Borexino

Gioacchino Ranucci
INFN - Milano

On behalf of the Borexino Collaboration

LNGS Scientific Committee
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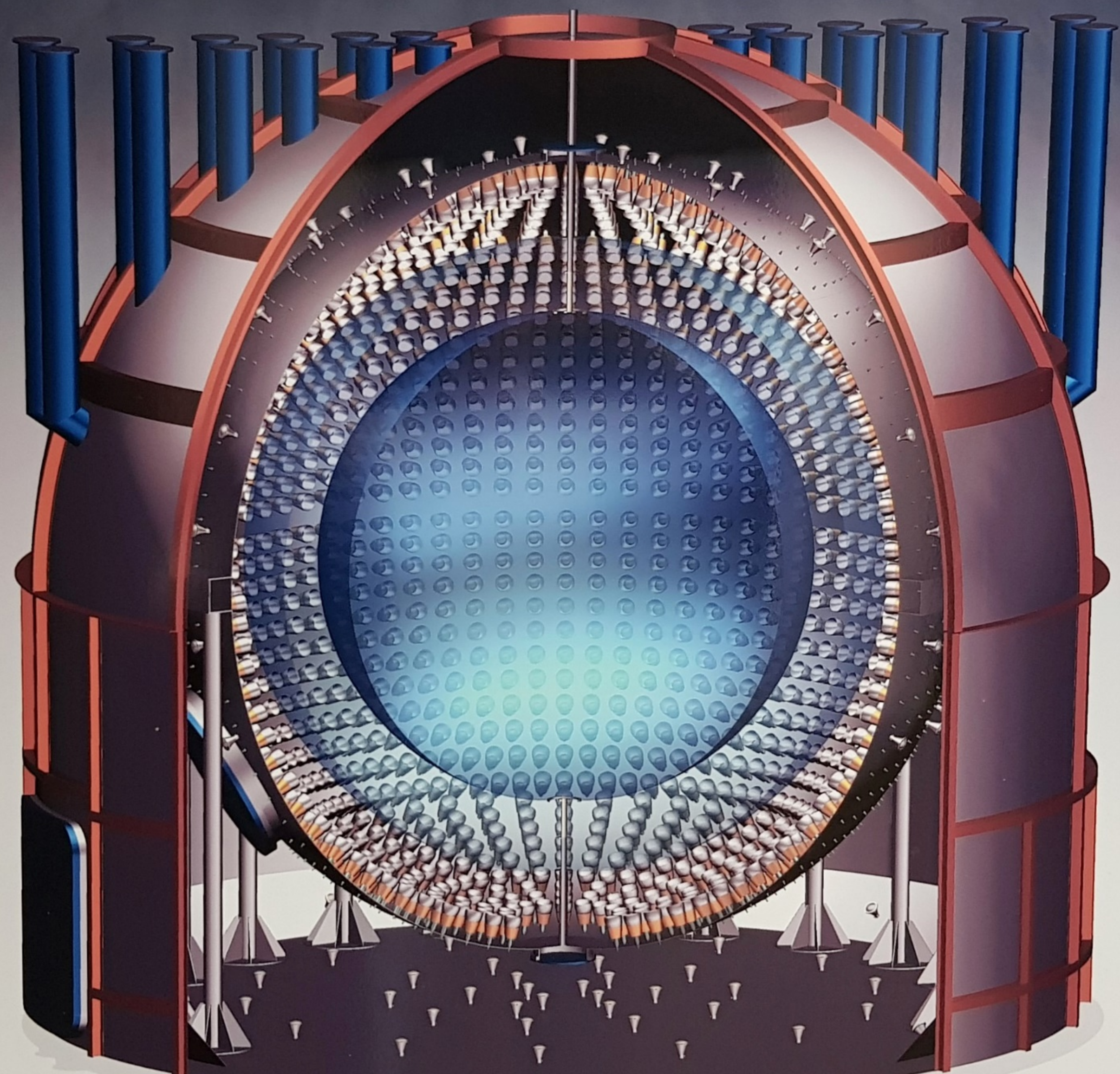
Borexino Experiment

Laboratori Nazionali del Gran Sasso

Bruno Pontecorvo International Award 2015



Enrico Fermi Award 2017

physicsworld
TOP 10 BREAKTHROUGH 2014

Francobollo di Posteitaliane
16 Settembre 2014

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< 7.5 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 → ^{210}Bi – ^{210}Po $\quad ^{210}\mathrm{Pb} \xrightarrow[(23\mathrm{y})]{\beta-} {}^{210}\mathrm{Bi} \xrightarrow[(5\mathrm{d})]{\beta-} {}^{210}\mathrm{Po} \xrightarrow[(138\mathrm{d})]{\alpha} {}^{206}\mathrm{Pb}\,(\mathrm{stable})$

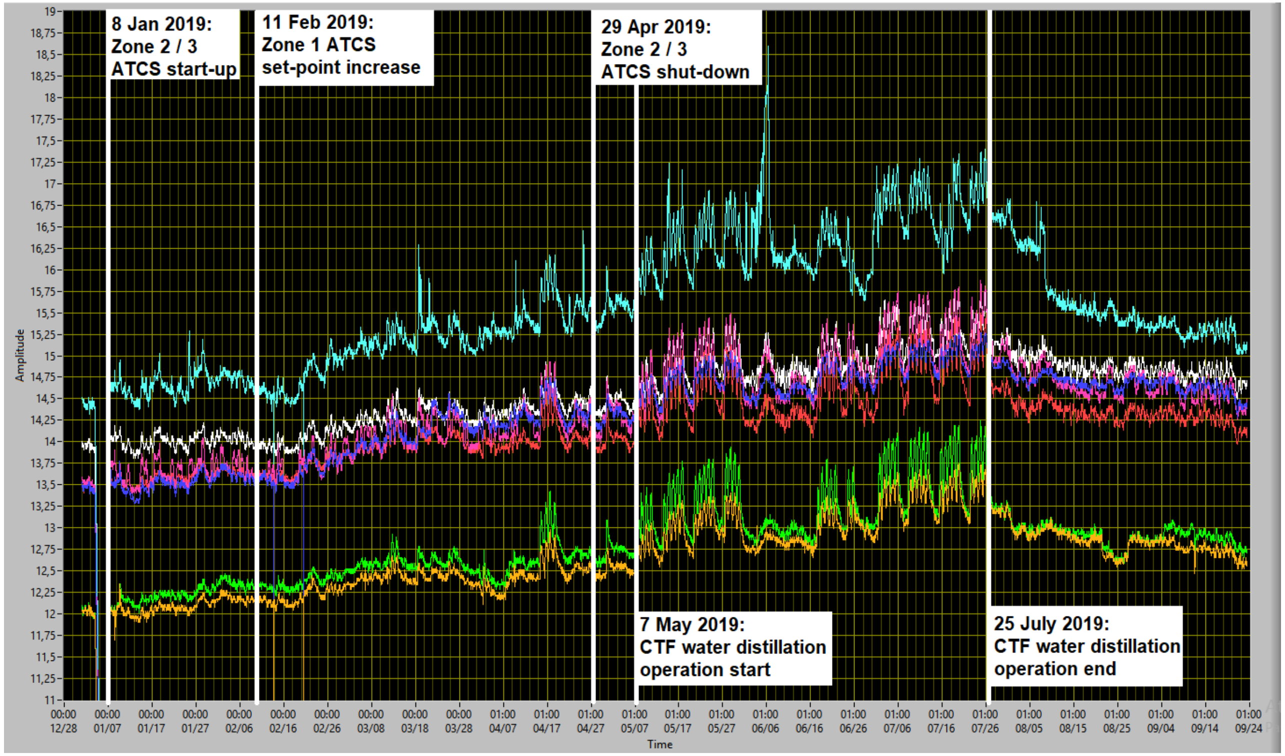
Requirement → stable scintillator to avoid Po-210 recontamination from the IV surface

Action → stabilize a vertical gradient to keep the fluid as static as possible and prevent the Po-210 migration (diffusion + convection) from the IV surface via thermal insulation of the Water Tank and by deploying active temperature control systems (ATCS) around it

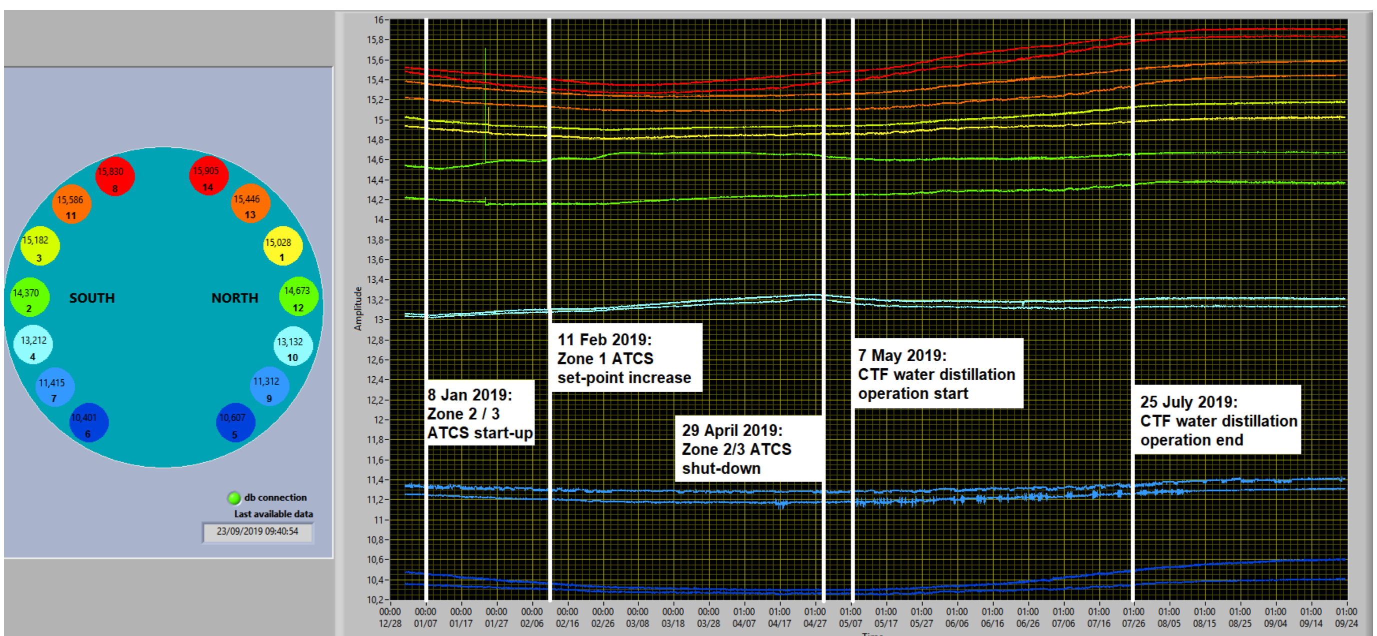
Final goal → Assess from the Po-210 value the Bi-210 constraint to be insert in the solar neutrino fit to extract the CNO rate

Program conceived in 2014 and implementation started in 2015

Detector thermal stabilization – enduring effort



Hall C Seasonal temperature variation in 2019

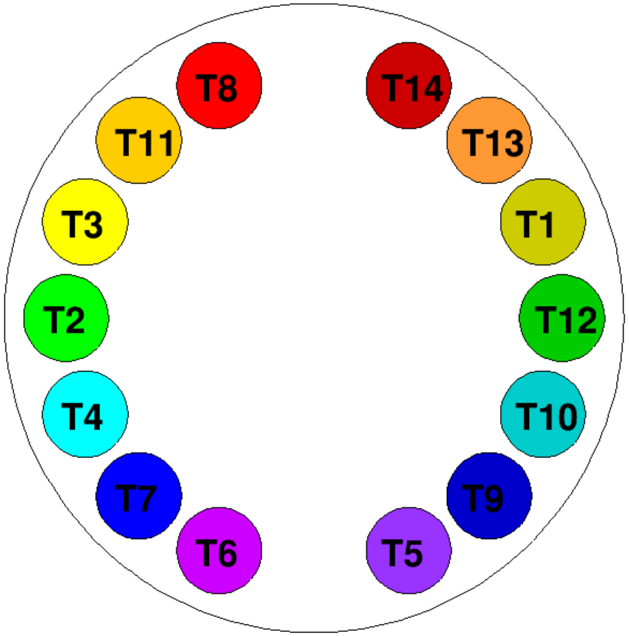


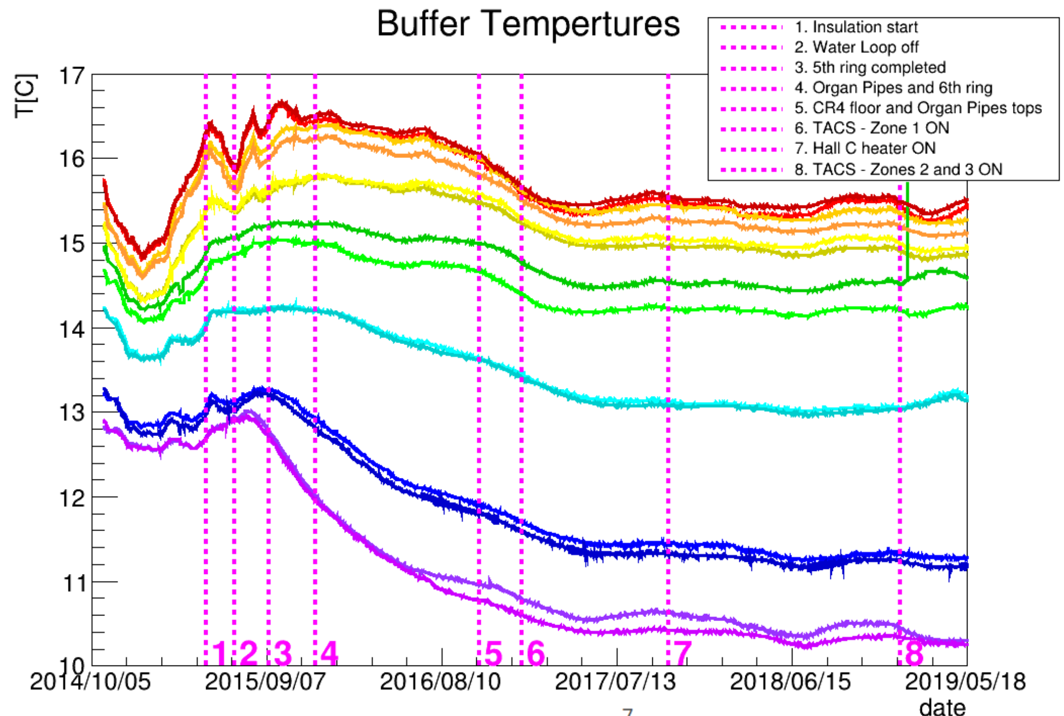
Inner temperature probes

Globally very high stability

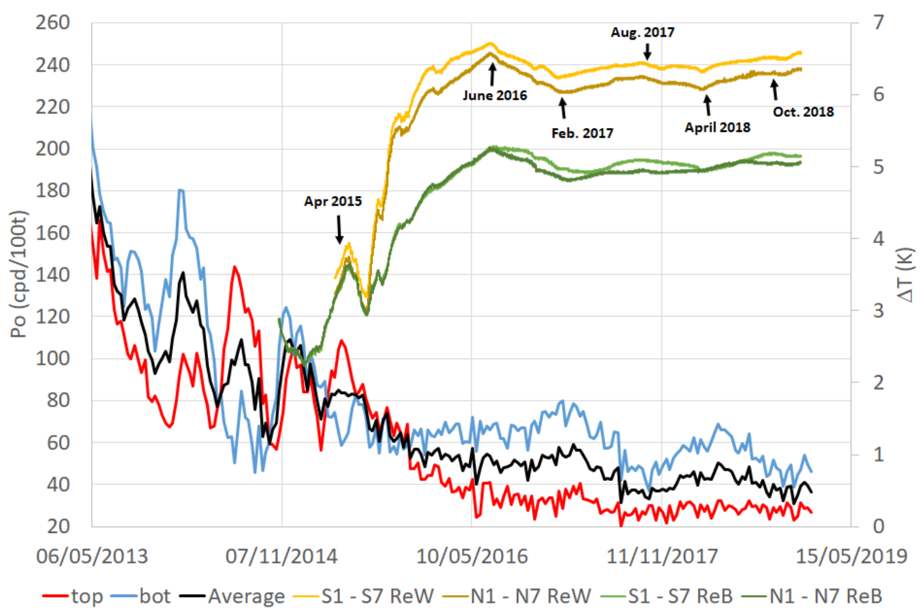
Increase effect in the last period due mainly to the increase of the set point of ATCS1 to further enlarge the vertical gradient, plus some residual effect of the external seasonal trend, see next slide

Residual impact of the external temp. seasonal variations on Polonium





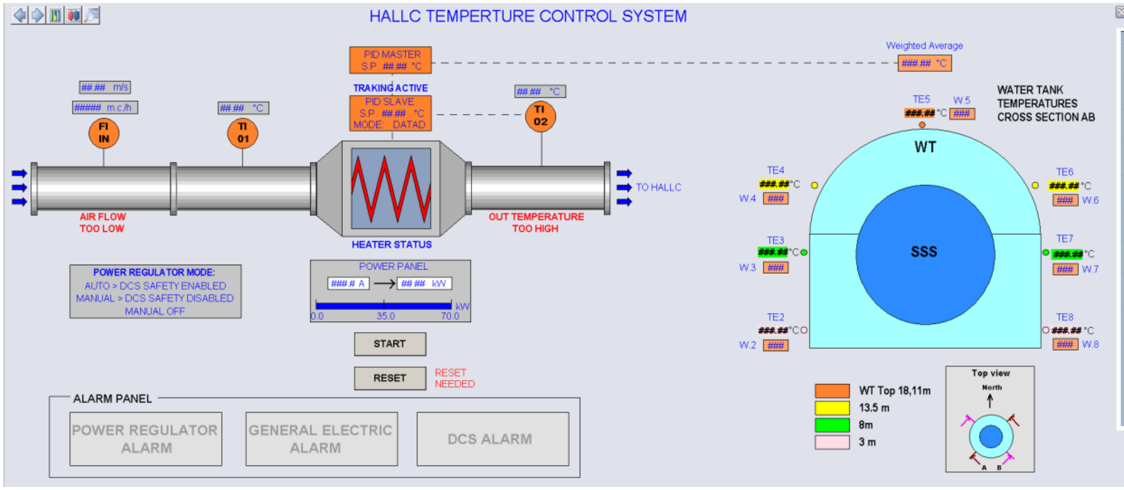
Po-210 rate greatly stabilized with respect to before the insulation of the Water Tank

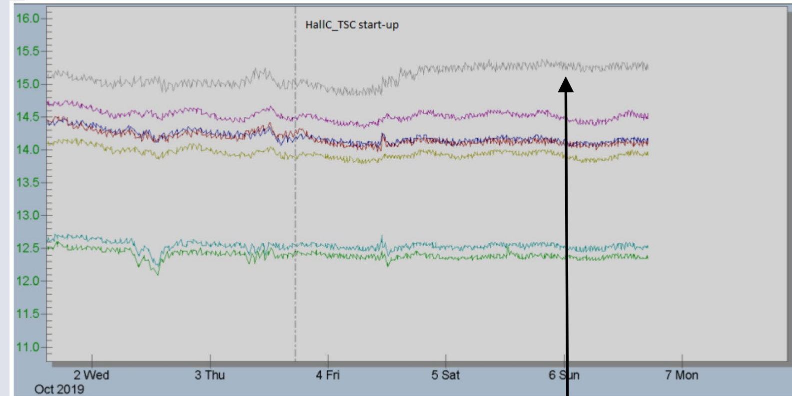


1°C outside → 0.1 °C in the buffer
Target 0.01 °C outside → negligible in the buffer

But, with a delay, still affected by the external temperature
→ we want to suppress also this residual effect

New Hall C temperature control system



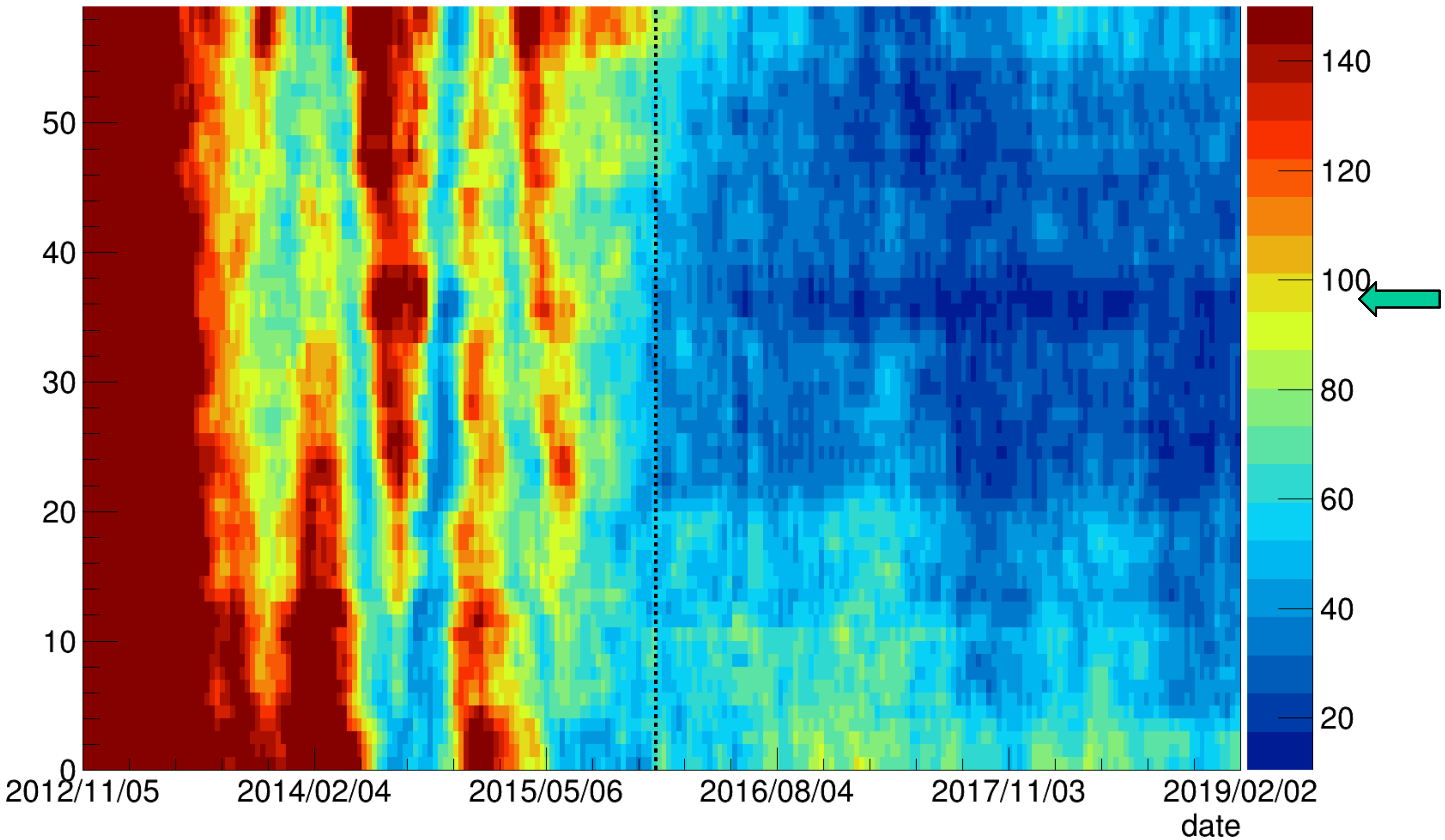


Early effect

It monitors and regulates the inlet air from the air duct to Hall C and can work also in a feedback mode: a short one close to the heater itself and a long term one (2-3 weeks) with the external sensors of the Water Tank, still under study

Installation completed a couple of weeks ago

Polonium spatial mapping



Stable minimum bubble 20 m^3 above the equator from which we can infer the intrinsic Po-210 and hence the Bi-210

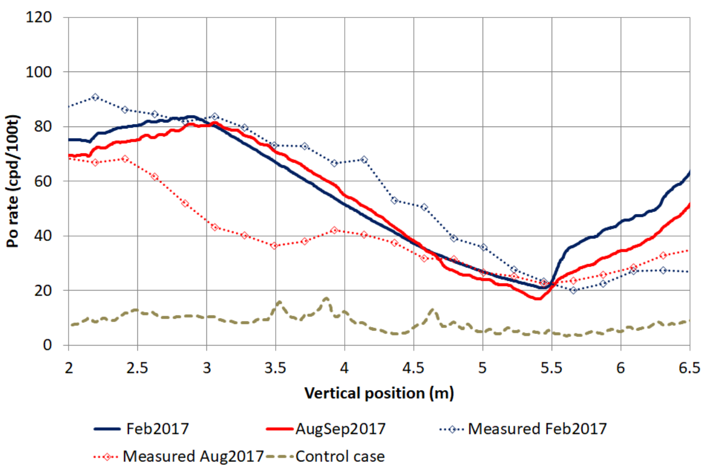
Po-210 (Bi-210) can be determined already in the configuration so far

Scope of the on-going actions (new ATCS, Hall C stabilization , changed set point of the first ATCS) → enlarge the minimum bubble and thus further improve the Po-Bi determination

Current stage of Po and Bi understanding

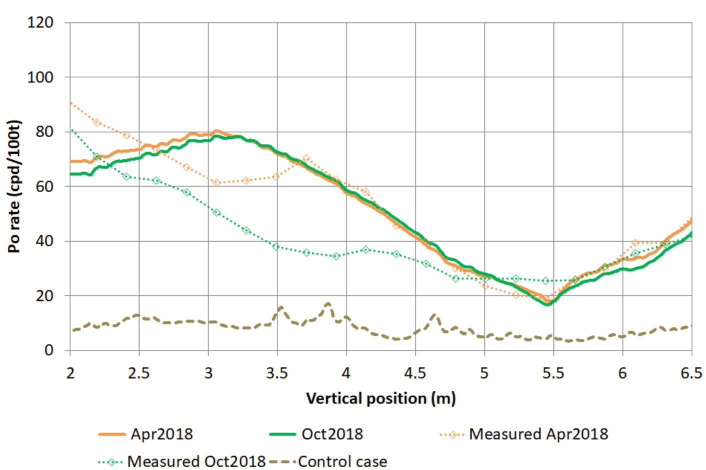
$$^{210}\mathrm{Pb} \xrightarrow[(23\mathrm{y})]{\beta^-} {}^{210}\mathrm{Bi} \xrightarrow[(5\mathrm{d})]{\beta^-} {}^{210}\mathrm{Po} \xrightarrow[(138\mathrm{d})]{\alpha} {}^{206}\mathrm{Pb}\,(\mathrm{stable})$$

Basis of the approach



2D Preliminary fluidodynamic simulation of Po-210 profile in the detector

Qualitative agreement with the data – the Po-210 mapping - including the location of the minimum just above the equator - To be confirmed with an on going 3D simulation



Po-210 rate inferred in the minimum bubble

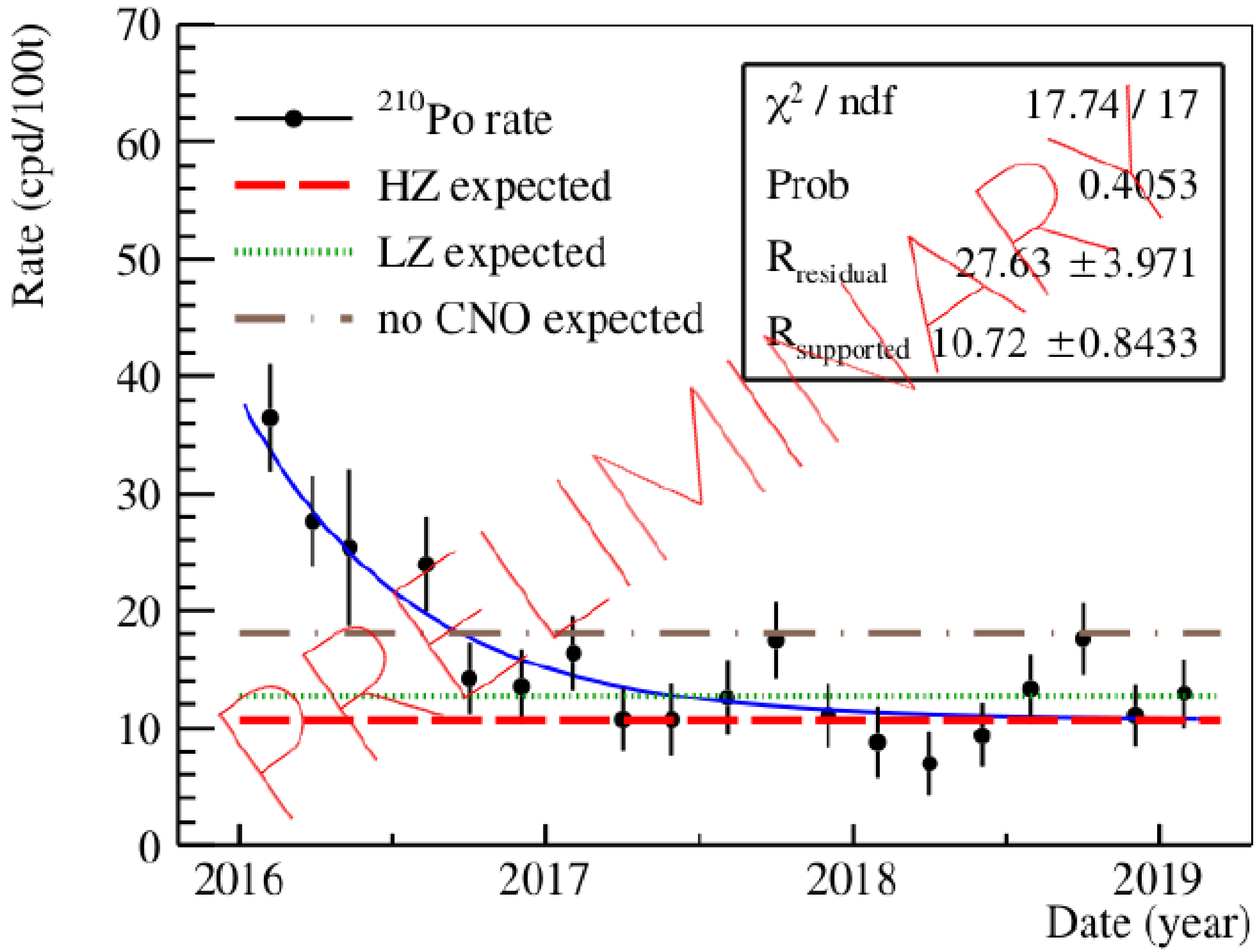
$$R(^{210}\mathrm{Po}) = 11.8 \pm 1.4\ \mathrm{cpd/100t}$$

The error includes the systematic effects like the uniformity in space and stability in time - 3 years from middle of 2016
Preliminary result under thorough scrutiny to confirm the systematic evaluation

Decay across the years of the Polonium in the minimum bubble

Reached the plateau thanks to the great thermal stability and reduction of liquid motion

The Po-210 (and hence Bi-210) asymptotic value compared with the spectral fit result done forcing the CNO to 0 does not saturate the contribution in the CNO region (brown dashed line) $\rightarrow$ extra component required !



Breakthrough result:
first clear indication that our data are sensitive to the CNO signal

Towards the spectral fit for CNO

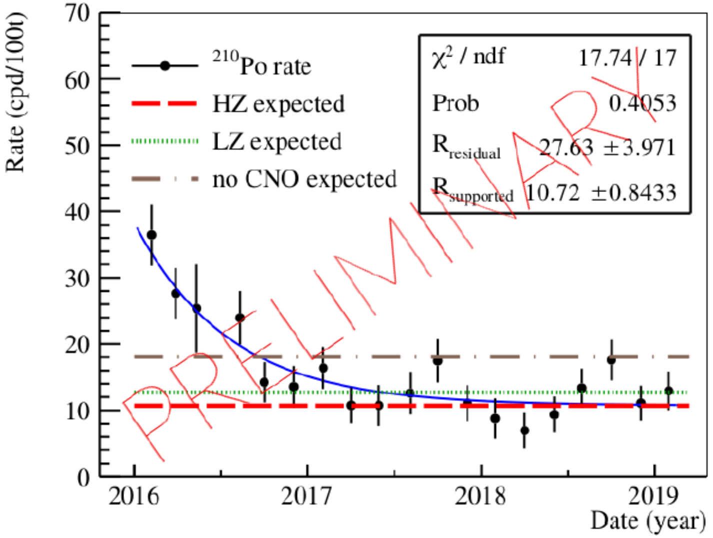
The same type of multivariate fit employed for the other solar neutrino fluxes

Additional crucial factor in the $\chi^2 \rightarrow$ Bi-210 penalty

Two alternatives: Gaussian penalty for a real Bi-210 value or semigaussian penalty for a Bi-210 upper limit in a conservative approach - in principle a modest residual contribution from the surface could still be present

However the Po-210 plateau in the bubble is well aligned with CNO (Hz/Lz red green lines) expectation providing a data driven indication that this potential residual contribution is marginal

Other constraint in the fit – pep - which is very solid

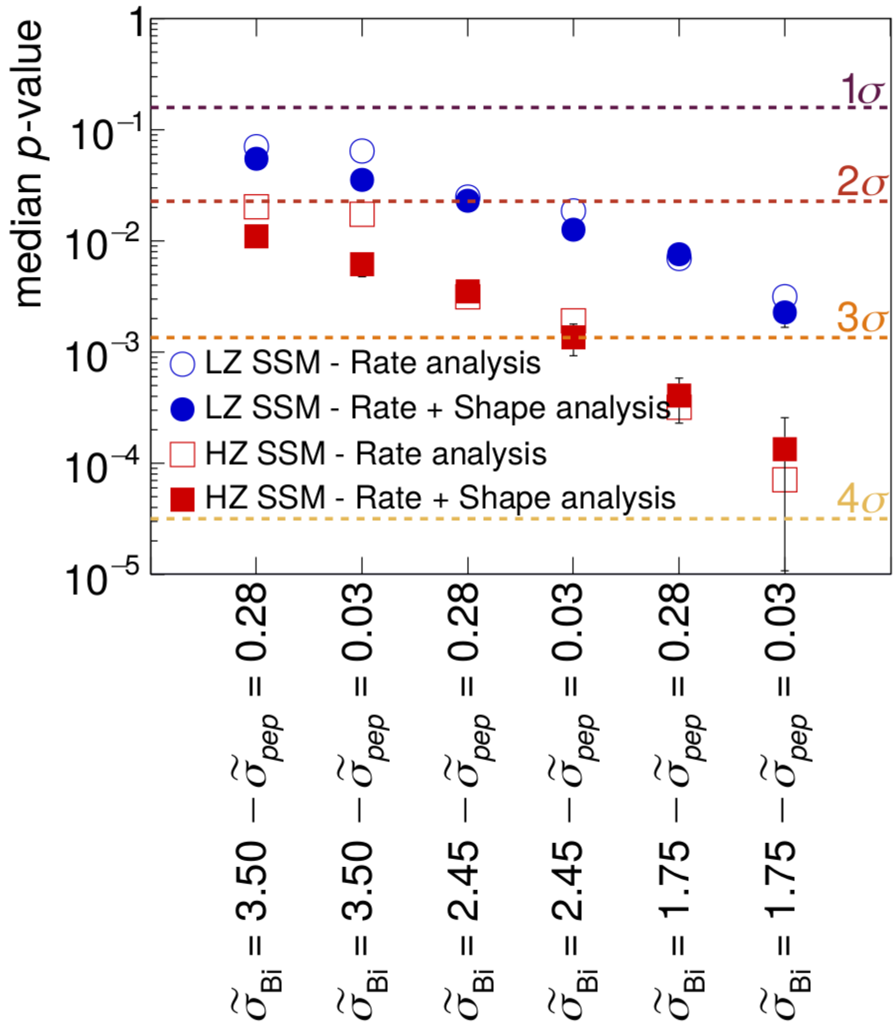


CNO Discovery sensitivity

The sensitivity depends on the strength of the signal (Hz or Lz) and upon the applied constraints (in counts per day in this figure)

It is equivalent to a counting experiment of signal (CNO) over background (Bi-210+pep)

An evidence between 3 and 4 σ is achievable



Other papers

After the Nature paper last Fall
(*Comprehensive measurement of pp-chain solar neutrinos*, Nature 562 (2018) 496)

- Two accompanying technical papers - detailed description of the analysis in the a) lower and b) higher energy window

  a) Accepted for publication in Phys. Rev. D.   b) under finalization

- Limits on non standard neutrino interactions for $\nu_e e-$ and $\nu_e \tau-$ couplings - No indications for new physics at the level of sensitivity of the detector $\rightarrow$ constraints on NSI parameters arXiv:1905.03512 submitted for publication

- updated geoneutrino analysis presented at TAUP 2019 conference - paper accepted for publication by PRD few days before the conference

- presented at TAUP also new limits about possible neutrinos and antineutrinos fluxes from astrophysical sources included DSNB - paper submitted to Astroparticle Physics

- Two ongoing papers in preparation : Atmospheric neutrinos interactions in Borexino and techniques for C11 tagging

Plants related activities

Refurbishment and improvement of Water Treatment Plant
After the 2018 refurbishment of Borexino Water Plant, in 2019 installation of an additional high efficiency Degasser for Radon removal

Precision cleaning of the purification related equipment
After the preliminary cleanings performed in 2018, this year cleaning of the D1 storage tank (100 m^3) → storage of Ultrapure Water to be used for Liquid Extraction during purifications

Production of Ultra-pure Water suitable for scintillator re-purification: 85 m^3 of Ultra-pure water stored in D1 tank, water taken from CTF for low Po-210 (CTF refilled)

The sequence of operations during water purification: CTF water treatment in the refurbished Water Plant, high efficiency distillation in the US Skids for organic Po compounds removal, transferring in deeply cleaned D1 tank in the Storage Area.

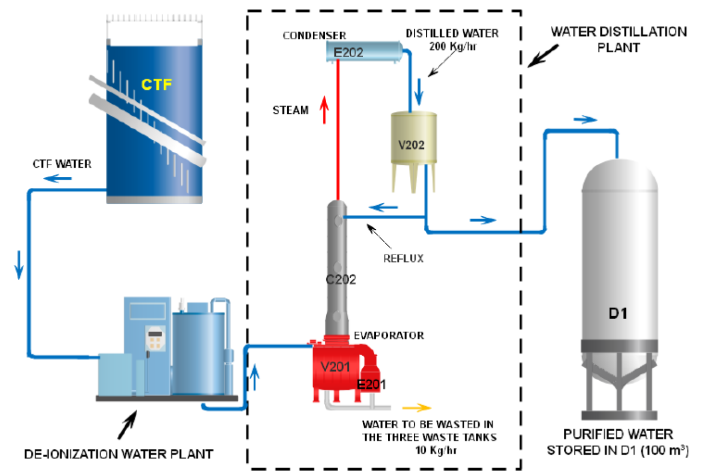


Figure 13: Path of water during Ultra-pure water production.

Electronics and DAQ

Stable data taking and high duty cycle essential for the CNO challenge

- Regular maintenance and reparation activities of the electronics

- Routine inspections of the PMTs' working conditions

  the failure rate is, since years, stabilized to approximately 5/6 per month, adequate to ensure the proper functioning of the detector for sure until the end of data taking and more. At the end of September 2019 the working PMTs were 1245.

- Crucial the reliability of the chillers for thermal stability of the electronic system

  Performed a thorough refurbishment of the two units in the electronics room

Conclusions

Borexino continues to produce a plethora of physics results of great value and impact

The Collaboration is fully focused to complete the program of the experiment by exploiting at best the unprecedented scintillator purity and data quality

The continuous push towards the improvement is witnessed by the recent additional efforts to ameliorate the already great thermal stabilization of the detector, to produce extremely high quality water and to guarantee the optimal working conditions of the electronics and DAQ

The central focus of our commitment the CNO quest has significantly advanced, with the recent further understandings in term of ^{210}Po –^{210}Bi, of thermal behavior of the detector, and of sensitivity and fit studies pointing to bright perspectives toward the CNO detection with the recent breakthrough output that our data are actually sensitive to the CNO signal