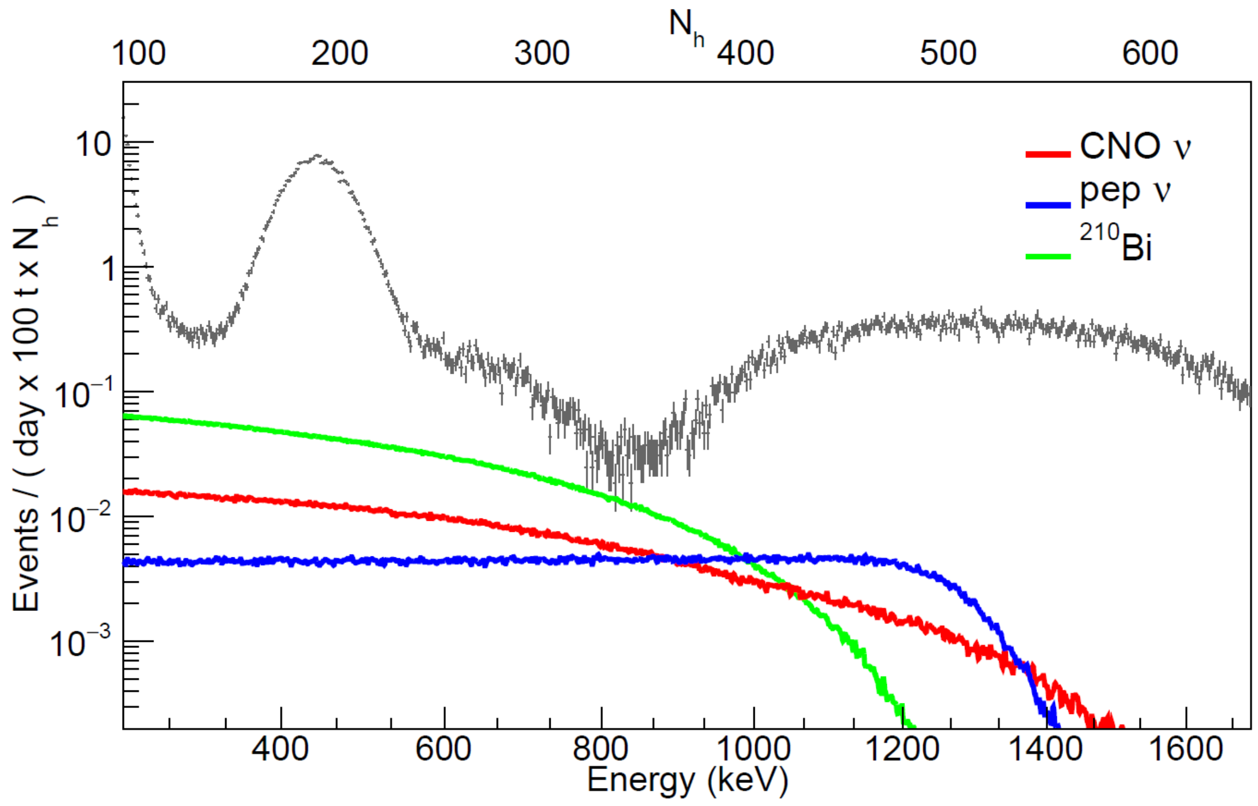
- The similarity between the CNO, pep and ^{210}Bi spectral shapes limits the sensitivity of Borexino;

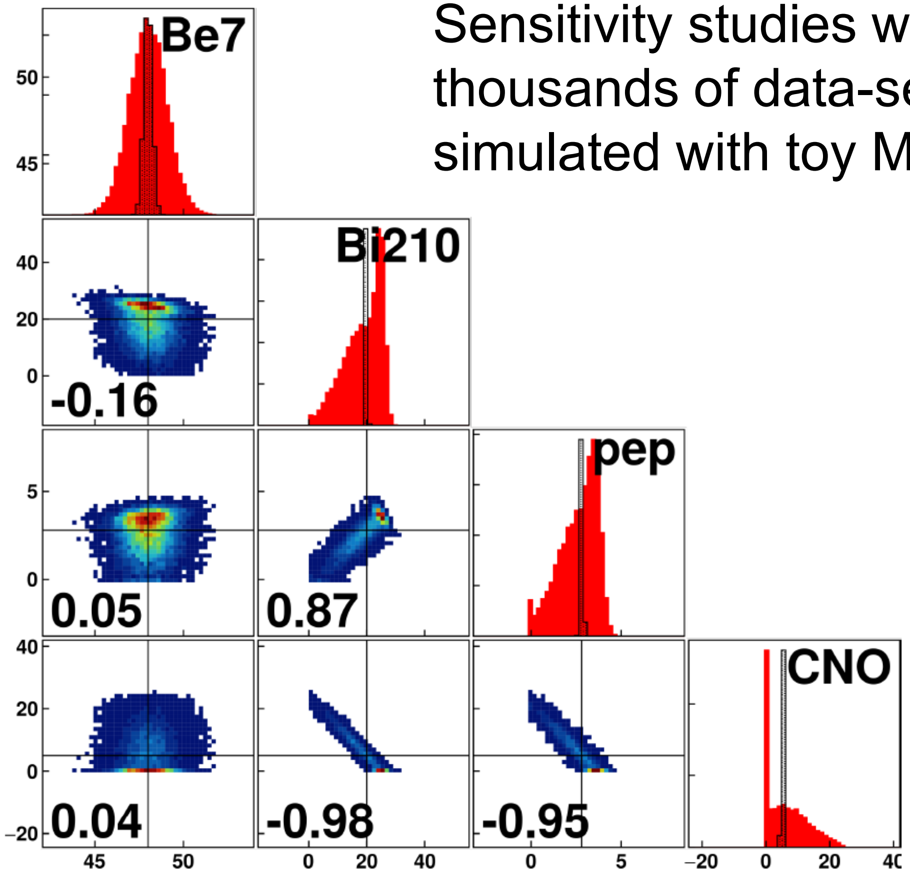
Note also the rates:

- CNO ν ~ 4-5 cpd/100t
- pep ν ~ 3 cpd/100t
- ^{210}Bi ~ 15-20 cpd/100t

What about CNO neutrinos?

Difficulties to extract the CNO rate



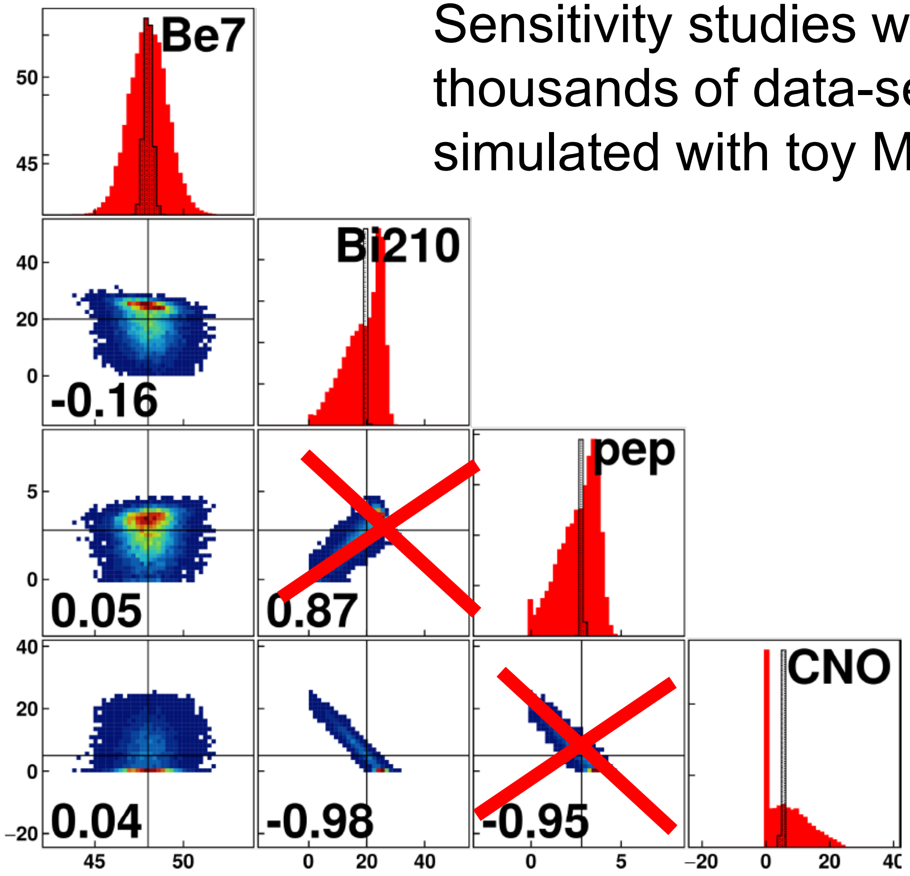


Sensitivity studies with thousands of data-sets simulated with toy MC

What about CNO neutrinos?

Limits on CNO neutrino rate

- To reduce correlations we put a constraint on the pp/pep ratio following the theoretical predictions:
- R(pp/pep): (47.7±1.2)
- In this way we obtain the most stringent limit on CNO flux;

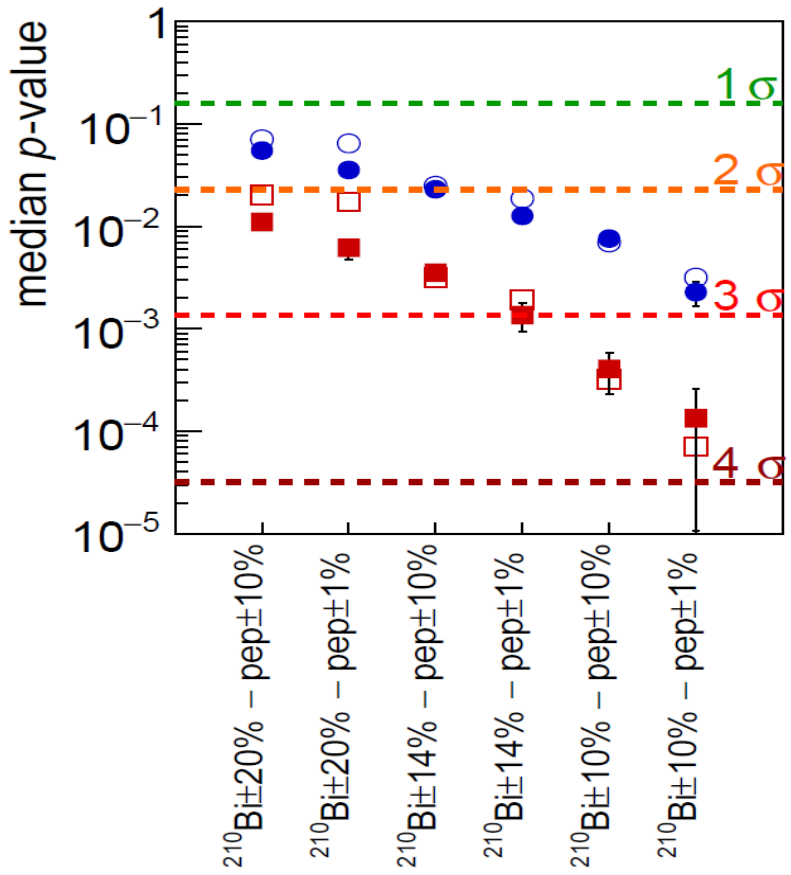


Sensitivity studies with thousands of data-sets simulated with toy MC

	Borexino results (cpd/100t)	Expected HZ (cpd/100t)	Expected LZ (cpd/100t)
CNO ν	<8.1 (95% C.L.)	4.91±0.56	3.62±0.37

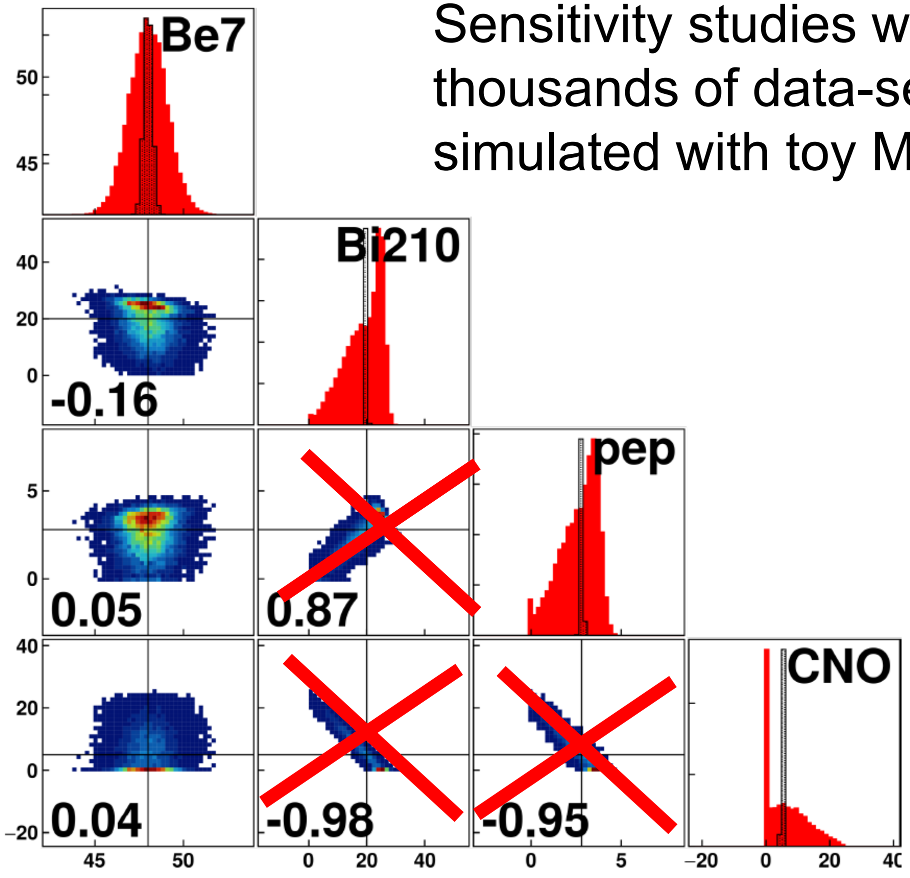
What about CNO neutrinos?

What if we could constraint also the ^{210}Bi rate?



Sensitivity studies with thousands of data-sets simulated with toy MC with different constraints on 210Bi and pep

Possibility to get a measurement of CNO flux between 2σ and 4σ



Sensitivity studies with thousands of data-sets simulated with toy MC

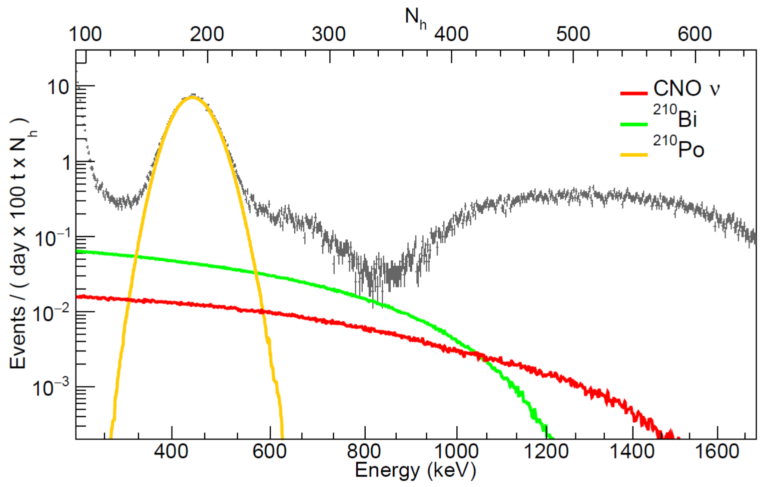
What about CNO neutrinos?

How could we constraint the ^{210}Bi rate?

- ^{210}Bi is coming from ^{210}Pb ;
- ^{210}Bi decays to ^{210}Po;
- At secular equilibrium the rate of ^{210}Bi is equal to that of ^{210}Po;

$$^{210}\mathrm{Pb} \xrightarrow[32\ \mathrm{y}]{\beta^-} {}^{210}\mathrm{Bi} \xrightarrow[7.23\ \mathrm{d}]{\beta^-} {}^{210}\mathrm{Po} \xrightarrow[199.1\ \mathrm{d}]{\alpha} {}^{206}\mathrm{Pb}$$

Possibility to measure the ^{210}Bi rate from the ^{210}Po rate



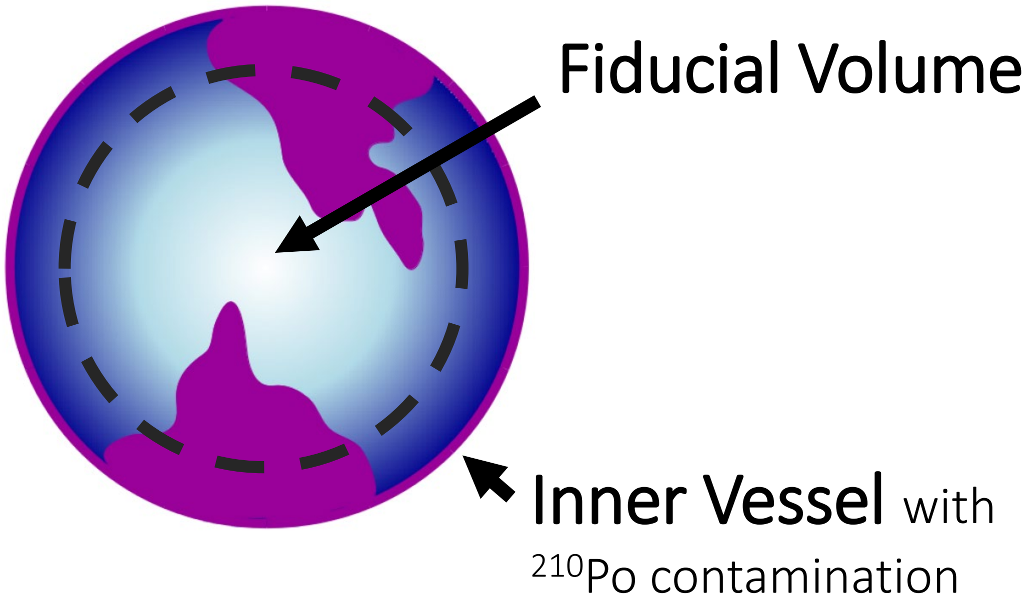
^{210}Po is “easier” to identify wrt ^{210}Bi:

- Monoenergetic decay → “gaussian” peak
- α decay → pulse shape discrimination

What about CNO neutrinos?

Problem

- There is ^{210}Po contamination on the vessel;
- Convective motions triggered by changes in temperature bring inside the scintillator ^{210}Po which is present on the nylon Vessel
- This breaks the secular equilibrium of the ^{210}Pb chain!



We need to thermally insulate the detector to stop convective motions!

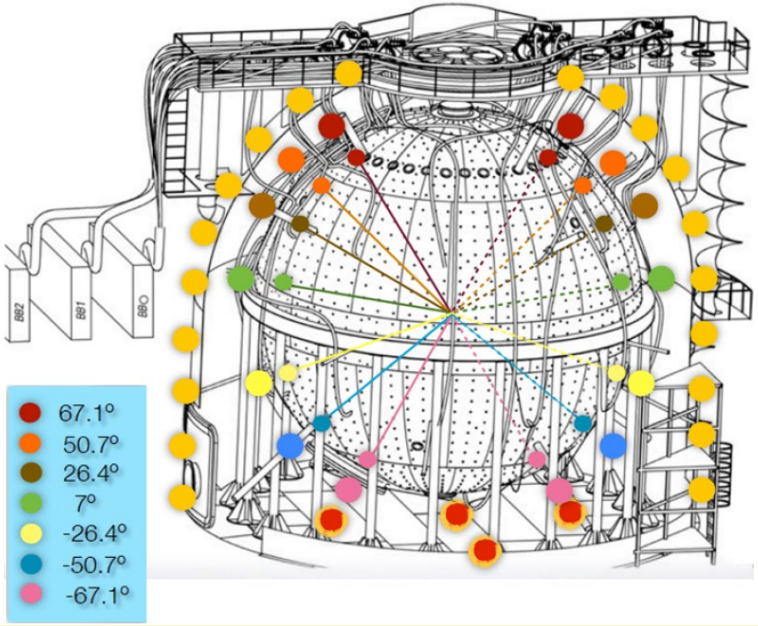
What about CNO neutrinos?

Hardware

- Insulation with rock wool (2015);
- Active T control sys;

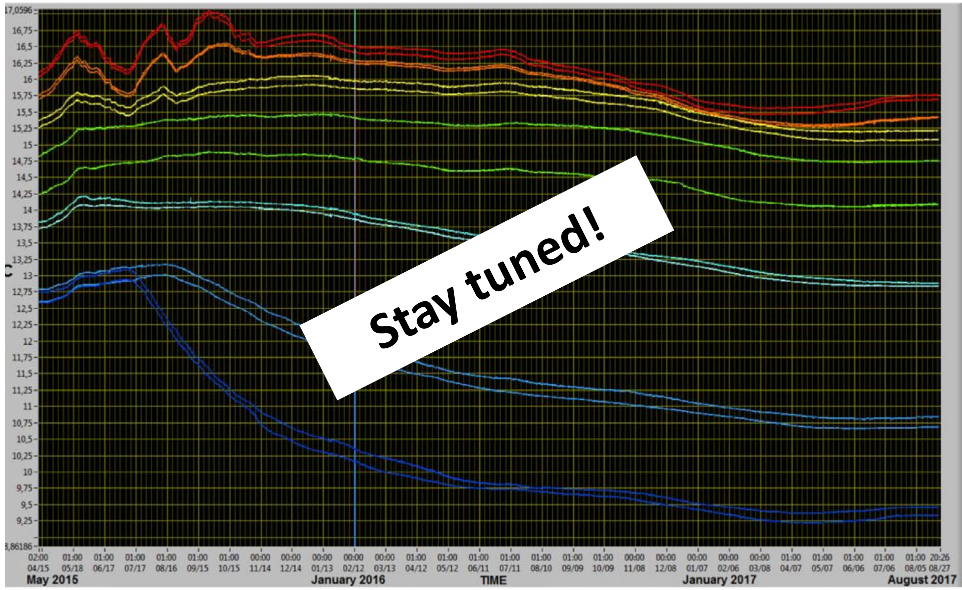
Monitoring

- 54 temperature probes located both in the buffer and in the external tank and at different levels



Results

- The temperature profile has stabilized after insulation;
- We are collecting data in these stable conditions to verify our capability to tag ^{210}Bi from ^{210}Po;



Barbara Caccianiga (BX collaboration) ``Borexino: comprehensive measurement of pp-chain solar neutrinos''

CONCLUSIONS

The present

The newest results of Borexino on pp-chain solar neutrinos

- Comprehensive study of all neutrinos from the pp-chain (pp, pep, ^{7}Be and ^{8}B) with the same detector and with a uniform data analysis procedure;
- Improved precision with respect to previous BX measurements (^{7}Be precision is now 2.7%!);
- >5σ evidence of the pep neutrino signal;
- Simultaneous test of the P_{ee} in the vacuum and matter dominated region;
- Hint towards the High Metallicity hypothesis coming from the ^{7}Be and ^{8}B ν measurement;
- First experimental determination of the ratio between ^{3}He-^{4}He and ^{3}He-^{3}He reactions in the Sun;

The future

We are not stopping here

- We continue to take data with temperature stabilized detector in an attempt to measure CNO ν;

Thank you!

Borexino Collaboration

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