Solar neutrino astronomy BOREXINO experiment

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Astroparticle Physics in Poland

Warsaw, May 11-13, 2015

BOREXINO Collaboration

INFN
Milano
München
Max-Planck-Institut für Kernphysik
Heidelberg
Hamburg
Mainz
Gran Sasso
Perugia
Genova
Napoli
TU Dresden
Jagiellonian Kraków

the Borexino Collaboration

JINR Dubna
Virginia Tech
Houston
Paris
Moscow
Los Angeles
Princeton
UMass Amherst
St. Petersburg
Kurchatov Moscow

The BOREXINO experiment is carried out by an international collaboration of around 100 scientists at 25 universities and institutes.

Cracow group (4 members) since the beginning: work on BOREXINO detector sensitivity.

Solar Model - Chemical Controversy

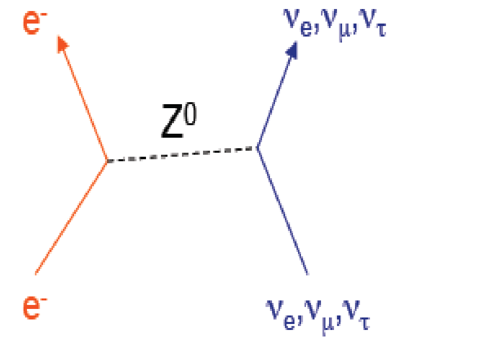
Bahcall, Serenelli and Basu, AstropJ 621, L85(2005)

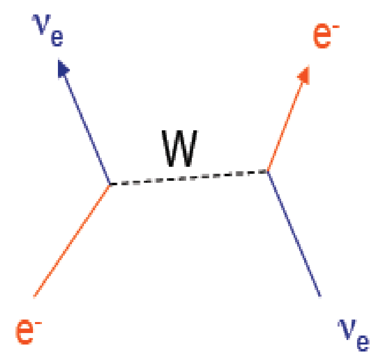
Φ $(cm^{-2}s^{-1})$	*pp* $(\times 10^{10})$	^{7}Be $(\times 10^{9})$	^{8}B $(\times 10^{6})$	^{13}N $(\times 10^{8})$	^{15}O $(\times 10^{8})$	^{17}F $(\times 10^{6})$
BS05 **high Z**	5.99	4.84	5.69	3.07	2.33	5.84
BS05 **low Z**	6.05	4.34	4.51	2.01	1.45	3.25
Δ	+1%	-10%	-21%	-35%	-38%	-44%
σ SSM	±1%	±5%	±16%	±15%	±15%	±15%

Helioseismology incompatible with low metallicity solar models. Could be resolved by measuring CNO neutrinos.

BOREXINO Detector – Detection principle

- Neutrino elastic scattering on electrons of liquid scintillator: $e^- + \nu \rightarrow e^- + \nu$;
- Scattered electrons cause the scintillation light production;
- **Advantages**:
  - Low energy threshold (~ 0.2 MeV);
  - High light yield and a good energy resolution;
  - Good position reconstruction;
- **Drawbacks :**
  - Info about the ν directionality is lost;
  - ν-induced events can't be distinguished from the events of β/γ natural radioactivity;
  - The expected rate of solar neutrinos in 100 tons of BX scintillator is ~40 counts/day which corresponds to ~$5 \cdot 10^{-9}$ Bq/kg





Extreme radiopurity is a must for a precision low energy neutrino spectroscopy.

E.g.:
- Rn in air ~ 10 Bq/kg
- Natural water ~ 10 Bq/kg
- Rn in Borexino ~ $1 \times \mathbf{10^{-10}}$ Bq/kg

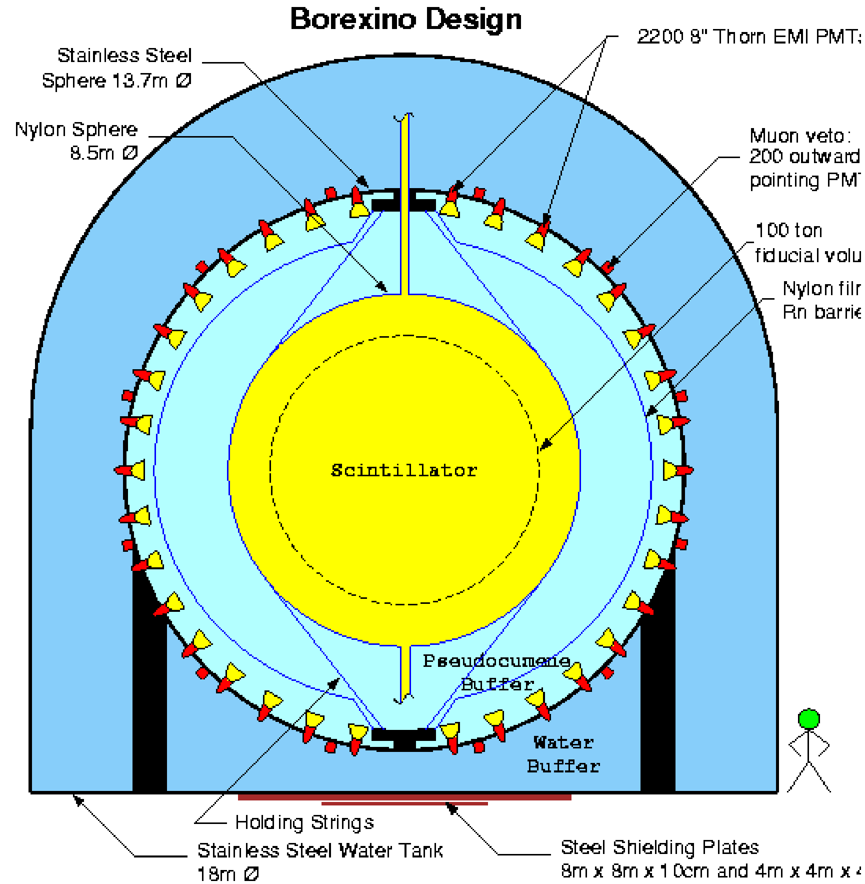
BOREXINO Detector

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

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;

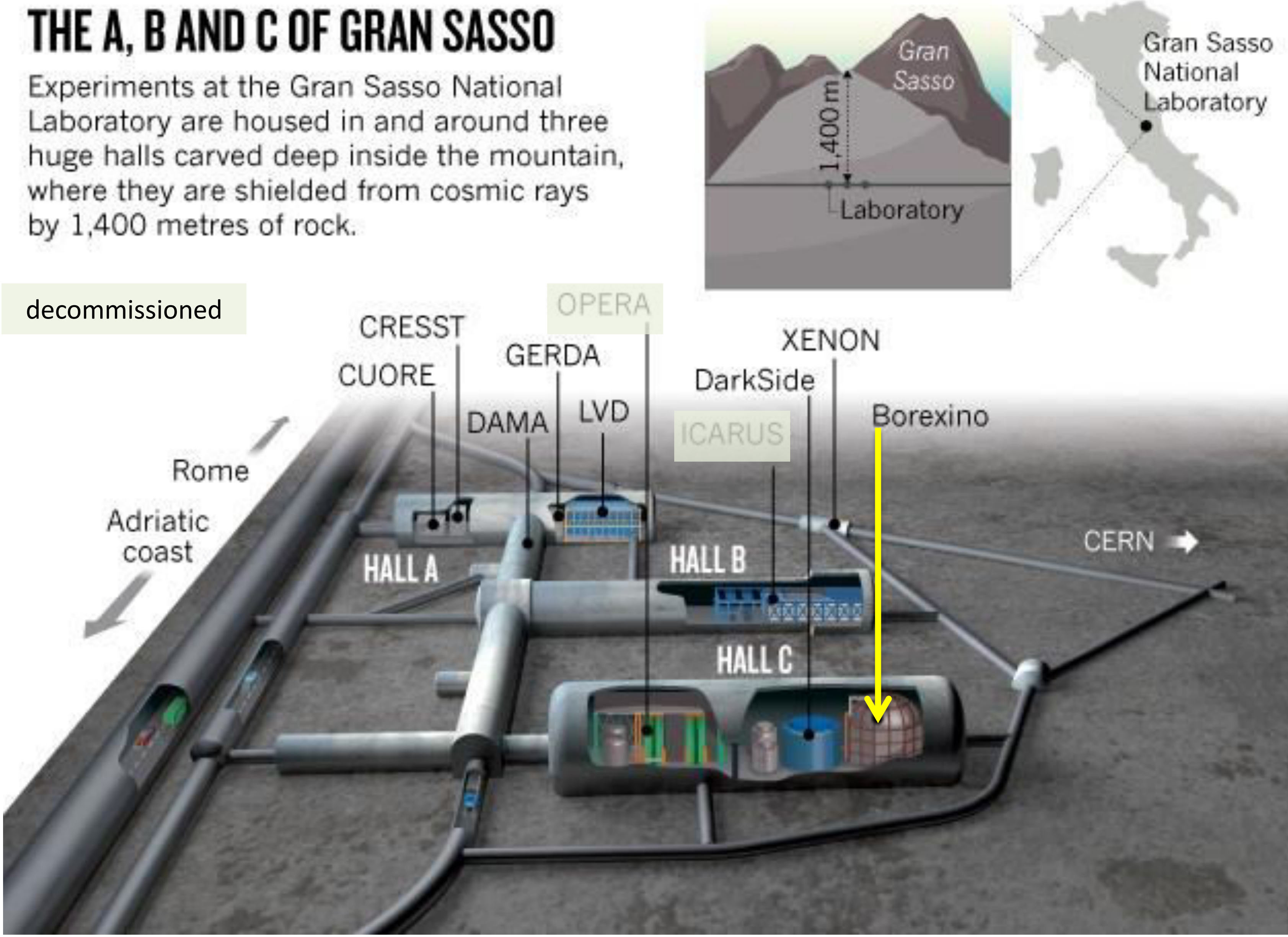
2nd shield: 2000 tons of ultra-pure water contained in a cylindrical dome;



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

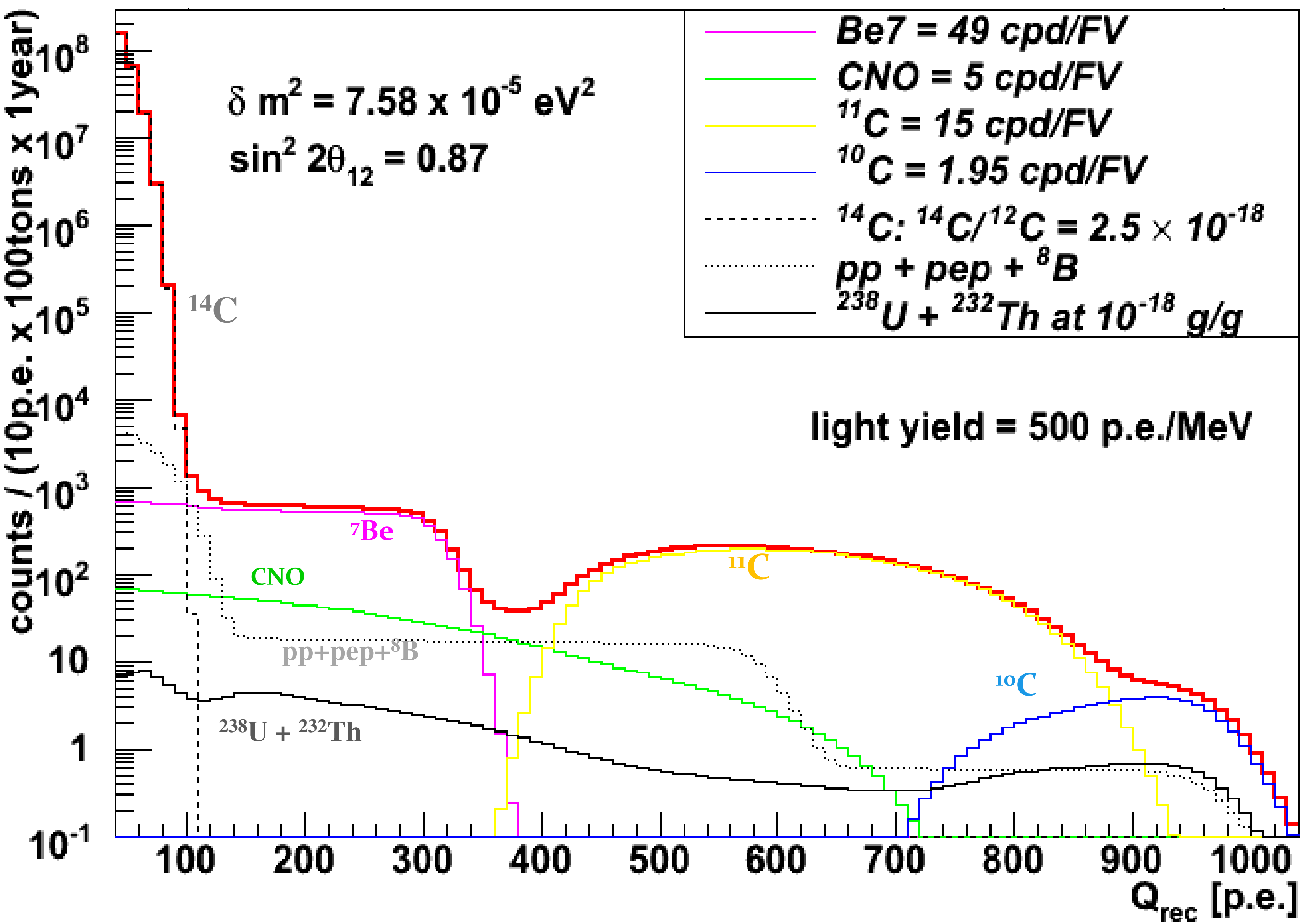
Borexino is located inside the Gran Sasso mountain in Italy

Gran Sasso INFN underground laboratory



© Nature 485, 435–438 (24 May 2012) doi:10.1038/485435a

The expected signal and the irreducible background



^{7}Be neutrino flux measurement

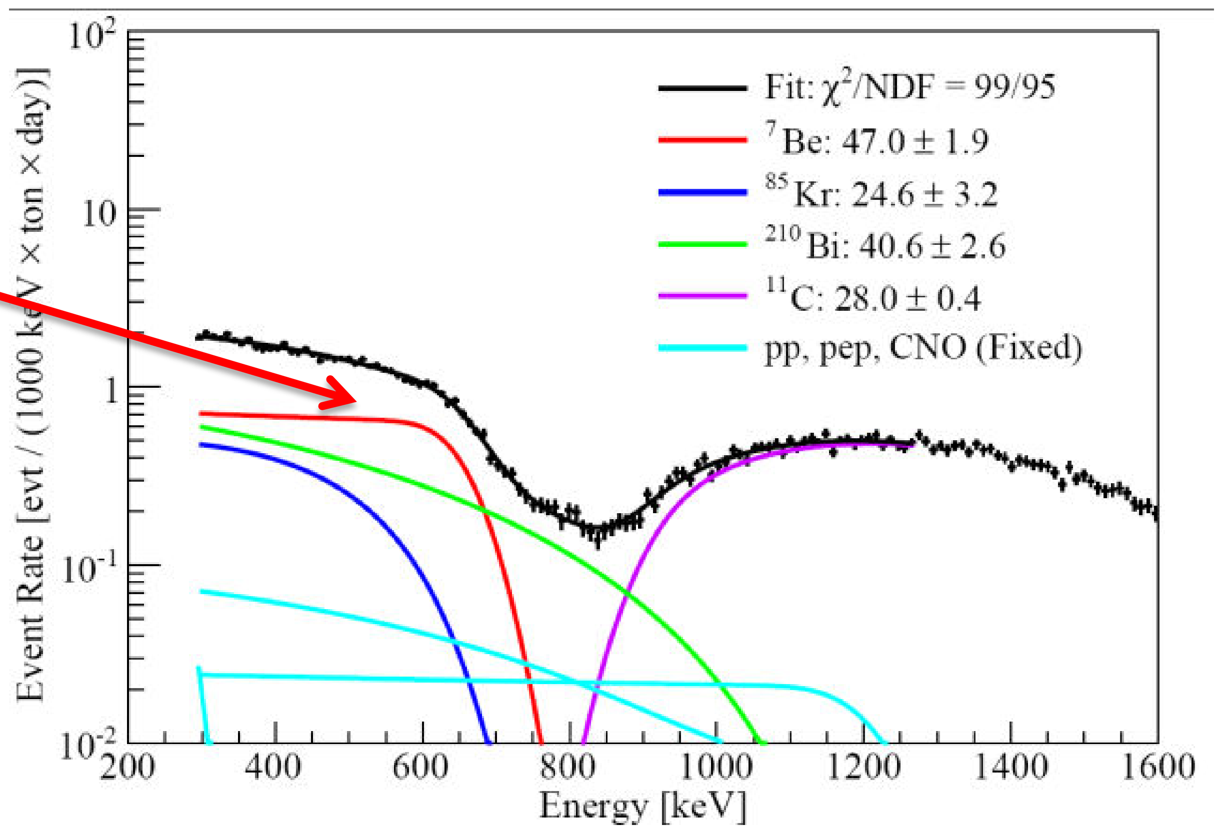
Precision Measurement of the ^{7}Be Solar Neutrino Interaction Rate in Borexino

Phys. Rev. Lett. 107, 141302 (2011)

$\phi_{Be} = (3.10 \pm 0.15) \times 10^9\ cm^{-2}s^{-1}$ $P_{ee} = 0.51 \pm 0.07$ at 0.862 MeV

- The final spectrum is fitted to a global signal plus background model to extract the value of the flux

Spectral feature: compton-like edge from scattered electrons



BOREXINO – most recognized results

2008: Direct Measurement of the ^{7}Be Solar Neutrino Flux with 192 Days of BOREXINO Data
Phys. Rev. Lett. 101 (2008) 091302

2010: Measurement of the solar ^{8}B neutrino rate with a liquid scintillator target and 3 MeV energy threshold in the BOREXINO detector Phys. Rev. D 82 (2010) 033006

2010: Observation of geo-neutrinos
Phys. Lett. B, 687 (2010) 299-304

2011: Precision Measurement of the ^{7}Be Solar Neutrino Interaction Rate in BOREXINO
Phys. Rev. Lett. 107 (2011) 141302

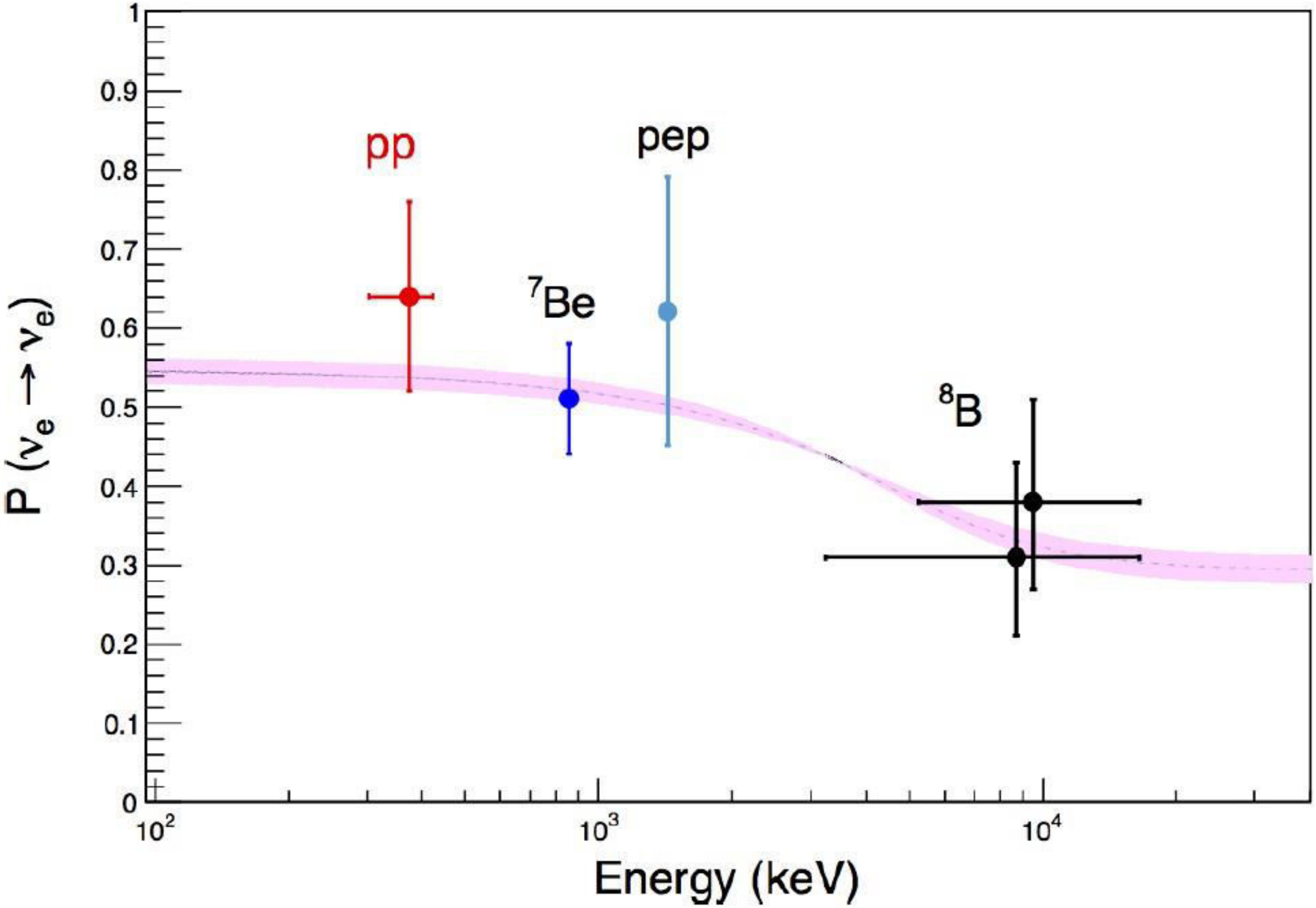
2012: First evidence of **pep** solar neutrinos by direct detection in BOREXINO
Phys. Rev. Lett. 108 (2012) 051302

physicsworld
BREAKTHROUGH OF THE YEAR
2014

2013: Measurement of geo-neutrinos from 1353 days of BOREXINO
Phys. Lett. B 722 (2013) 295–300

2014: Neutrinos from the primary proton–proton fusion process in the Sun
Nature 512 (2014) 383–386

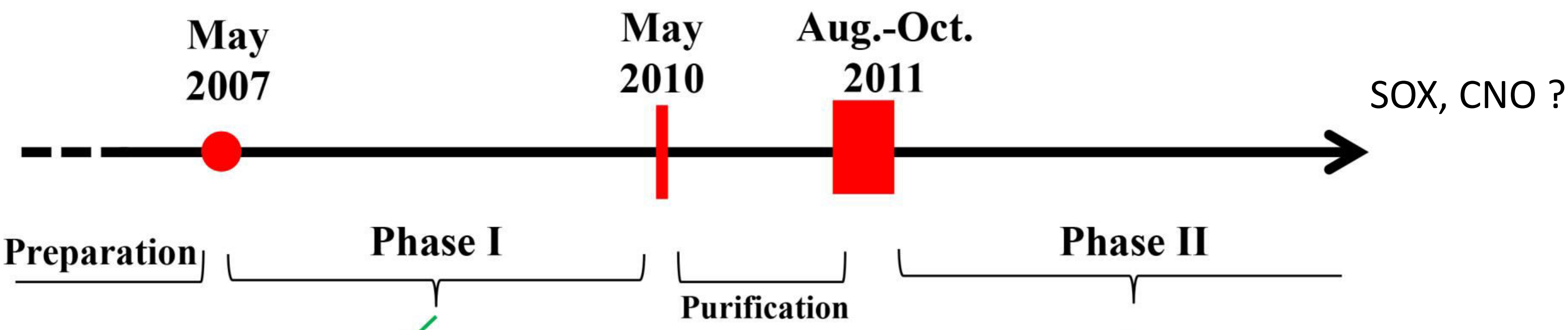
Borexino measured electron neutrino survival probability for 4 different nuclear reactions



Now Borexino alone provides the validation of the MSW – LMA neutrino oscillation paradigm over the entire solar neutrino spectrum

The missing point is CNO for which we have only an upper limit so far

BOREXINO timeline



- (First) solar ^{7}Be-ν measurement
- ^{7}Be-ν day-night asymmetry
- Low-threshold ^{8}B-ν
- First pep-ν detection
- Best upper limit on CNO-ν
- ^{7}Be-ν seasonal modulation

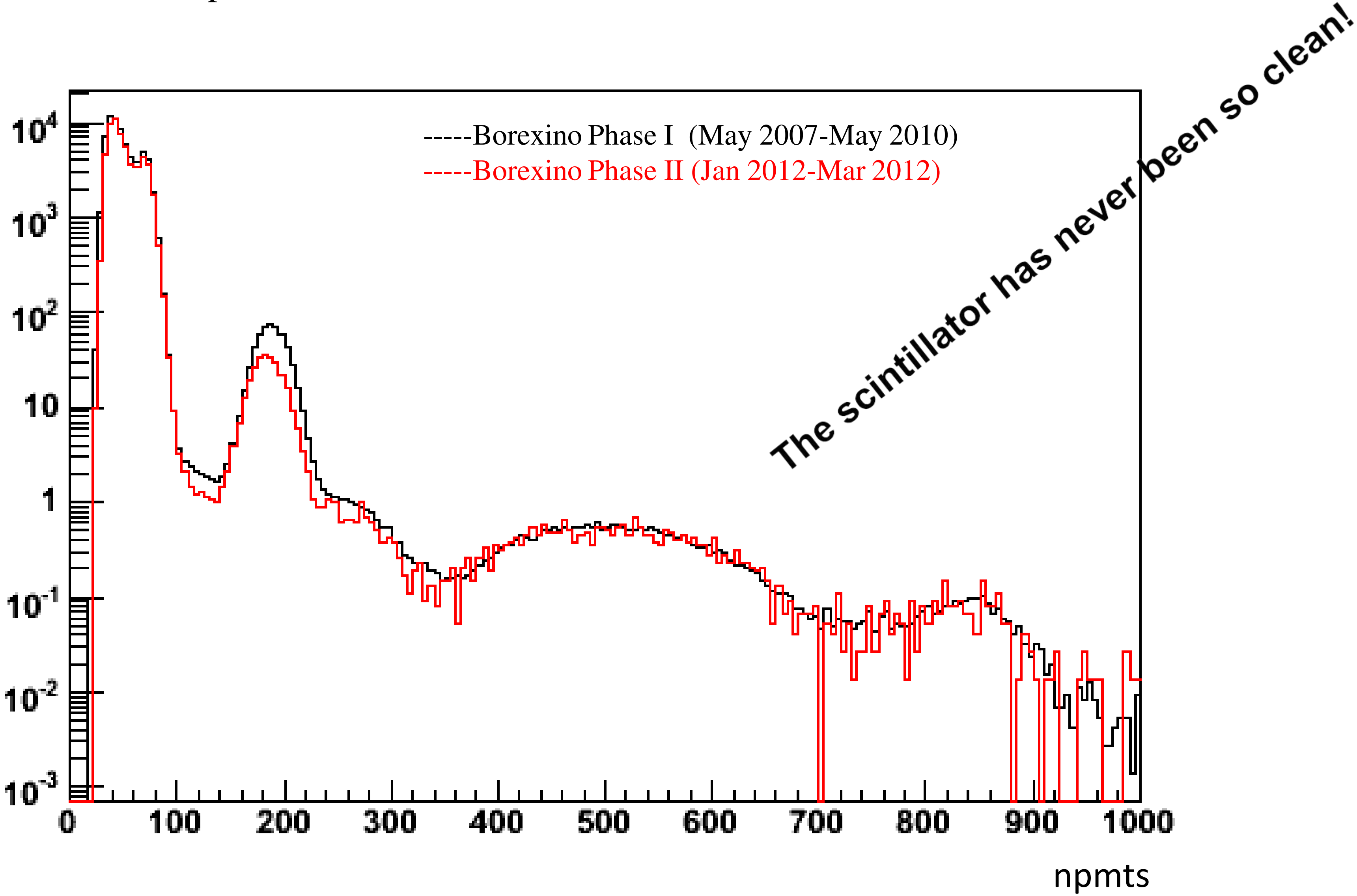
- First geo-ν observation at > 4σ (initial phase II data included)

- Muon seasonal variations
- Limits on rare processes
- Neutrons and other cosmogenics

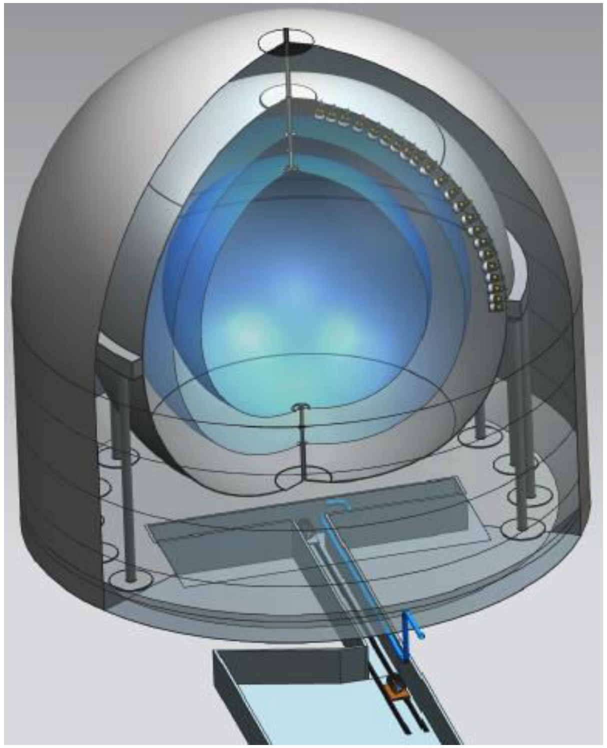
- Measurement of pp-ν flux new milestone towards the full solar-ν spectroscopy
- New round of the previous measurements with improved precision
- Short-baseline ν oscillations: SOX
- With further purification : Measurement of CNO-ν flux (beyond phase II)

Borexino Phase 2: new challenges

Comparison between Phase 1 and Phase 2 data



Short distance ν_e Oscillations with Borexino (SOX)

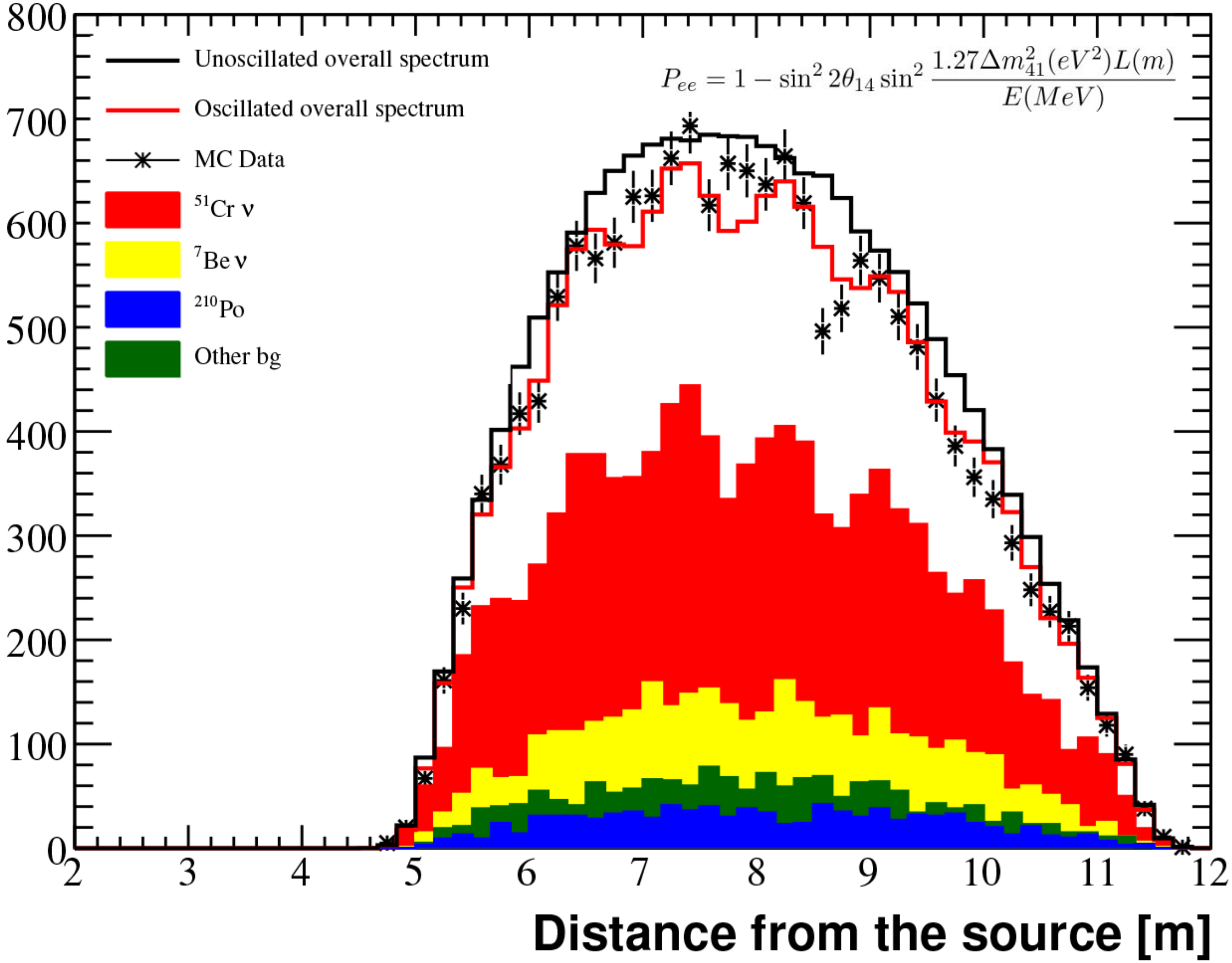


Sterile Neutrino Searches: The „SOX" Experiment.

Intense neutrino sources will be placed in tunnel under Borexino to search for short-baseline neutrino oscillations.

10 MCi ^{51}Cr 750 keV mono-energetic neutrinos and 100 kCi ^{144}Ce anti-neutrino source (E_{max} = 3 MeV) to be used.

Short distance ν_e Oscillations with Borexino (SOX)



Example of a possible outcome of the ^{51}Cr experiment with $\sin^2(2\vartheta_{14}) = 0.3$ and $\Delta m^2_{41}=2$ eV^2. Data points are obtained with a full Geant-4 simulation. The signal (red band) is dominating

Outlook

Complete analysis of Phase 2 data

- calibration campaign to further reduce systematic uncertainties;
- improved measurement of ^{7}Be ν (3% error? challenging!) and other solar neutrino families;
- Attempt to measure CNO ν: very challenging!

Sterile neutrino program (SOX)

- In 2016 the ^{144}Ce-^{144}Pr anti-neutrino source will arrive in Gran Sasso and data taking for sterile neutrino program will start;

(98-01) KBN → (02-05) KBN → (06-09) MNiSW → **(09-13) no fund.** → 2013-2016 NCN

NCN grants support of our group:

- HARMONIA: 2013 - 2016
- SONATA BIS: 2014 - 2017

NARODOWE CENTRUM NAUKI