Borexino

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On behalf of the Borexino Collaboration

LNGS Scientific Committee
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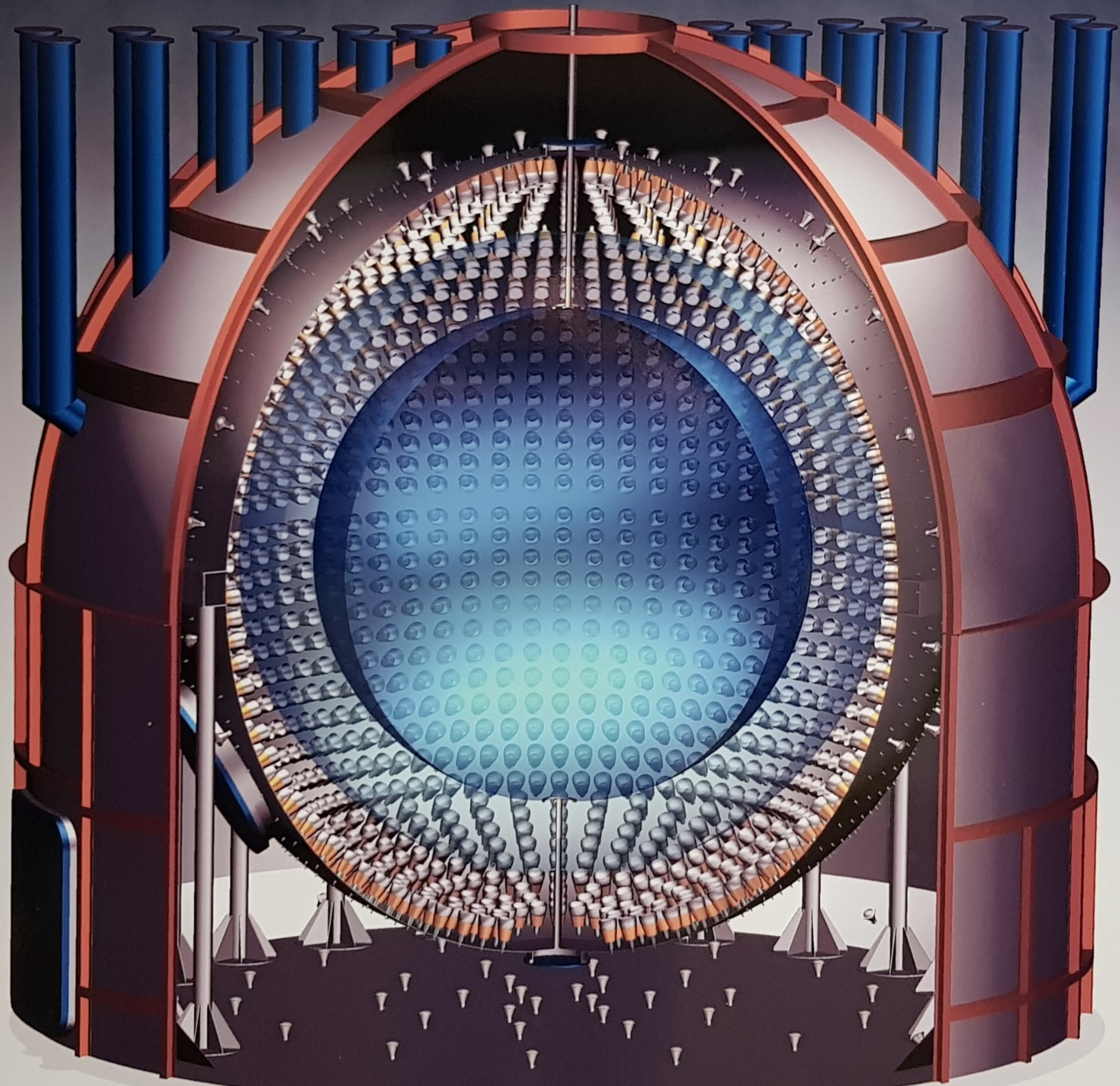
Borexino Experiment

Laboratori Nazionali del Gran Sasso



Bruno Pontecorvo International Award 2015

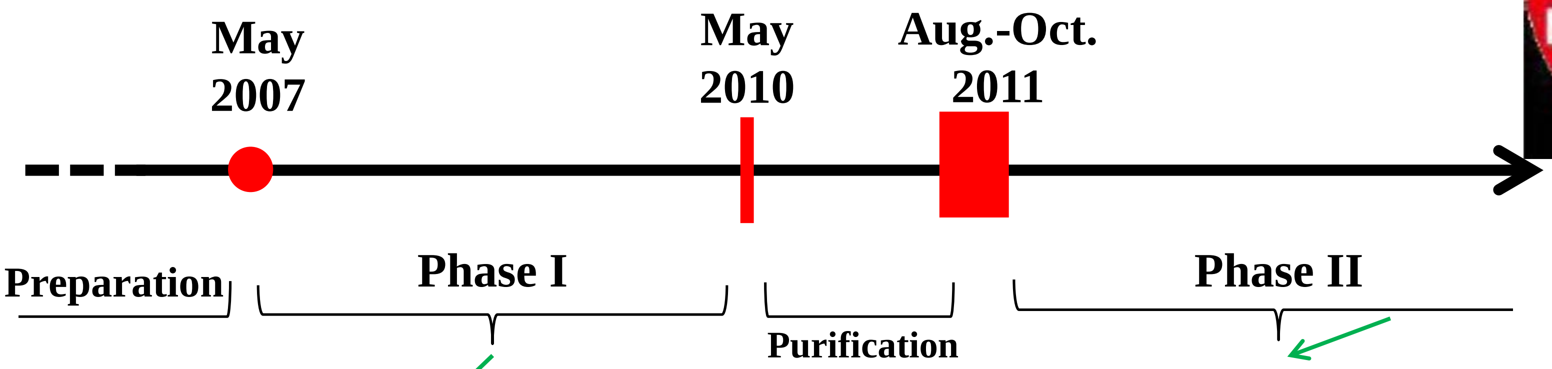
Enrico Fermi Award 2017

Francobollo di Posteitaliane
16 Settembre 2014

Borexino program and achievements at a glance

physicsworld TOP 10 BREAKTHROUGH 2014

Totally unprecedented accomplishment in the solar neutrino arena: almost complete **precision** solar ν spectroscopy by a single experiment - Borexino alone validates the LMA MSW flavor conversion paradigm



- **First specific 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**

- **Geo-ν observation at ~ 4.5 σ (initial phase II data included)**

- **Muon seasonal variation**
- **Limits on rare processes**
- **Neutrons and other cosmogenics**

- Real time spect. measurement of pp-ν flux (2014) milestone towards the full solar-ν spectroscopy
- Improved signif. of Geo-ν detection 5.9 σ (2015)
- Improved limit on electron decay (2015)
- Null association with gamma ray bursts (2017)
- Annual modulation (2017)
- Null association with GW (2017)
- New round of the previous lownu solar measurements with improved precision pp ^{7}Be (2.7%) pep (5σ) (2017)
- Neutrino magnetic moment limit (2017)
- New ^{8}B flux with low threshold (2017)

“Although historically by measuring Δm^2_{21} KamLAND has uniquely selected the LMA solution, now the solar neutrino experiments alone can do this due to new measurements by Borexino, which validated the solution at low energies, and due to higher accuracy of other results.“
M. Maltoni and A.Yu. Smirnov EPJA 52 , 87 2016

Main task for the rest of phase II
- **Quest for the CNO-ν flux – only possible in BX**

Updated global framework of the experiment

After the remarkable achievements concerning the solar program described in the previous meeting and after the termination of SOX (communication of INFN of February 1st), the Collaboration has recently started to refocus its efforts in view of the next period of running

Such a period will be focused on the completion of the current scientific program of the experiment, which aims to pursue the ultimate goal in the solar neutrino field → the challenging detection of the CNO flux

Other studies and activities : anti-ν's and geo-neutrinos, muon flux, limits on NSI, participation to SNEWS and GW+neutrino consortia

The science of Borexino in 2017 at a glance

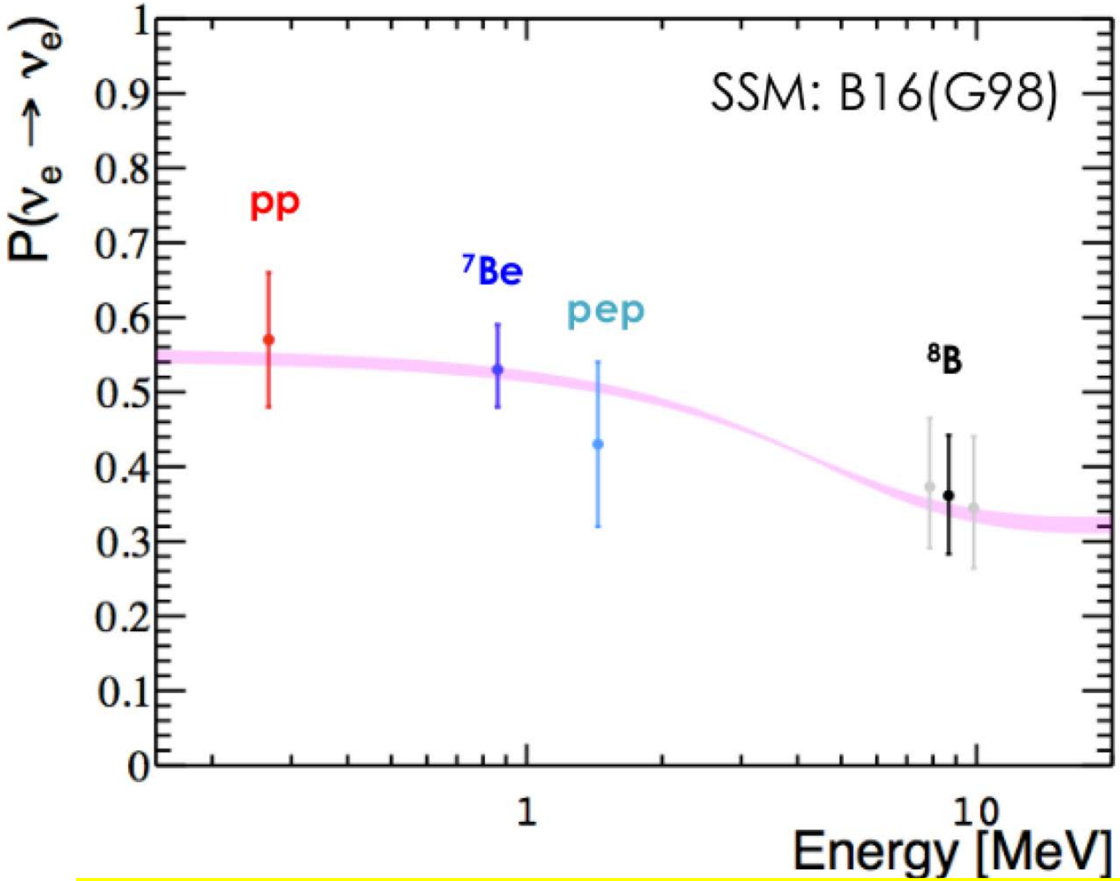
Simultaneous low energy spectroscopy

Improved precision of the fluxes with phase II data

^{7}Be 2.7%

FURTHER REINFORCE FROM BOREXINO ALONE VALIDATION OF THE LMA-MSW FLAVOR CONVERSION PARADIGM OVER THE FULL SOLAR NEUTRINO SPECTRUM

From ^{7}Be and ^{8}B phase II results hint toward high metallicity SSM



Theoretical electron neutrino survival probability compared with the Borexino experimental points (HZ)

The complete spectroscopy from **pp to ^{8}B** represents the first and unique determination of the pp cycle → **final crowing of the experimental quest for the burning mechanism fueling the Sun!**

Quantitative probe of the pp solar fusion long advocated by John Bahcall

$$R = \frac{Rate(^3He+^3He)}{Rate(^3He+^4He)} \quad R = \frac{2\,\Phi(^7Be)}{\Phi(pp)-\Phi(^7Be)}$$

Measured value:

$$R = 0.18 \pm 0.02$$

arXiv:1707.09279

Expected values: (C. Pena Garay, private comm,)

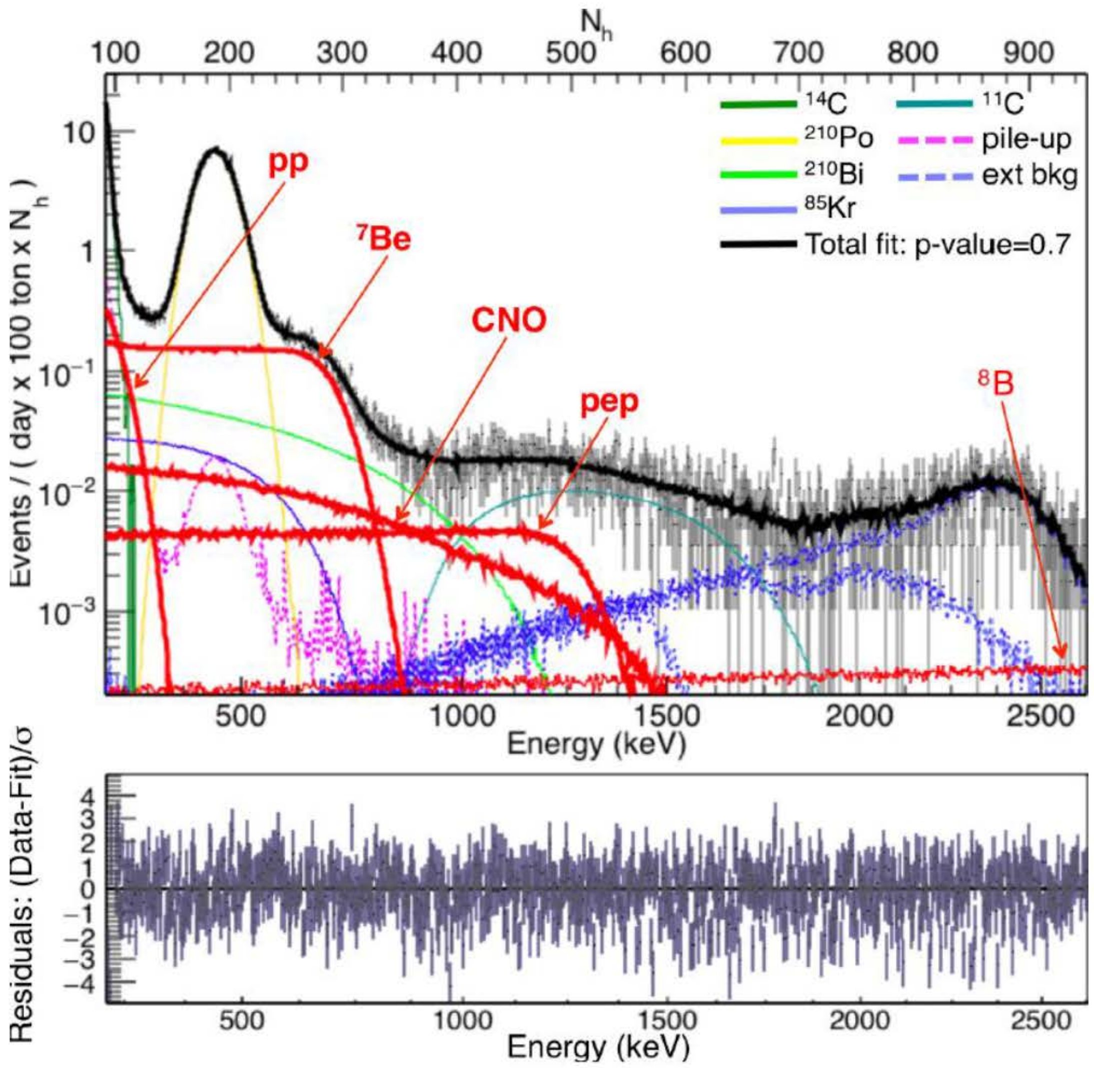
$$R = 0.180 \pm 0.011 \quad HZ$$
$$R = 0.161 \pm 0.010 \quad LZ$$

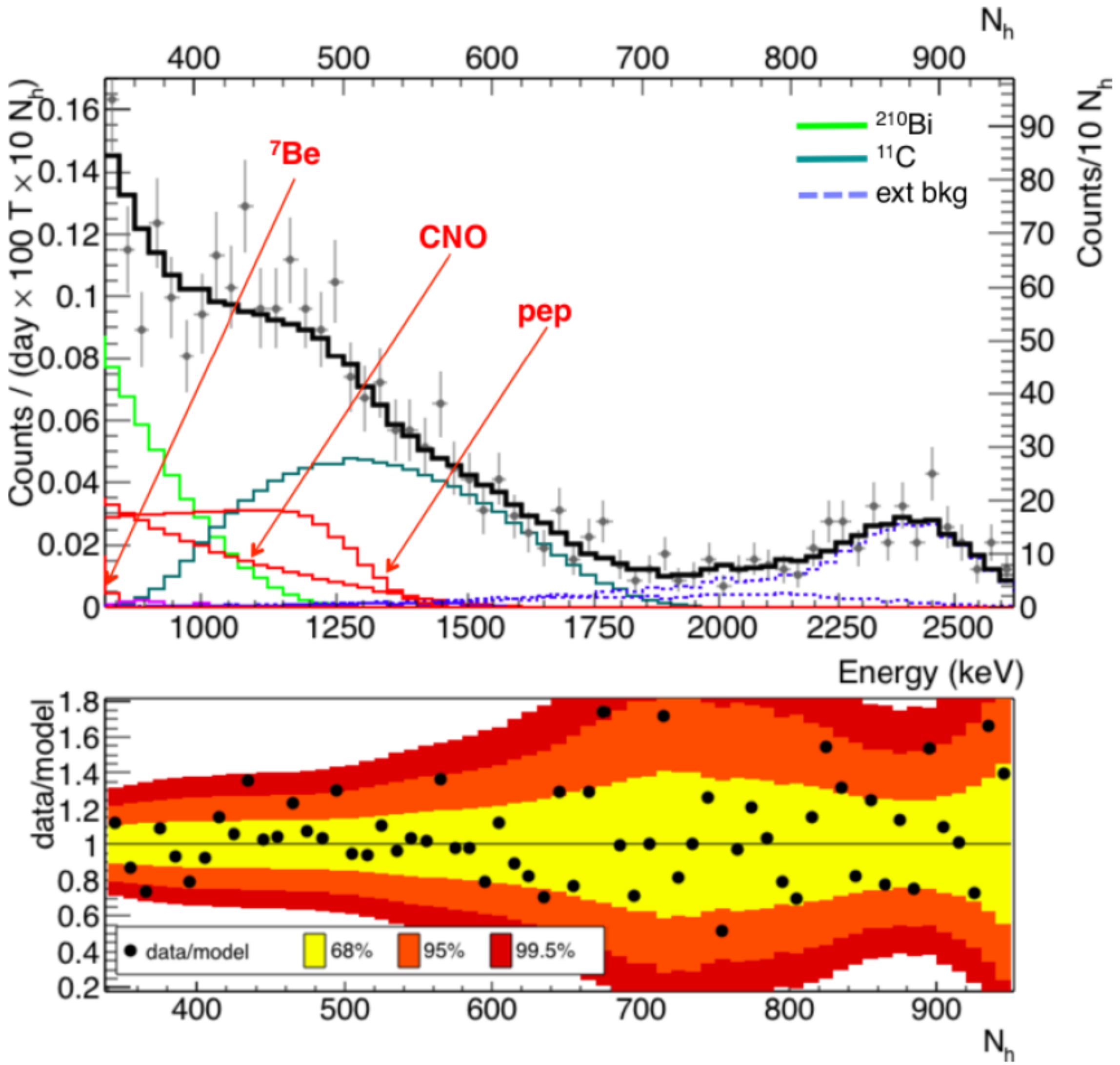
Borexino crowns a more than one century long scientific adventure

Full spectroscopy and evidence of the pep scattering edge

Released at TAUP@SNOLAB **arXiv:1707.09279**

More than 5σ evidence for the pep signal





CNO: the ultimate frontier of Borexino

Unprecedented Low background (@ 95% C.L :Th< 5.7 10^{-19} g/g U < 9.4 10^{-20} g/g Kr< 7.1 cpd/100 tons) and thermal stability → Borexino is the only experiment where the CNO measurement - extremely challenging - is in principle possible

Recall: problem ^{210}Bi background in the CNO energy region

Handles to solve it : 1) ^{210}Bi – ^{210}Po link and 2) purification to remove the ^{210}Bi

In progress → follow the Polonium trend profiting of the achieved thermal stabilization until either we will determine the sought Bismuth level, or until we will ascertain beyond any doubt that this attempt will not lead to a precise enough determination of such a level

Next and last step → Both occurrences followed by a purification cycle. In the former case, we would come up with a first hint of the CNO flux which later would be reinforced by the data after the purification cycle hopefully successful in bringing down the ^{210}Bi rate; in the latter occurrence, the purification would be the last possible tool to pursue the CNO determination, again if it will be effective in decreasing the ^{210}Bi

Other key elements of our experimental strategy

Mandatory a calibration campaign before the purification (last calibration in 2009) for the accurate interpretation of the CNO data

In view of the purification

- ✓ Added two columns to improve the water quality for the water extraction – not yet tested for the operational difficulties at the Lab
- ✓ A program has been devised for the thorough conditioning and cleaning of the plants – procedure approved and discussion with the external authorities in progress for its actual implementation
- ✓ To keep to the maximum degree of functionality of the overall fluid system $\rightarrow$ performed the upgrade of the control system that has compensated for the obsolescence of the previous 20 years old version

Reached and maintained an astonishing level of thermal stabilization in such a big liquid set-up

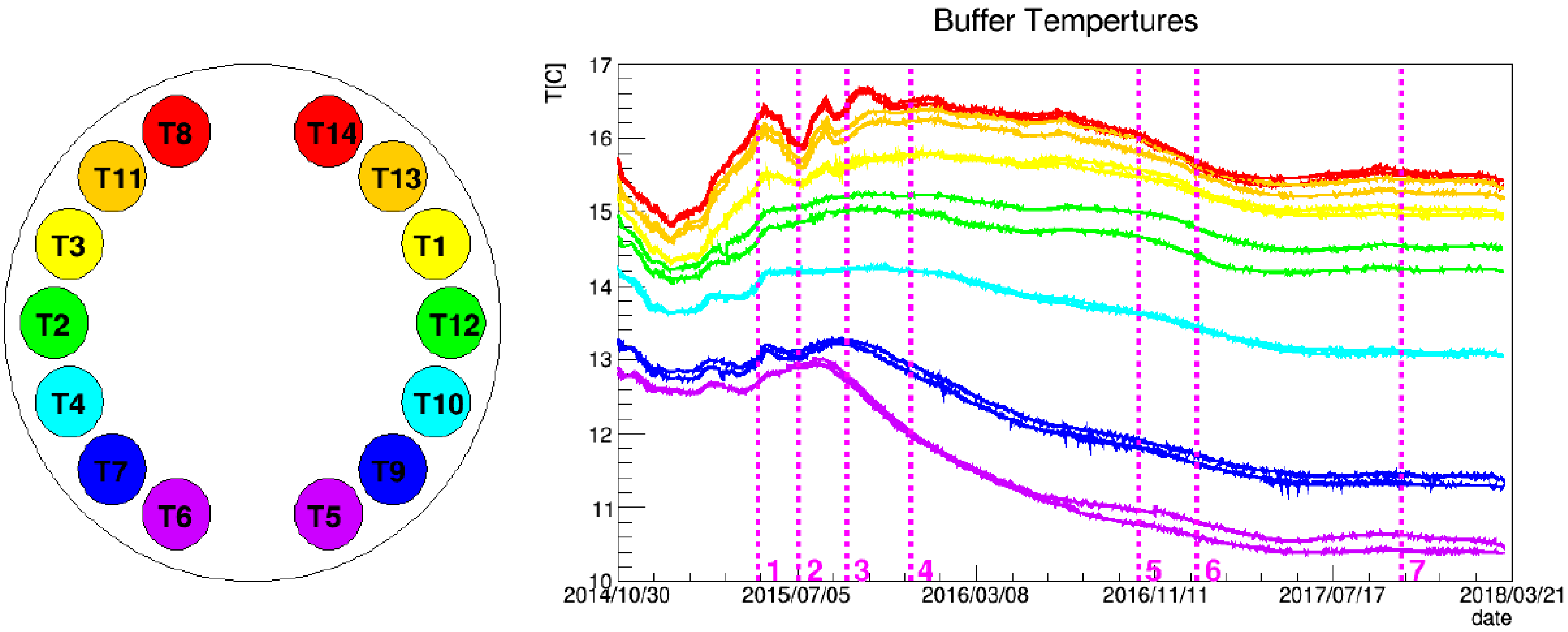
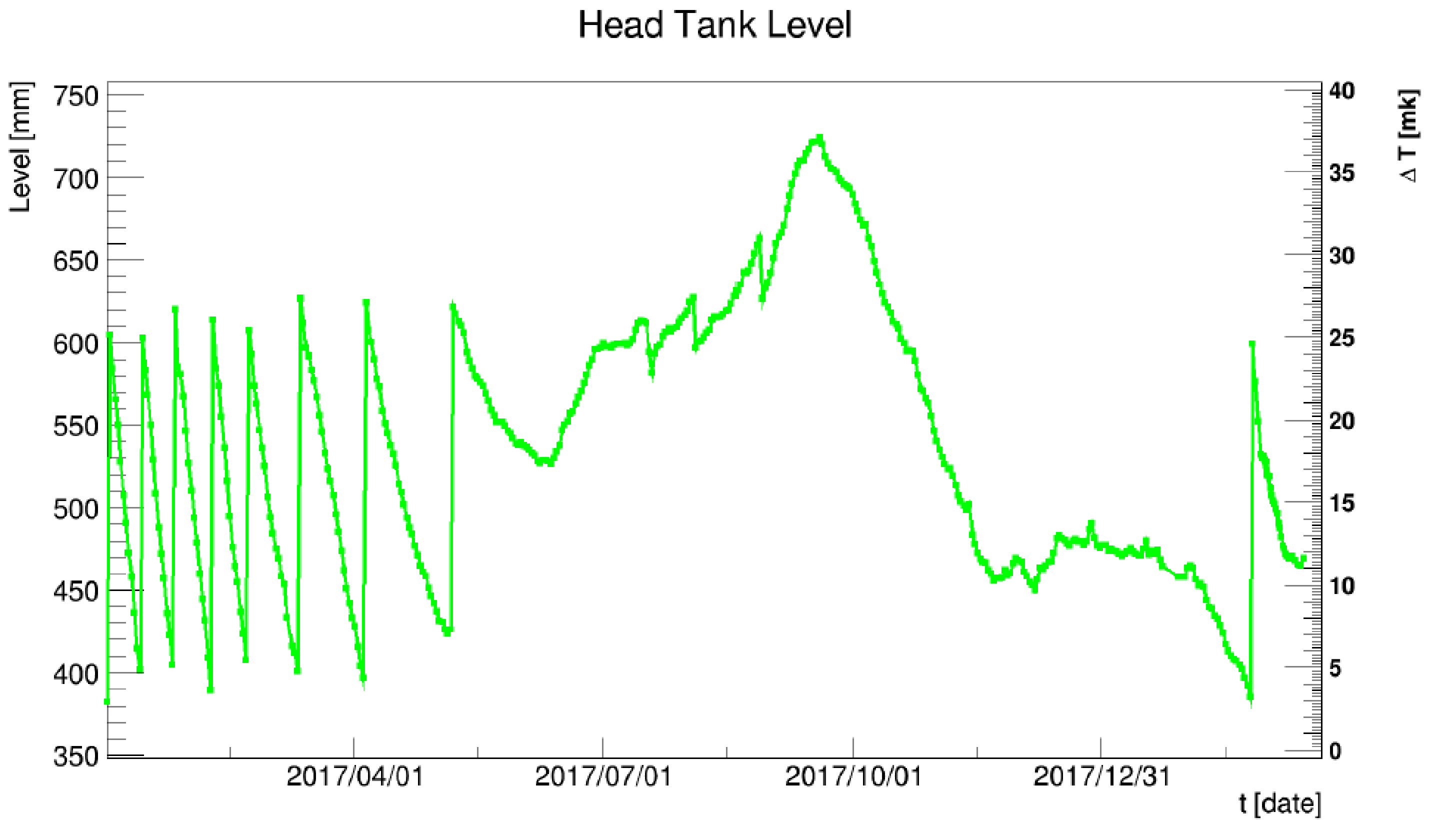


Figure 1: Inner Buffer temperature sensors. Vertical magenta dashed lines represent the most important operations of the thermal stabilization program: From the left to the right: 1. insulation started, 2. Water Loop turned off, 3. 5th ring insulation completed, 4. Organ Pipes and 6th ring insulation completed, 5. CR4 floor and Top Organ Pipes insulation completed, 6. Temperature Active Control System tests started and 7. Hall C active control started.

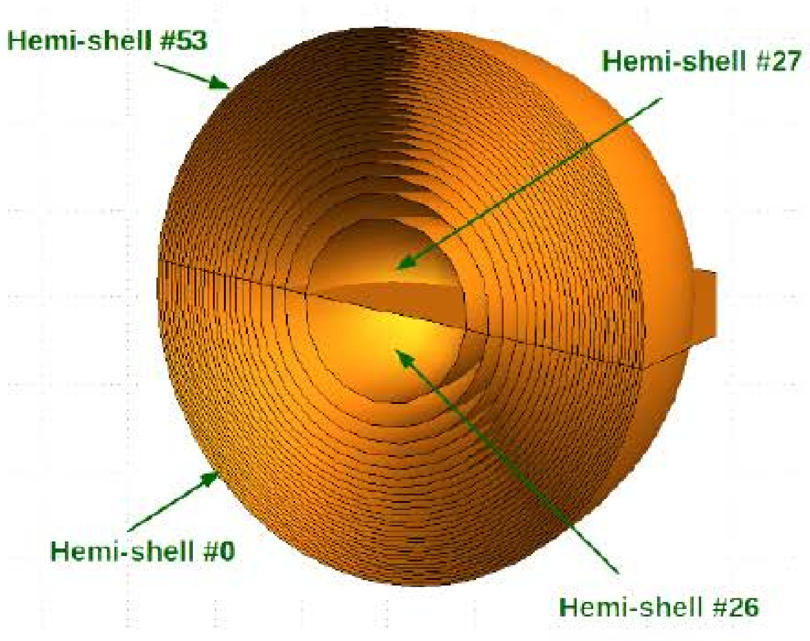
Another way to appreciate the degree of achieved thermal stability – the level in the Head expansion tank



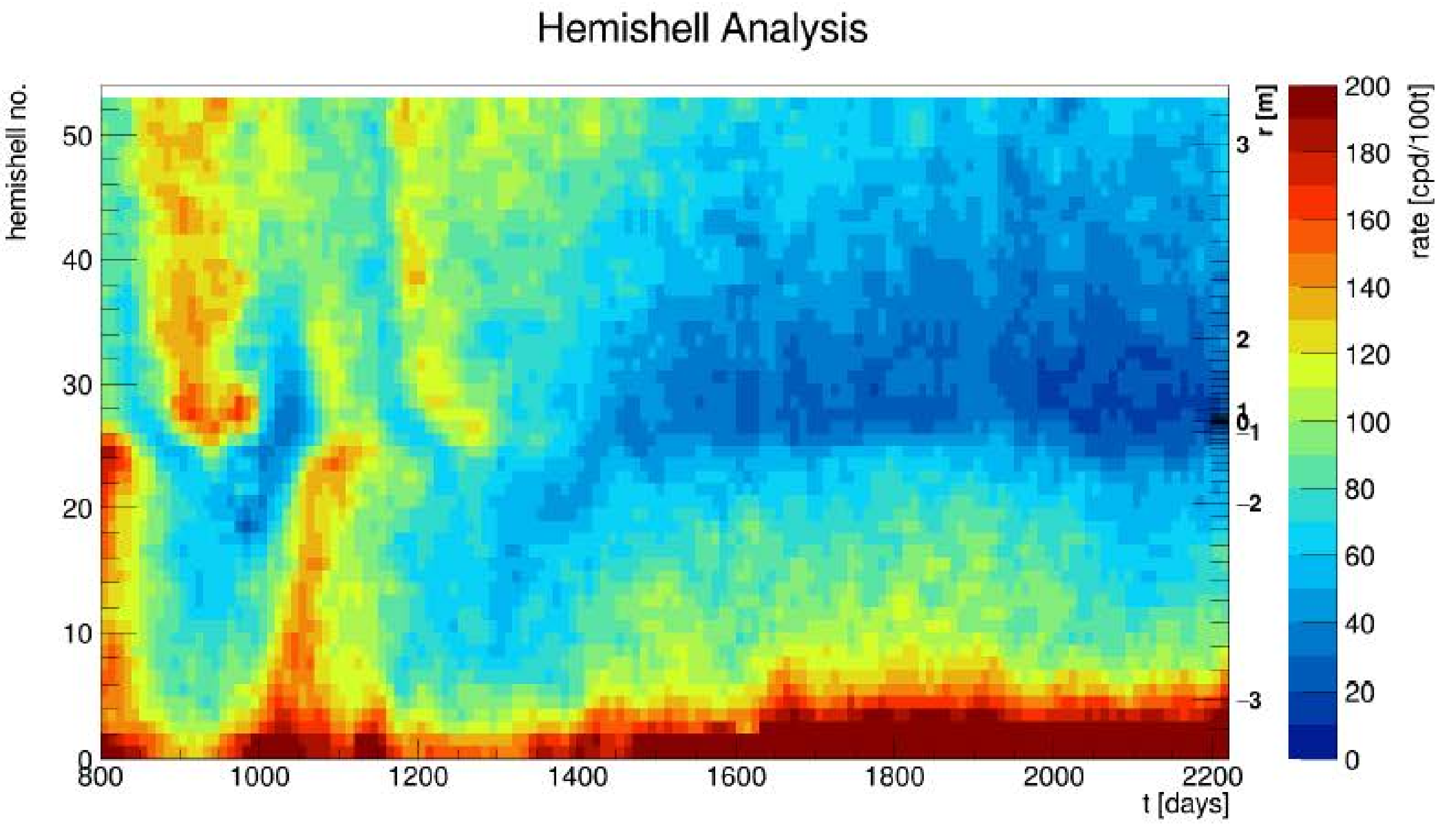
In this scale 100 mm corresponds to an average temperature interval of 0.01 K. The variation in the period from December 2017 to January 2018 (last part of the graph) corresponds thus to a temperature change of 0.005 K. The spike at the end of the time range is due to a recent pseudocumene refill

In the Fall activated the regulation of the ventilation air of Hall C.

Polonium mapping



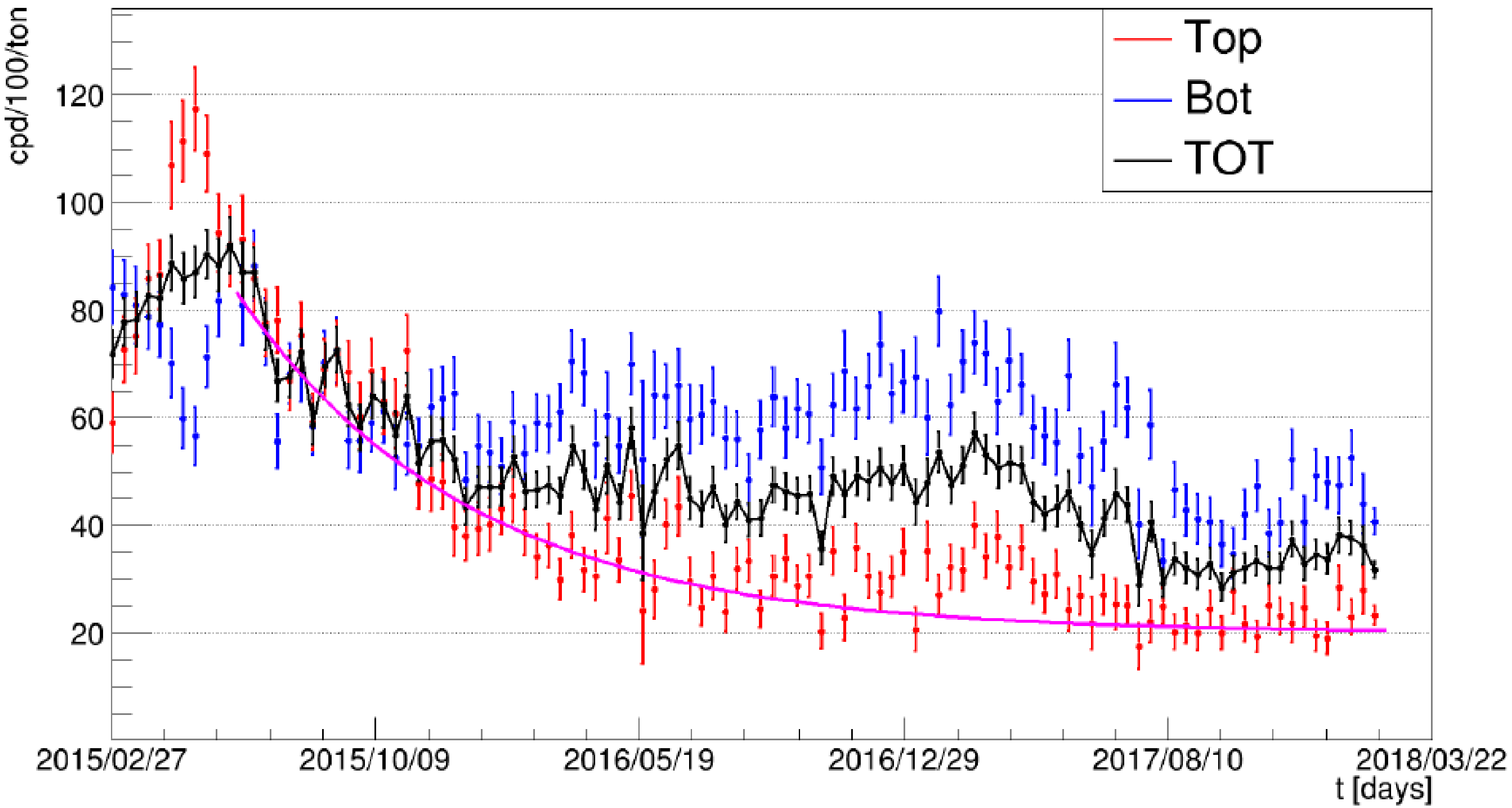
(a)



(b)

Polonium evolution from beginning of insulation

$r < 2.5$ m and $|z| < 1.5$ m



The stability conditions to determine the ^{210}Bi rate now exist and make this attempt grounded on a solid and concrete basis. In any case, if despite this favorable framework the ^{210}Po level at the bottom will not sufficiently stabilize, we are evaluating the possibility to restrict our analysis to a smaller region, encompassing most of the top volume, where the stabilization of the ^{210}Po looks much more promising

CNO Statistical sensitivity

- ✓ Quantitative calculation based on Toy MC and standard hypothesis test approach
- ✓ Only rate or rate plus shape analysis (full multivariate fit)
- ✓ External constraints very important to gain sensitivity in the CNO determination

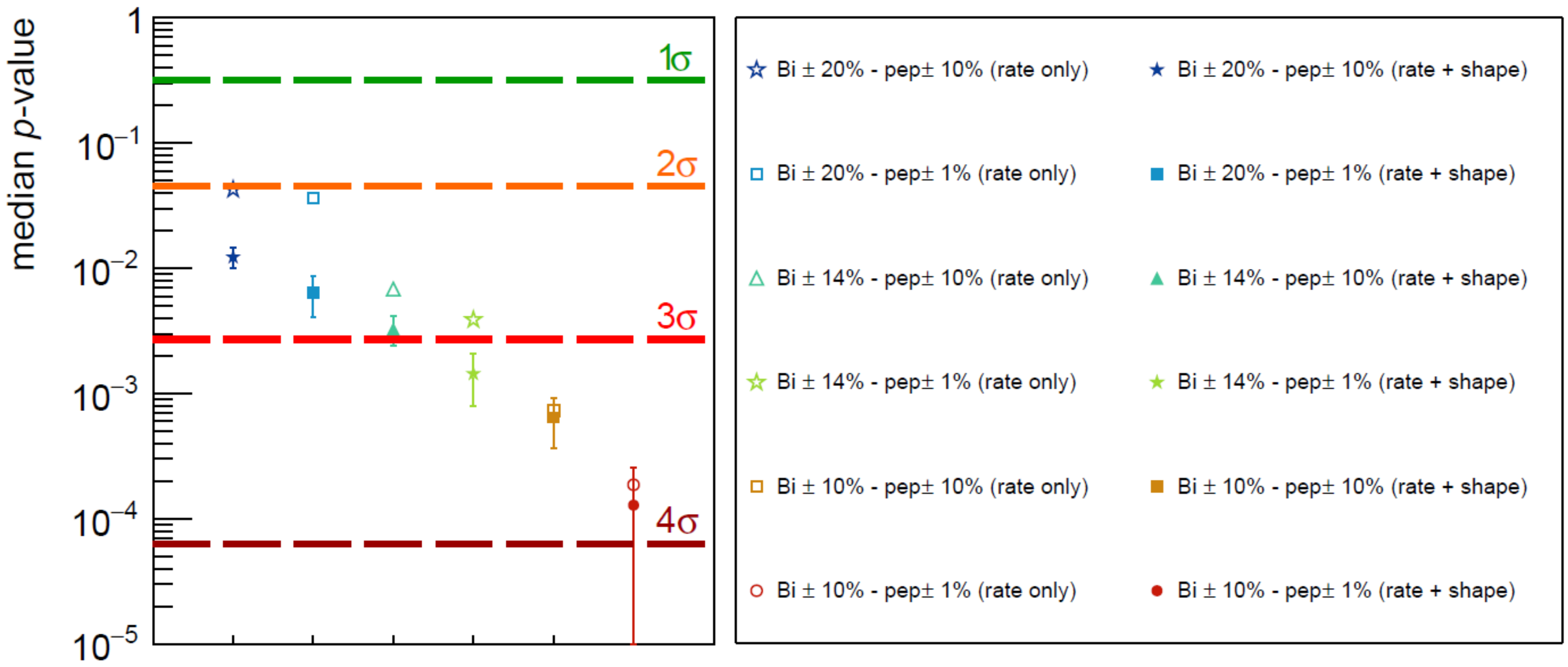
  Pep 10% (from SSM) or 1% (luminosity constraint)

  ^{210}Bi assumed known in the range 20% to 10% from the experimental measure

- ✓ Calculated both the strength of the CNO signal and the significance of its detection
- ✓ Significance shown in the next slide plot for the HZ CNO signal under different input assumptions

  Rate, rate plus shape, value of the two constraints

Achievable evidence of the CNO detection



Significance ranging between 2 and 4 σ depending upon the Bismuth and pep constraints

For weaker constraints additional improvement from the rate plus shape analysis with respect to the shape only computation

Calculation for the HZ signal

Calculation providing a very solid foundation for the prosecution of our enduring CNO quest

Conclusions

After the great success in investigating the pp chain in the Sun $\rightarrow$ **ultimate goal of Borexino the CNO flux**

Astonishing thermal stabilization and unprecedented low background of the scintillator the two cornerstones for the CNO quest

Sequence of our strategy: ^{210}Bi- ^{210}Po link with the current data taking, accomplishment of the calibration, purification cycle through water extraction and final data taking period

If with these actions, we get a measurement of the ^{210}Bi rate with an accuracy of 20% or better, which is feasible with our detector, the statistical sensitivity analysis that we have performed demonstrates that with this value as constraint in our fit to the data, there is a realistic possibility that we can achieve a significant evidence of the CNO neutrinos, ranging between 2 and 4 σ.

On the basis of this promising evaluation, the Collaboration is therefore fully committed over the next years to continue the quest for the CNO neutrino flux

From the report of 6 months ago "We do not promise that we will achieve it, since as for any challenging research breaking new ground its results will be known only at the end, but we are committed to exploit to the maximum possible level the capabilities of the detector towards this exciting goal"