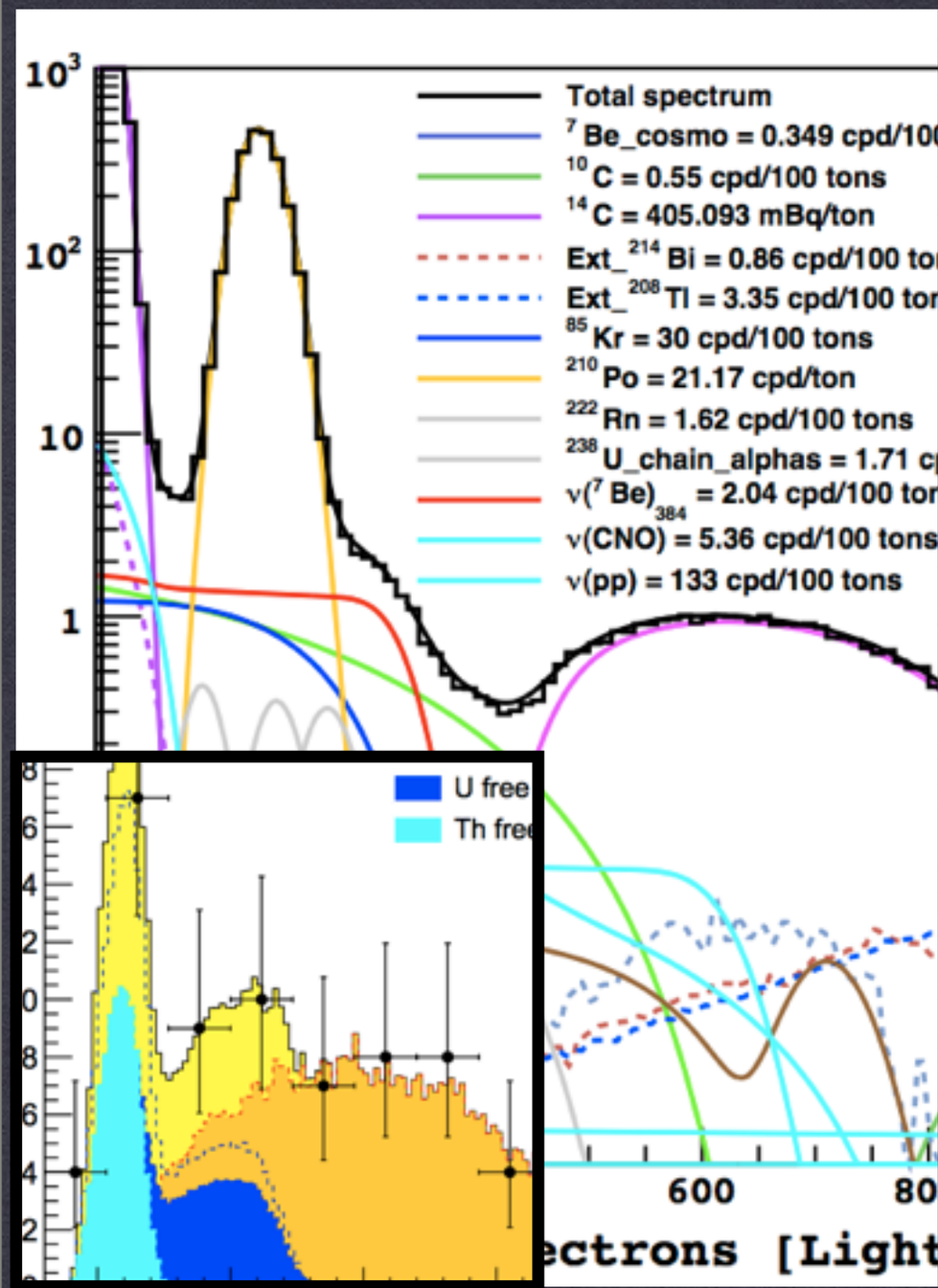


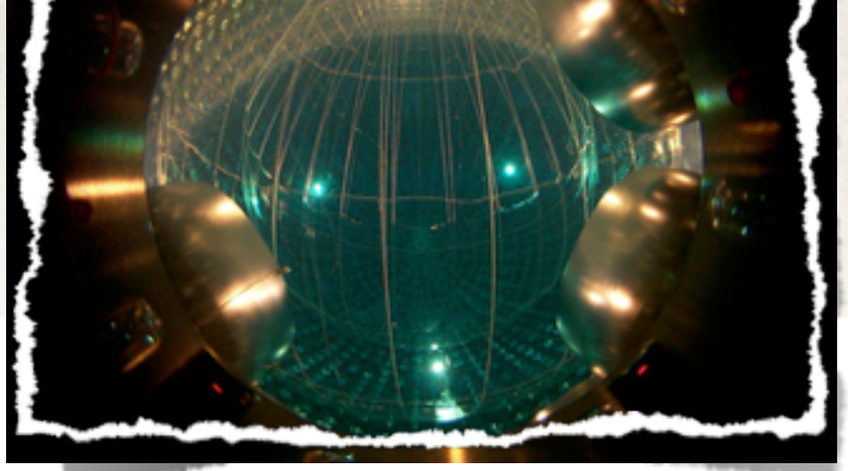
BOREXINO & SOX

Solar, geo and sterile neutrino observatory

23rd May, 2016 | David Bravo-Berguño (Borexino/SOX Collaborations)

Outline

- **Detector** overview
- **Results** update
  - **Geo**-neutrino latest
  - Recent achievements in **solar** observations
- **Ongoing** efforts
  - **Wideband** solar neutrino **spectroscopy**
  - **CNO** neutrino studies
  - **Temperature monitoring and management** systems
- Solar-to-sterile **calibration** campaign
- **SOX-Ce** source for anomalous oscillation studies
  - **Source** characteristics and experiment outline
  - **Calorimetry** and **sensitivity**



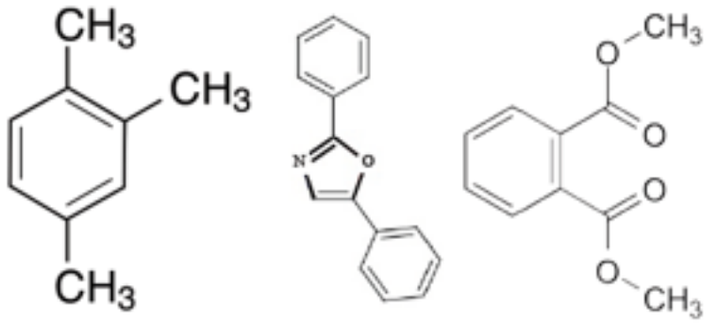
Located in LNGS
(3600mwe)

~488 pe/MeV

~19% eff.

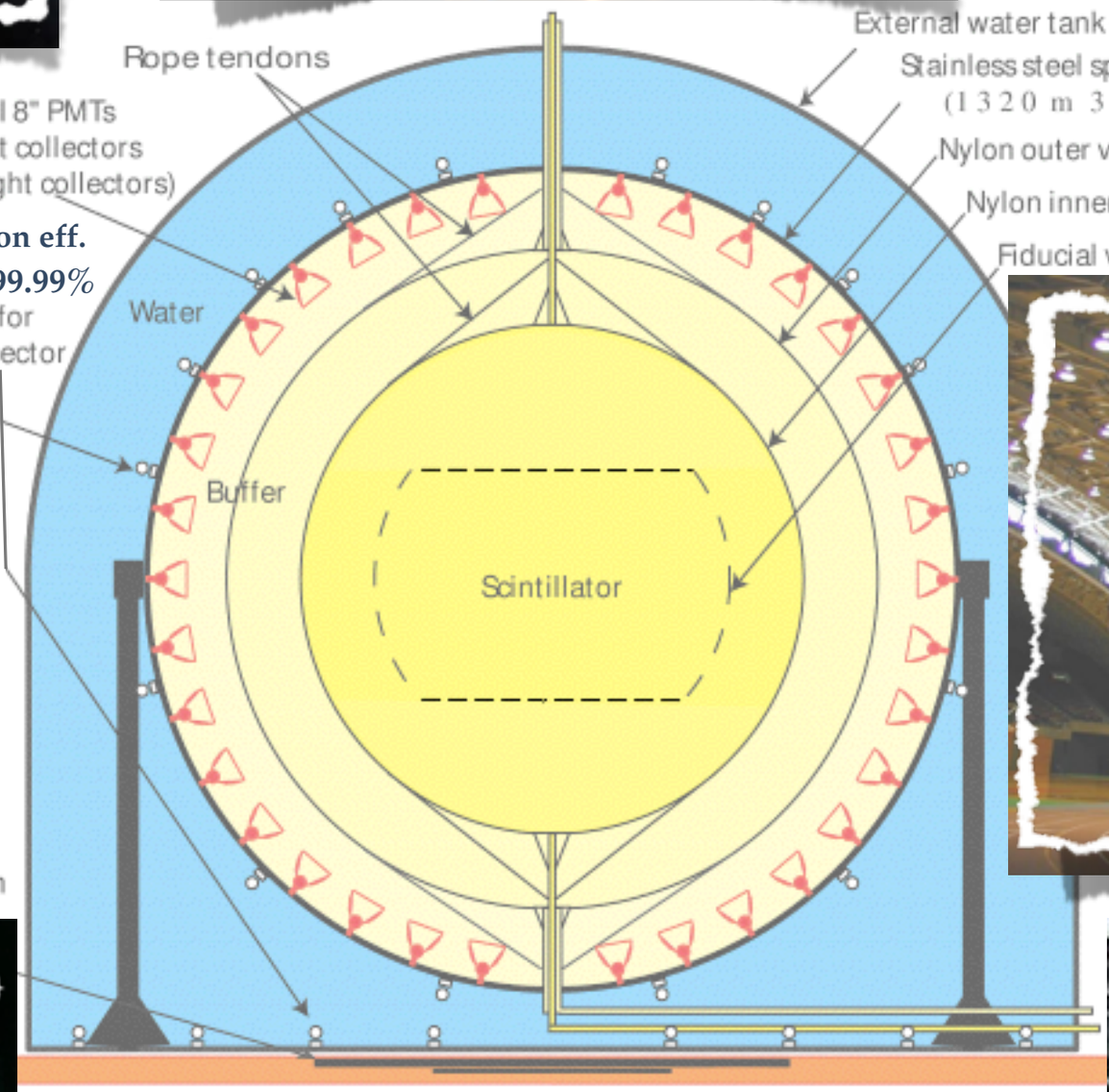
Muon discrimination eff.
with pulse-shape: **>99.99%**
208 PMTs in water for
External Muon Detector

PC *PPO (1.5g/L)* *DMP (2g/L)*



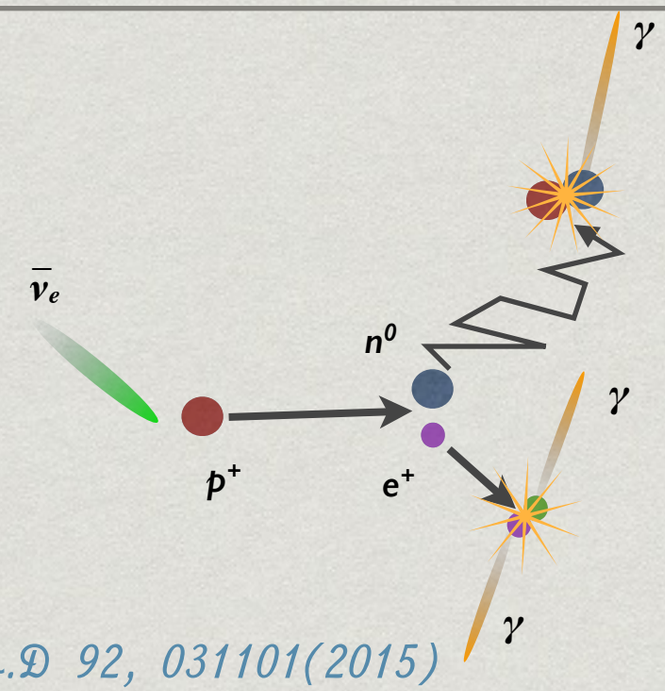
~5% energy res.

~**10cm** position res.



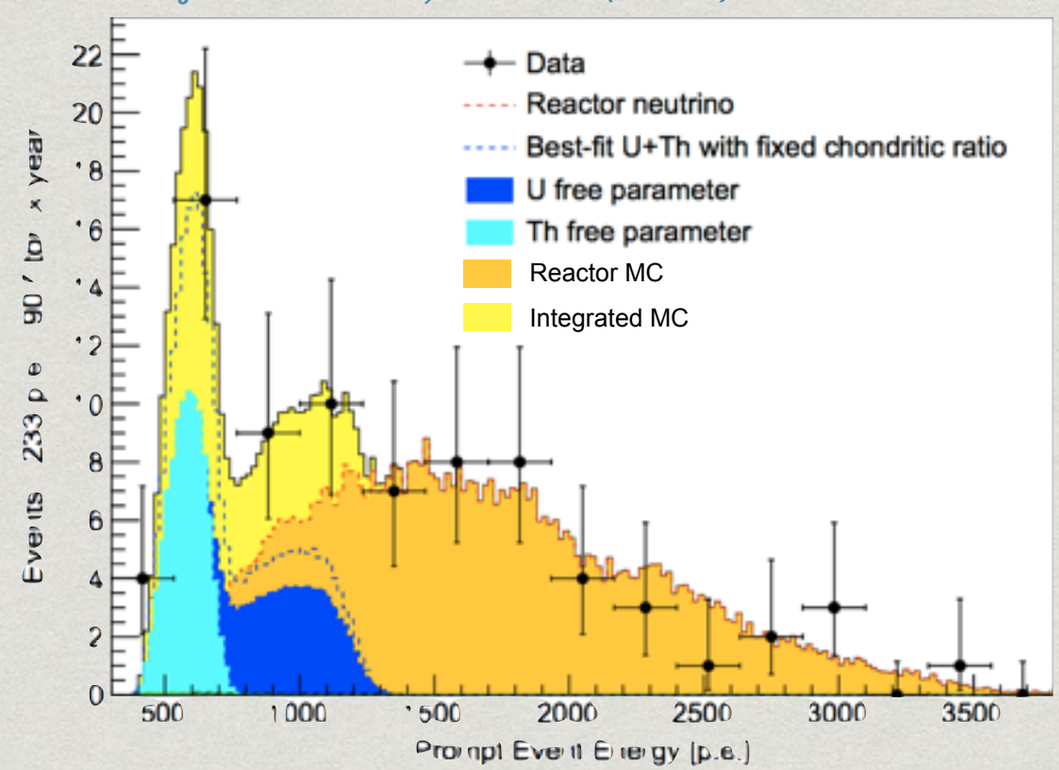
1100 tons of PC (+PPO in IV & DMP in buffer)
300 tons IV (spherical), ~100 tons FV
ν_e-electron elastic scattering

Geo-ν latest result



- **I**nverse**B**eta**D**ecay channel
  (1.8 MeV threshold: no ^{40}K or ^{235}U; only **^{238}U/^{232}Th**)
- **5.9σ** observation
- 77 golden $\bar{\nu}$ candidates:
  $23.7^{+6.5}_{-5.7}$ (stat) $^{+0.9}_{-0.6}$(sys) geo-ν
- Reactor loads known to ~4%.
  No Italian reactors
- All other **backgrounds** (mainly (α,n) in buffer, accidental coincidences and ^{8}Li-^{8}He) **very low**:
  $0.78^{+0.13}_{-0.10}$ events.
- Statistics-limited ~27% precision, can just improve!

Phys.Rev.D 92, 031101(2015)

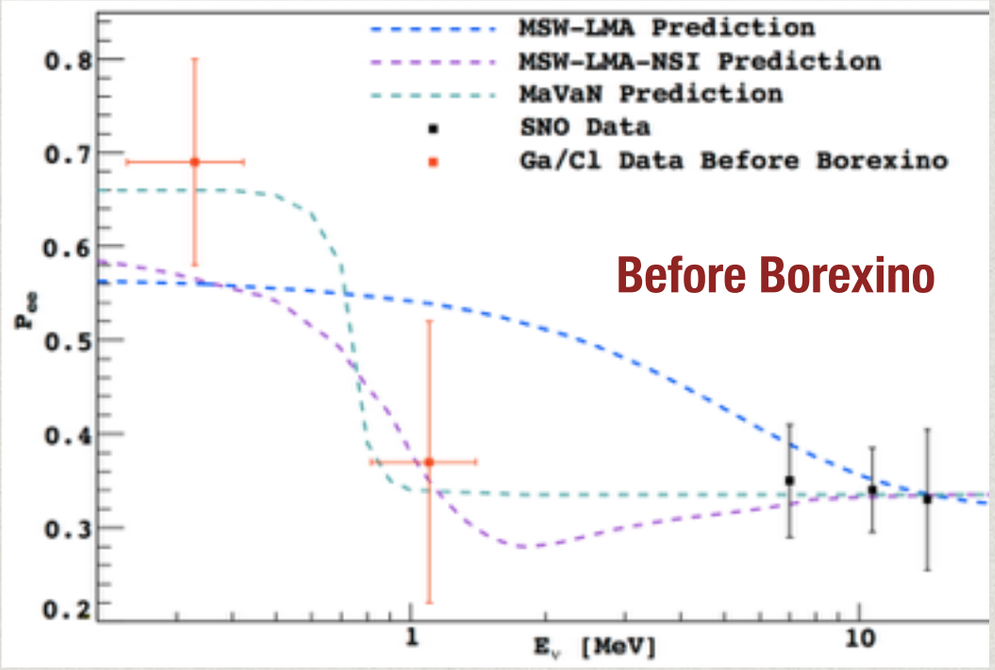


S_{mantle}=0 rejected at 98% c.l.

Cosmochemical Bulk Silicate Earth model disfavored

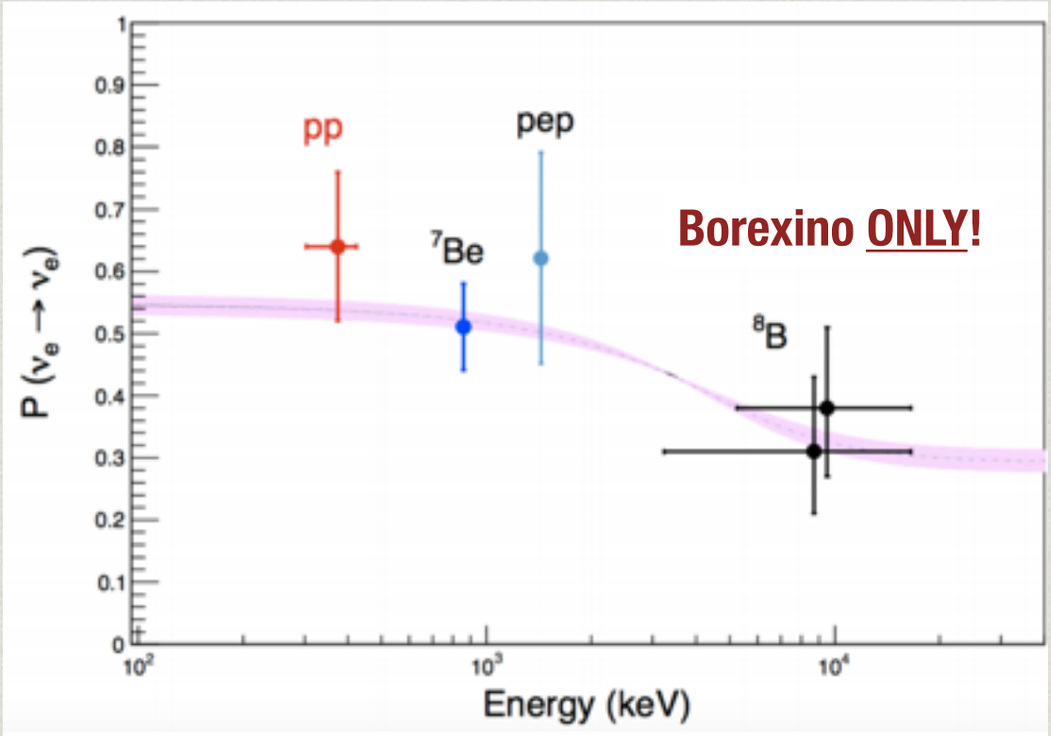
Solar ν observation latest

- Borexino's solar observation program has directly measured **all but 2*** of the solar ν spectrum components:
  - **^{7}Be** *vs* (5% precision): **1st direct detection**
  - **^{8}B** *vs* (20% precision): lowest threshold (3 MeV)
  - ***pep*** *vs* (20% precision): **1st direct detection**
  - ***pp*** *vs* (10% precision): **1st direct detection**



- In addition, it set the best **CNO** *ν* flux limit (**<7.7·10^8 cm^{-2}s^{-1}**,95% c.l.)

- Also: **seasonal modulation** of solar *ν* flux, (lack of) **day-night asymmetry** in the vacuum-dominated region, **MSW-LMA** verification through P_{ee} (& best limit on **e$^-$ decay** by 100x!)



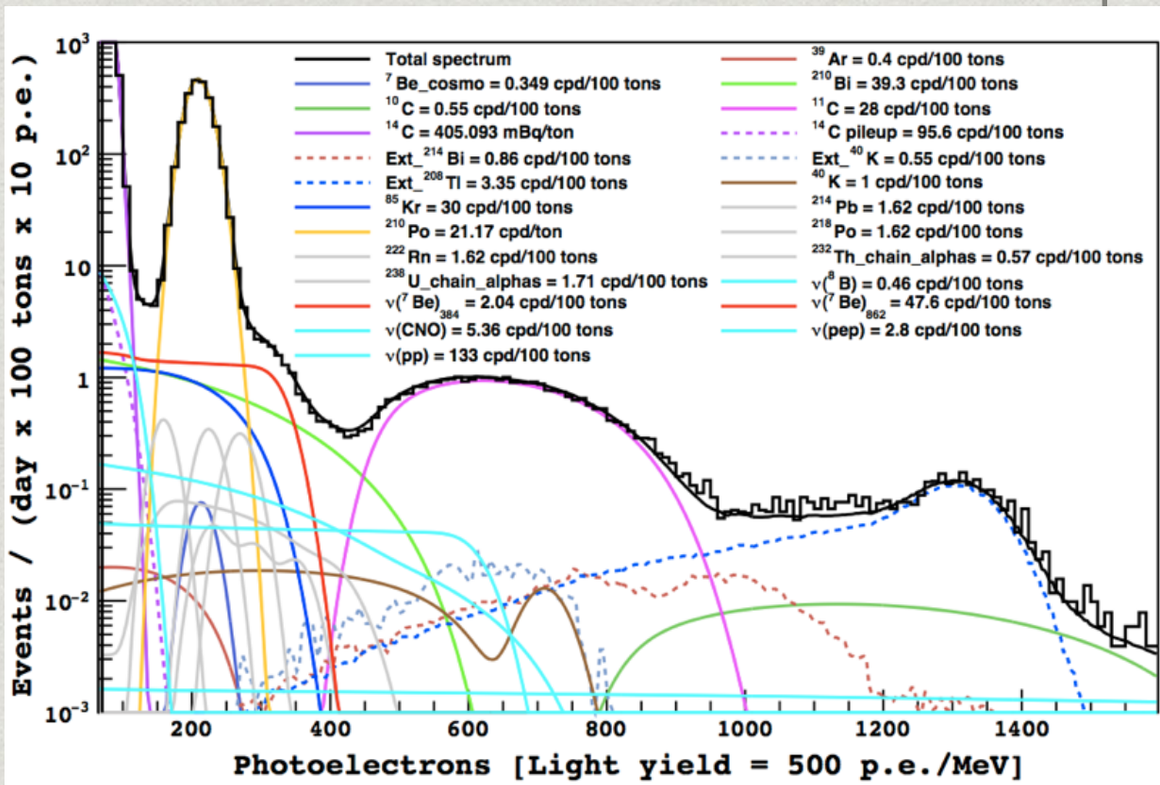
**hep is too feeble, CNO is work in progress*

Toward **wideband** solar ν spectroscopy

- Incorporate **new statistics** to increase **precision**
- **Phase II** data (2012-today) **cleanest** and most stable = lower background contributions
- First direct **CNO** detection? At least improve best limit: **solar metallicity problem**
- **Full spectrum** analysis & fit:
  - New **neural network** α/ß PSD
  - **T**hree-**F**old **C**oincidence revamp (^{11}C)
  - New fitting tools

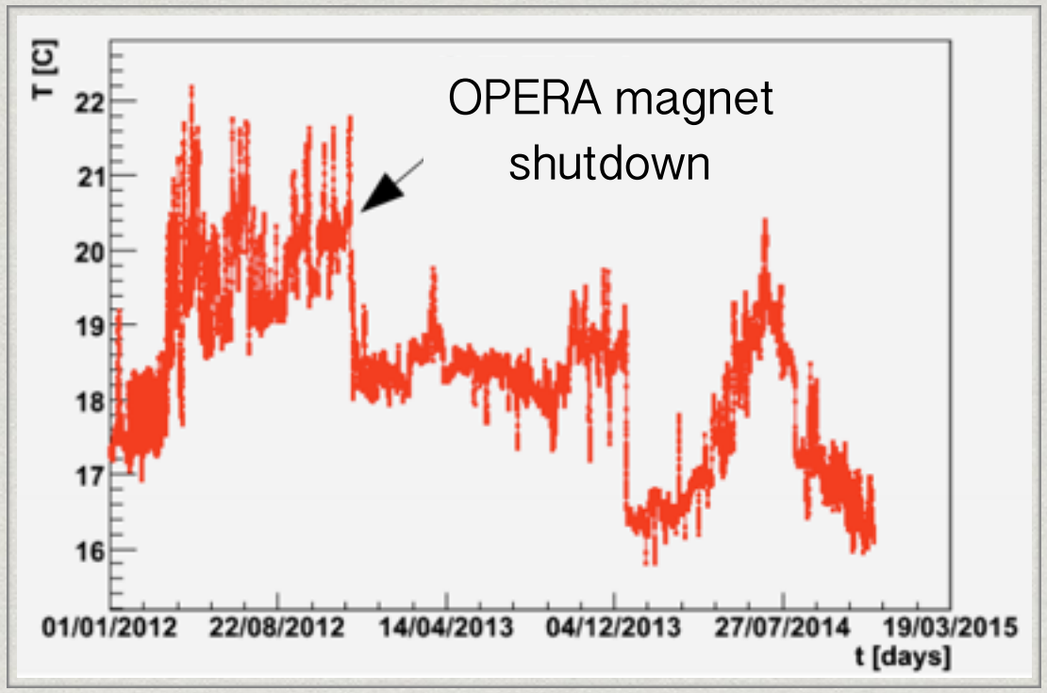
Best background reductions

	Ambient	**Phase I** (original design reduction requirement)	**Phase II**
^{14}C	~10^{-12} g/g	~$2\cdot10^{-18}$ g/g (1x)	same
^{238}U	~10^{-5} or 10^{-6} g/g	~10^{-17} g/g (0.1-0.001x)	<$9\cdot10^{-20}$g/g
^{232}Th	~10^{-5} or 10^{-6} g/g	~10^{-17} g/g (0.1-0.001x)	<$7\cdot10^{-19}$g/g
^{210}Po	~?	[70,1] cpd/100t ([70,1]x)	<1 cpd/100t
^{85}Kr	~1 Bq/m^3	30±5 cpd/100t (30x)	<7 cpd/100t



Thermal Insulation System (*TIS*)

- ^{210}**Bi** levels need to be known with extreme **precision** (**<10%** at the current other backgrounds levels) and **stability** to have a shot at **CNO**
- Historically:
  Large, uncontrolled ambient **temperature fluctuations** in the experimental Hall.
- Some mechanism (possibly **convection**?) cause ^{210}Po (^{210}Bi daughter) background shifts and out-of-equilibrium reintroduction in the FV
- **Large effort** (**$$** & **manpower**) to install **20cm-thick mineral wool** (λ_D~0.03W/(m·K)) + **reflective coating** around the **WHOLE** detector



Project start: early 2015

↓

Installation start: May 2015

↓

Cylindrical walls finished: July 2015

↓

All tank (some I-beams & pipes): Oct-Nov 2015

↓

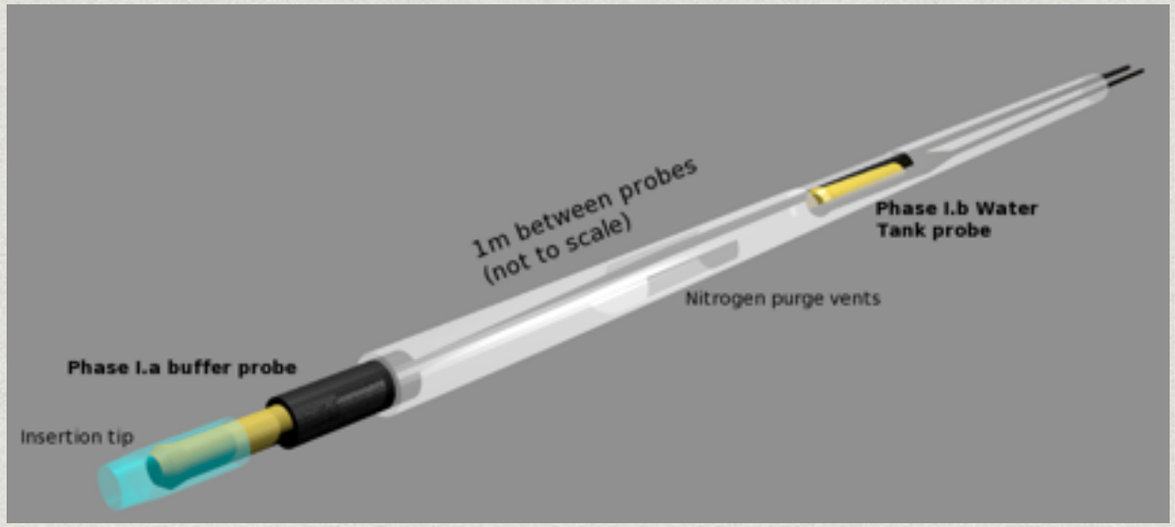
TIS complete: Dec 2015

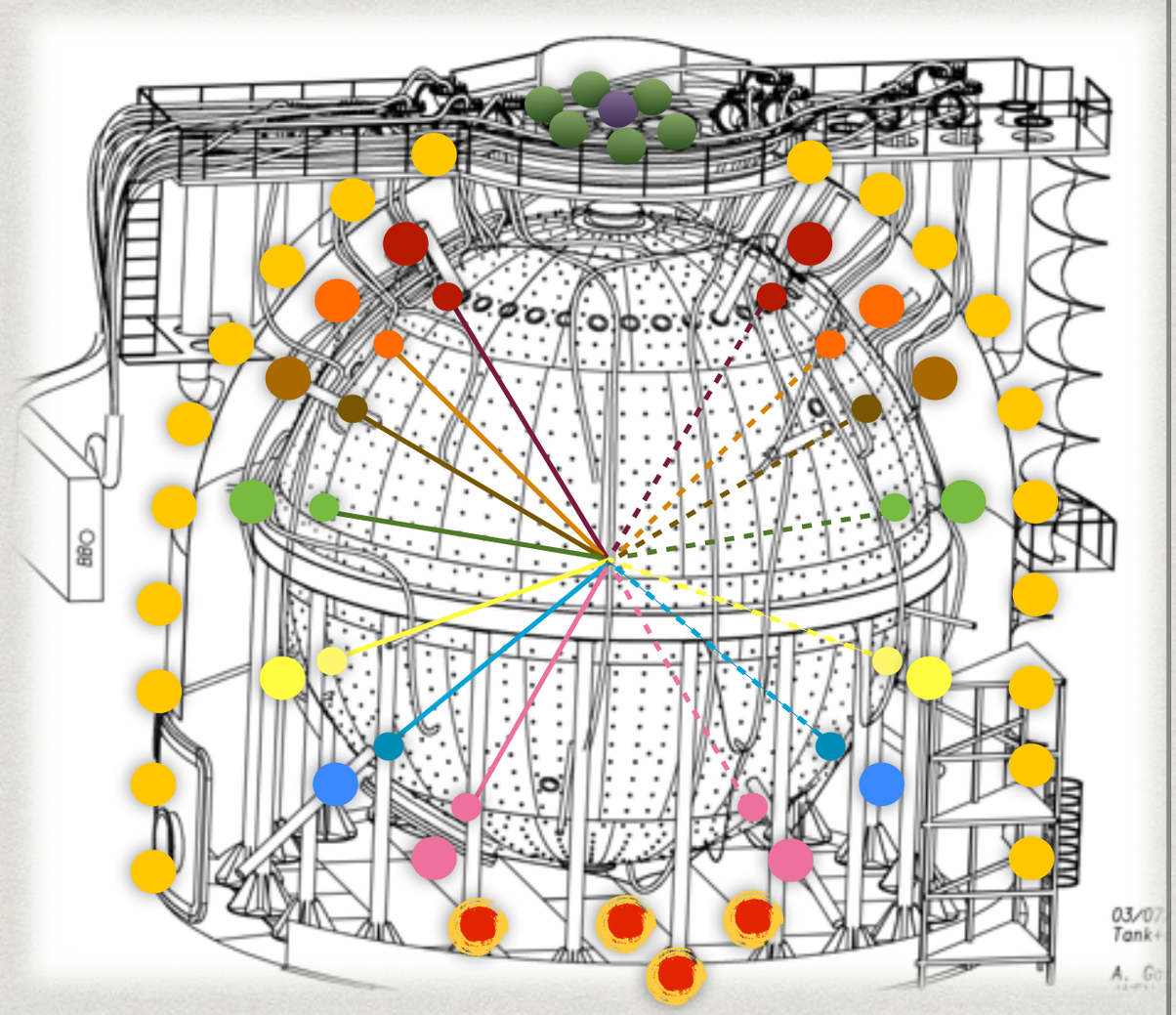
↓

Active Gradient Stabilization: Feb 2016

Latitudinal **T**emperature **P**robe **S**ystem (*LTPS*)

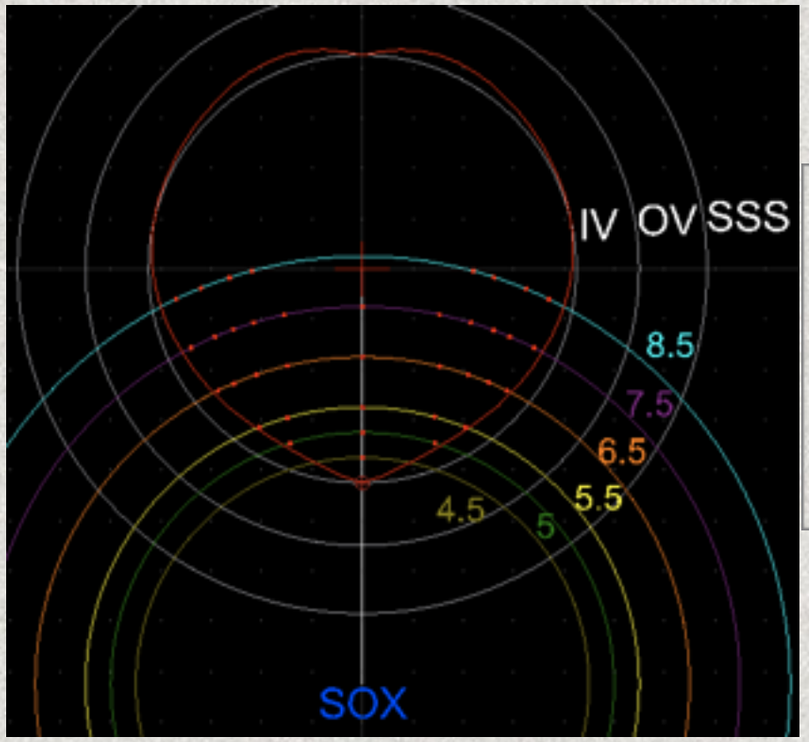
- **65+** new internal and external **monitoring probes**, with dedicated centralized electronics
- Basic heritage system too coarse (and degraded) for latest extended objectives
- Custom-calibrated V**ernier Extra-Long 30m** TPL-BTA (AD590JH) probe with **~0.1ºC absolute** accuracy and **~$\mathcal{O}$(0.01)ºC resolution** stability
- **FLUENT fluidodynamical simulations** in progress in collaboration with Milano Polytechnic University to understand past & present currents





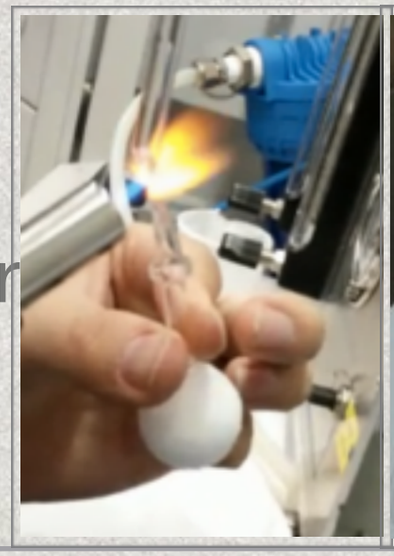
Solar-to-sterile calibrations

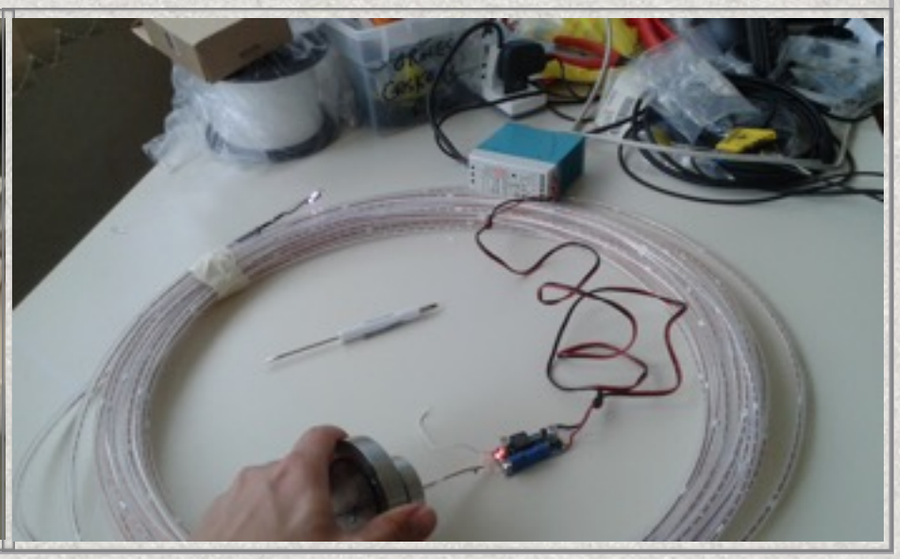
- **New calibration campaign** needed after the 2009-10 one:
  - Investigate detector **response changes.**
  - New data for **MC tweak.**
  - SOX **inhomogeneous signal** vs solar
  - Opportunity for studies that were not feasible during the first campaign
- Upgraded **IR source location** system
- "High"-activity (~70 Bq) **unquenched** ^{222}**Rn** sources
- "High"-activity **γ** and **e**$^{+}$ sources
- New **AmBe** source with Ni foil for high-energy γs + **AmC** low background neutron source



HW ready, getting good data until transition

(late this year, early 2017)



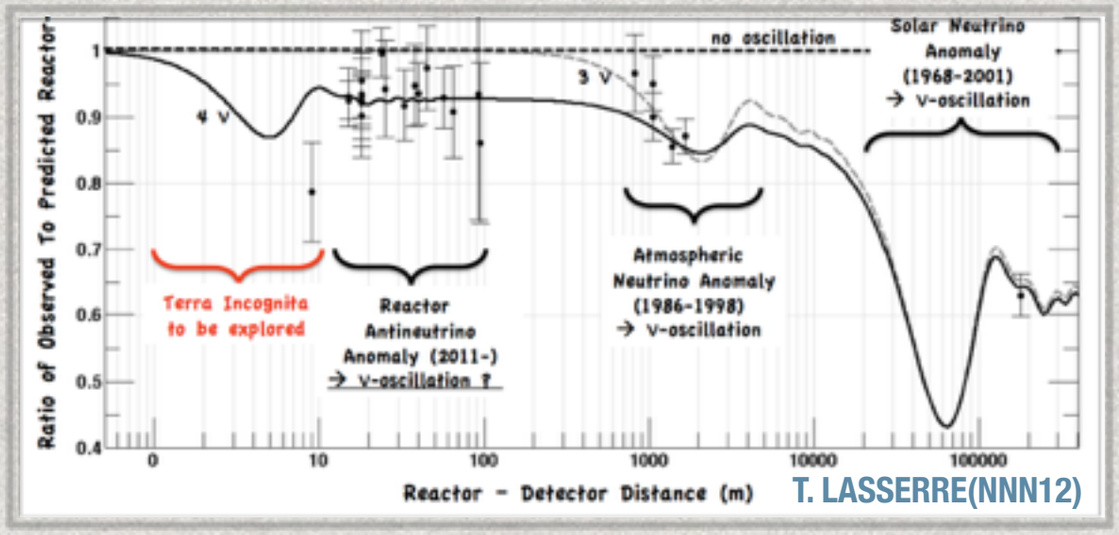


The future: light sterile neutrino short-baseline search

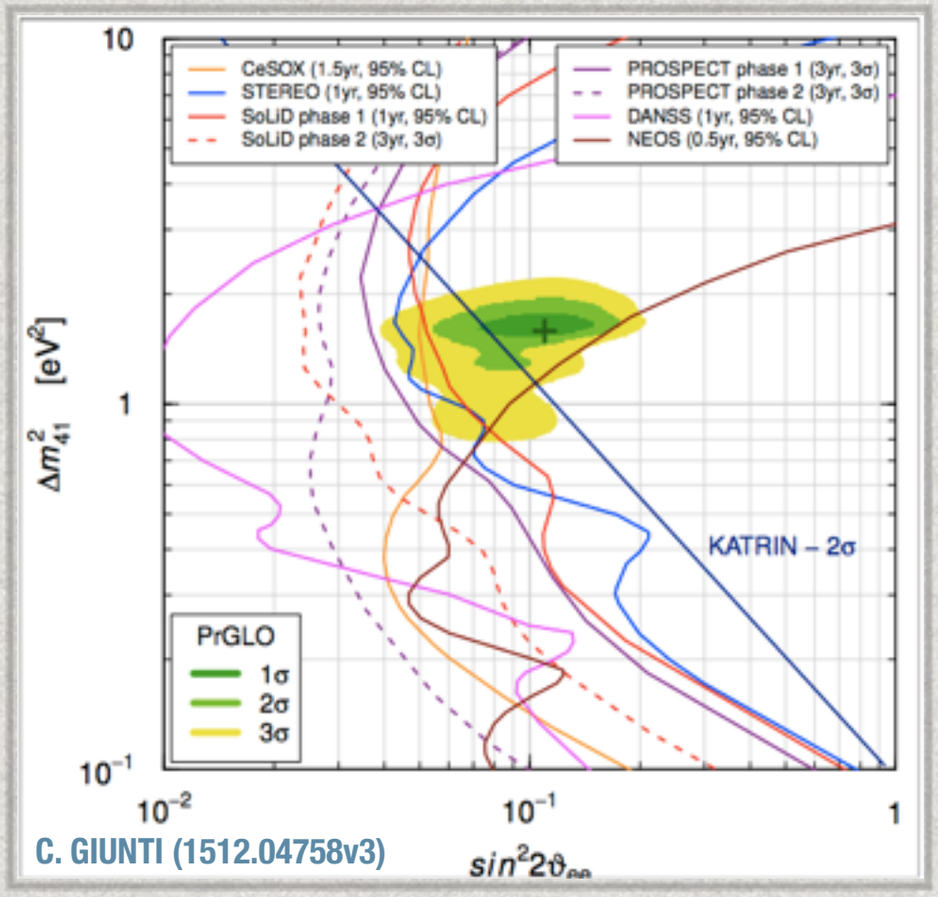
Can there be a fourth (or fifth...) neutrino that doesn't couple with the W or Z^0 bosons:

STERILE?

- Borexino is sensitive to most promising mass scale: **~<1eV²**, (see-saw type I with light sterile neutrinos, 3+1 or 3+2 models; many other models proposed)
- Visible oscillation in short-baseline experiment (other short-distance oscillation effects on P_{ee}?)
- Need a powerful ~**1-10MeV** source separated from the detector by **1-10m**.



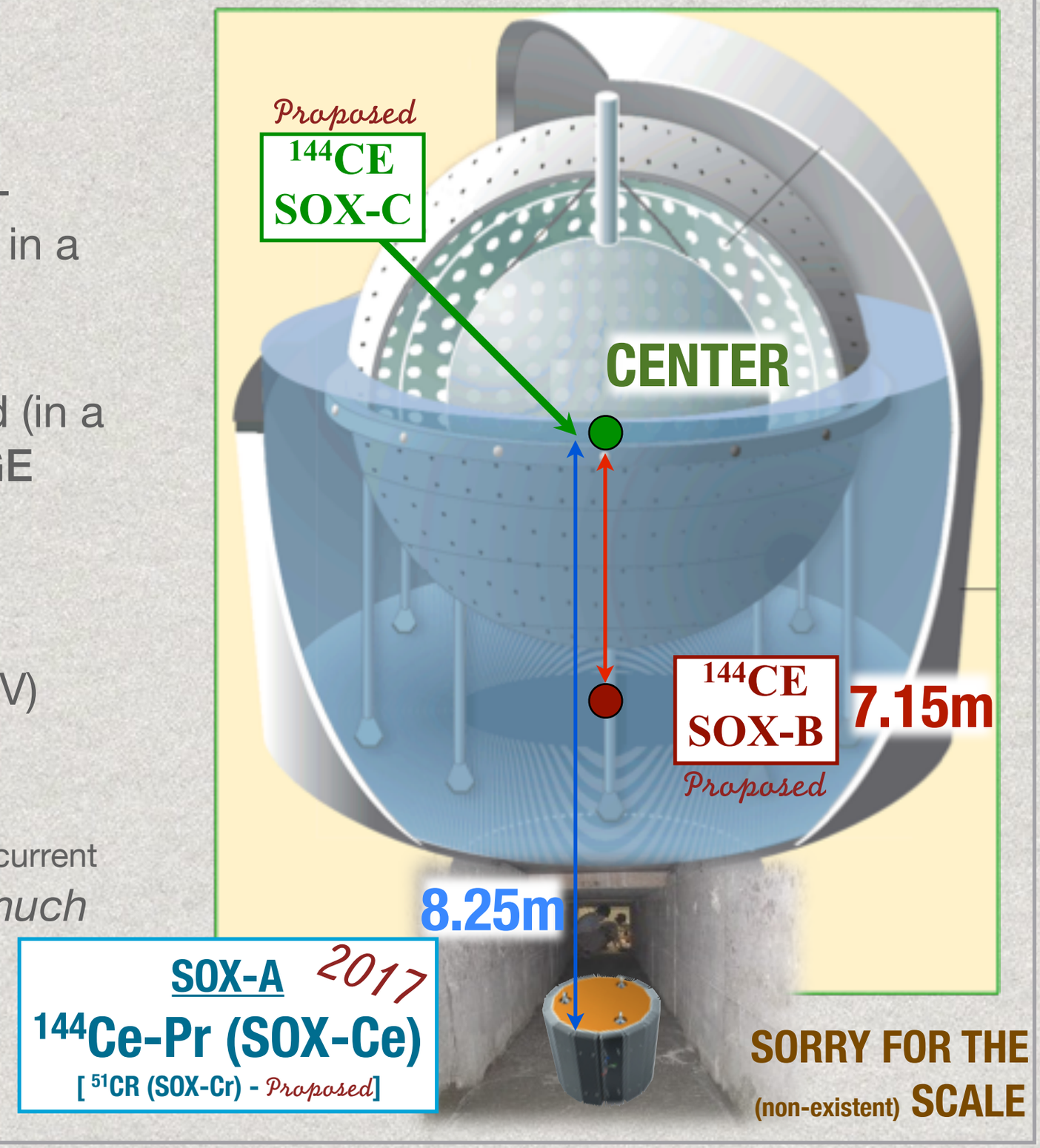
T. LASSERRE(NNN12)



C. GIUNTI (1512.04758v3)

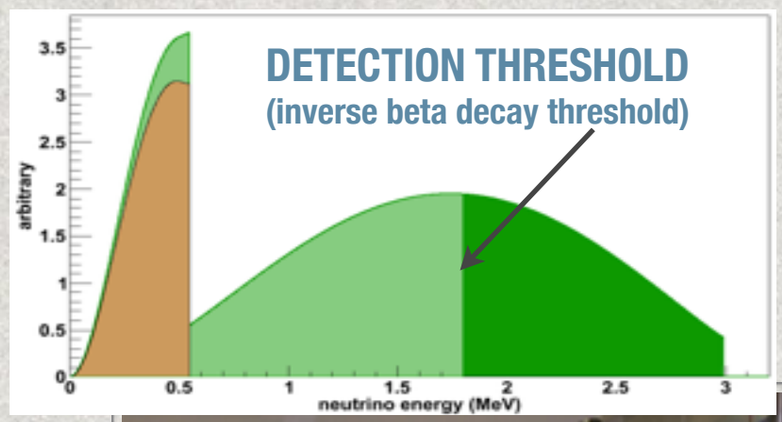
Short-distance Oscillations with BoreXino

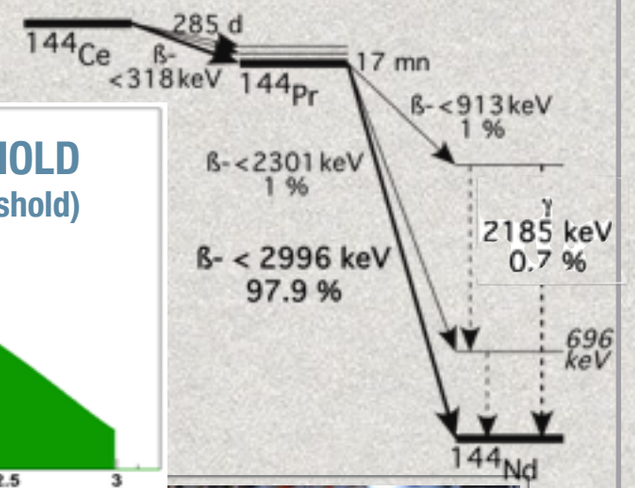
- Borexino aims to test **low L/E** (anti)neutrino anomalies using well-known external or internal sources in a well-understood detector
- Concept successfully implemented (in a smaller scale) in **GALLEX** and **SAGE**
- Also:
  - ***Weinberg angle*** precision measurement at low energy (~1MeV)
  - Tightening limits on ***neutrino magnetic moment***
  - Check of g_A and g_V (vector and axial current coefficients for the Fermi CC interaction) at *much lower energy* than current limits

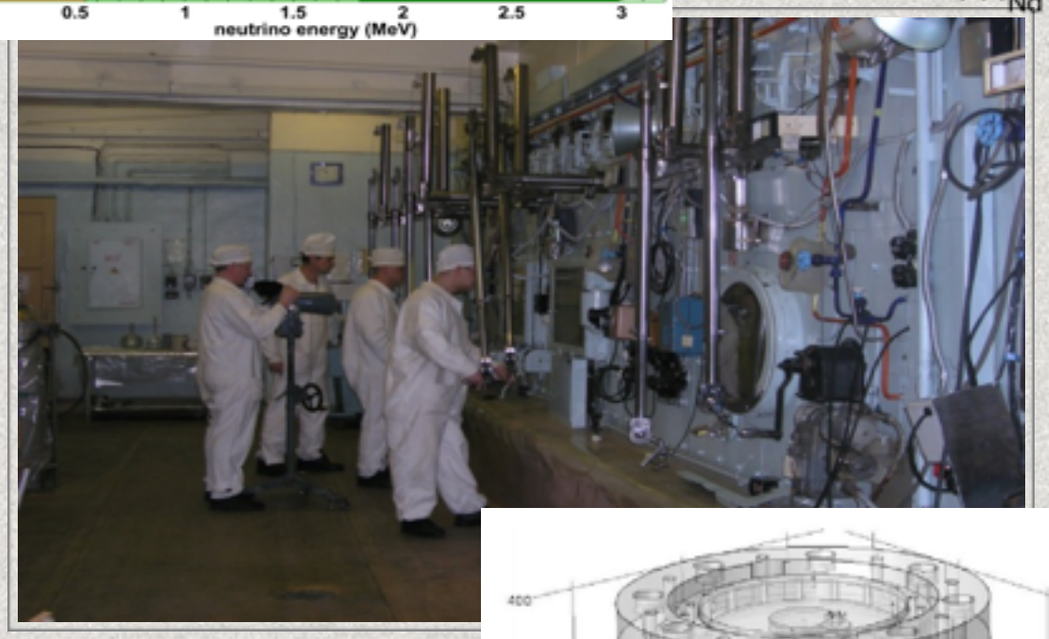


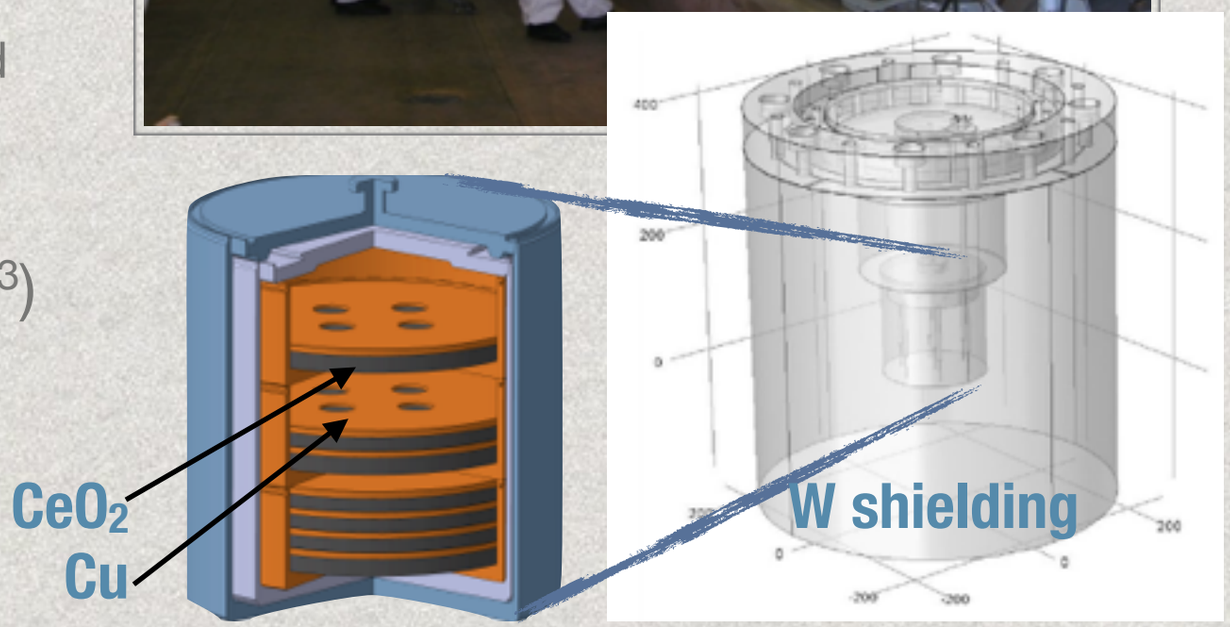
$\bar{\nu}_e$ source description

- **150 kCi** (new batch of **higher-activity spent fuel** recently made available) of ^{144}Ce-^{144}Pr [$\tau_{1/2}(\beta^-)$~296d] for a ~1.5 year campaign
- **Thermal limits** stable (~40-50ºC shield exterior) in conjunction with calorimeter operation
- Production in **Mayak** (Russia), transport by rail to **St. Petersburg** - then ship to **LeHavre**, and road (through Cadarache and Frascati) to **LNGS** (1Q 2017).
- **19cm**-thick **W** alloy shield (>18.0 g/cm^3) + hermetic plug



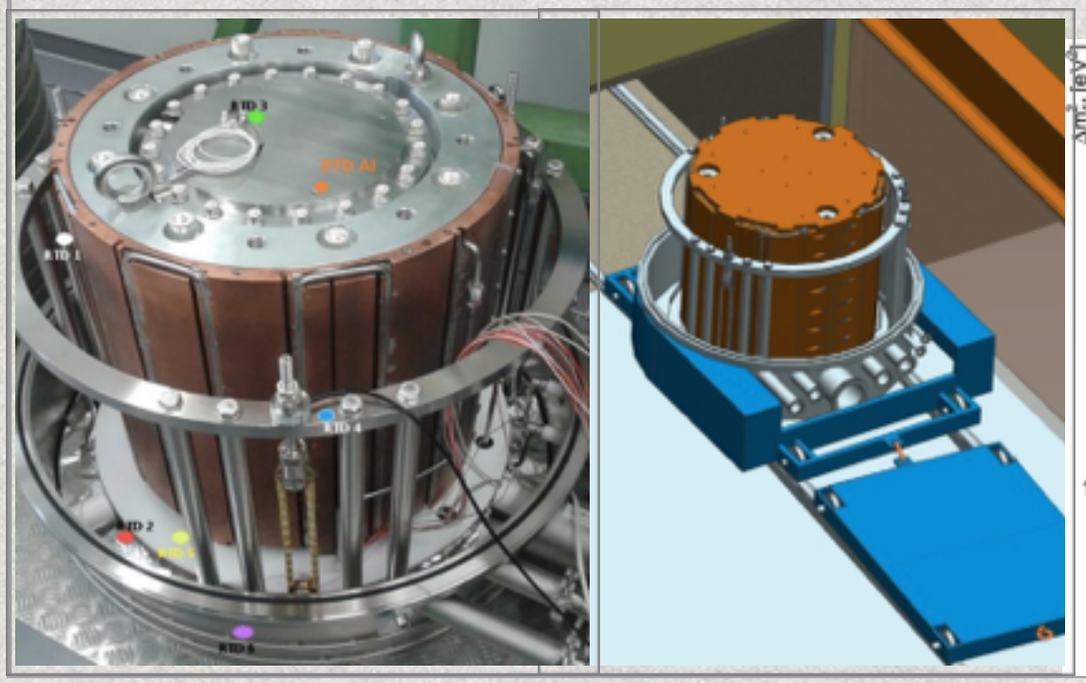


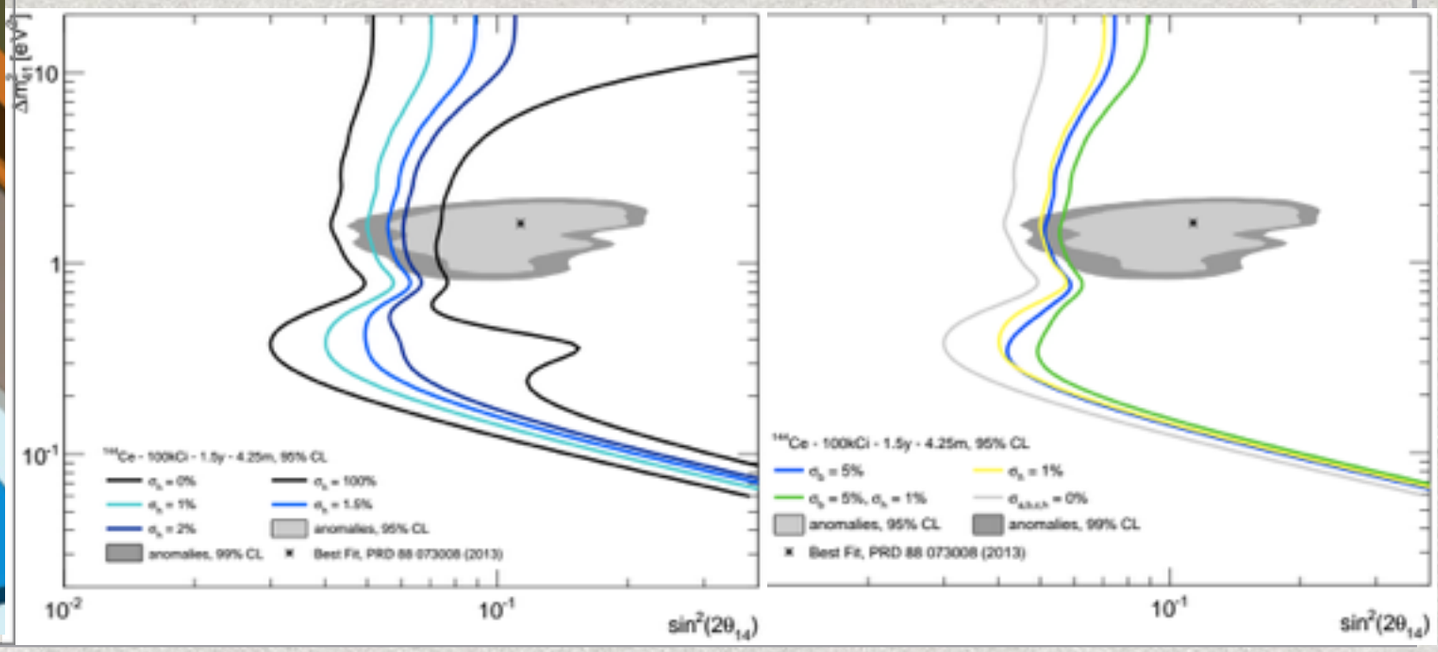




Calorimetry and sensitivity

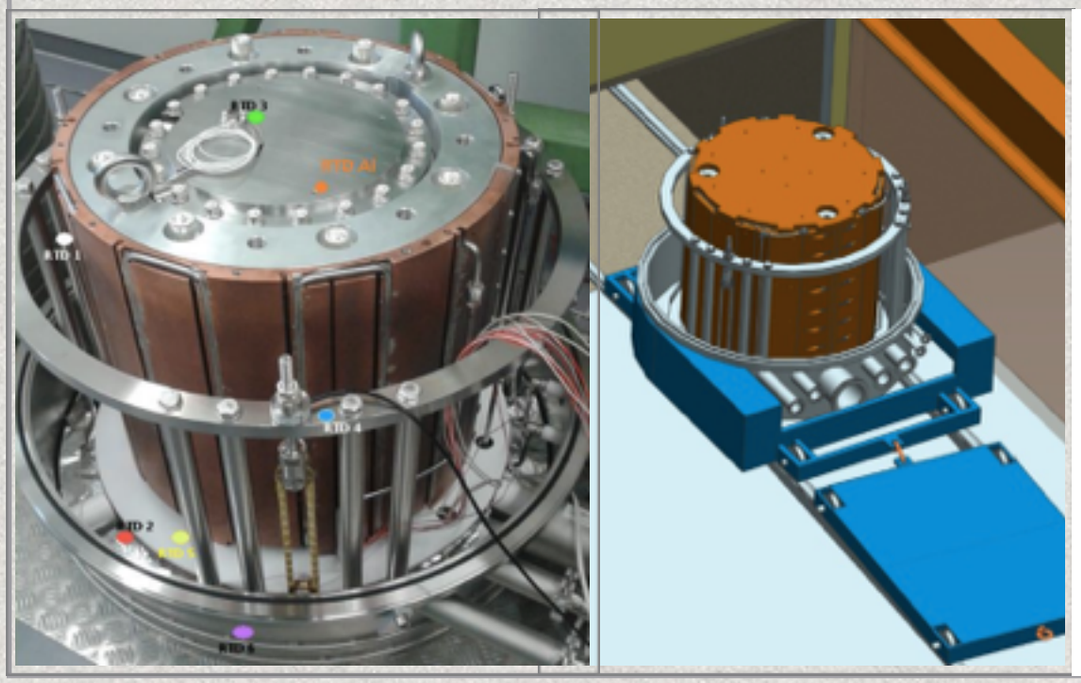
- **~<1%** calorimetry measurement needed for **independent activity** determination
- **Two** independent **water-loop calorimeters** (CEA Saclay & Genova/TUM): one of them doubles up as a **deployable platform** to operational position (developed for **continuous calorimetry** of the SOX-^{51}Cr source)
- **Inner vessel shape** (and with it, Fiducial Volume) determination is paramount, although worst-case sensitivities still cover all 95% c.l. anomaly - **calibrations** will hugely help on South Pole
- Cerium **spectral shape** and **background** determinations (~contaminants) very advanced

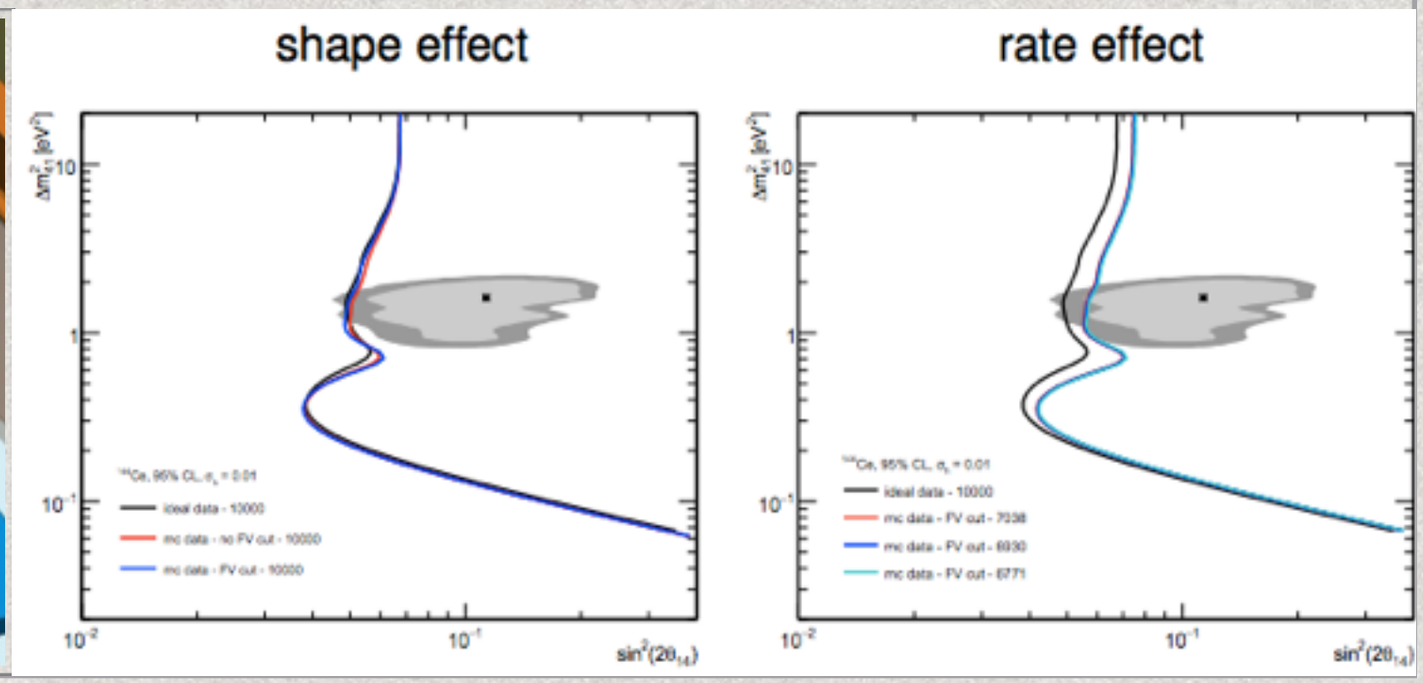




Calorimetry and sensitivity

- **~<1%** calorimetry measurement needed for **independent activity** determination
- **Two** independent **water-loop calorimeters** (CEA Saclay & Genova/TUM): one of them doubles up as a **deployable platform** to operational position (developed for **continuous calorimetry** of the SOX-^{51}Cr source)
- **Inner vessel shape** (and with it, Fiducial Volume) determination is paramount, although worst-case sensitivities still cover all 95% c.l. anomaly - **calibrations** will hugely help on South Pole
- Cerium **spectral shape** and **background** determinations (~contaminants) very advanced





[20,5]% Phase I solar ν detections
(*pp*,*pep*,^{8}B,^{7}Be,CNO limit, D/N asymm., seasonal mod.)

5.9σ Phase I+II geoν detection (27%)

Rare processes
(e^- decay, Pauli violation, solar axions, heavy ν_s)

Calibrations 2009-10

Purifications 2011-12
(much lowered Phase II backgrounds)

+

Updated calibrations 2017

Borexino **T**hermal **M**anagmt **S**ystem (TIS & LTPS)=
= background control

[10,3]% Phase I+II wideband solar ν spectroscopy results
(*pp*,*pep*,^{8}B,^{7}Be,new CNO studies., geoν…)

SOX-Ce $\overline{\nu}_e$ source program
(*anomalous oscillations, steriles, g_A & g_V, Weinberg angle…*)

…and much more!

The End

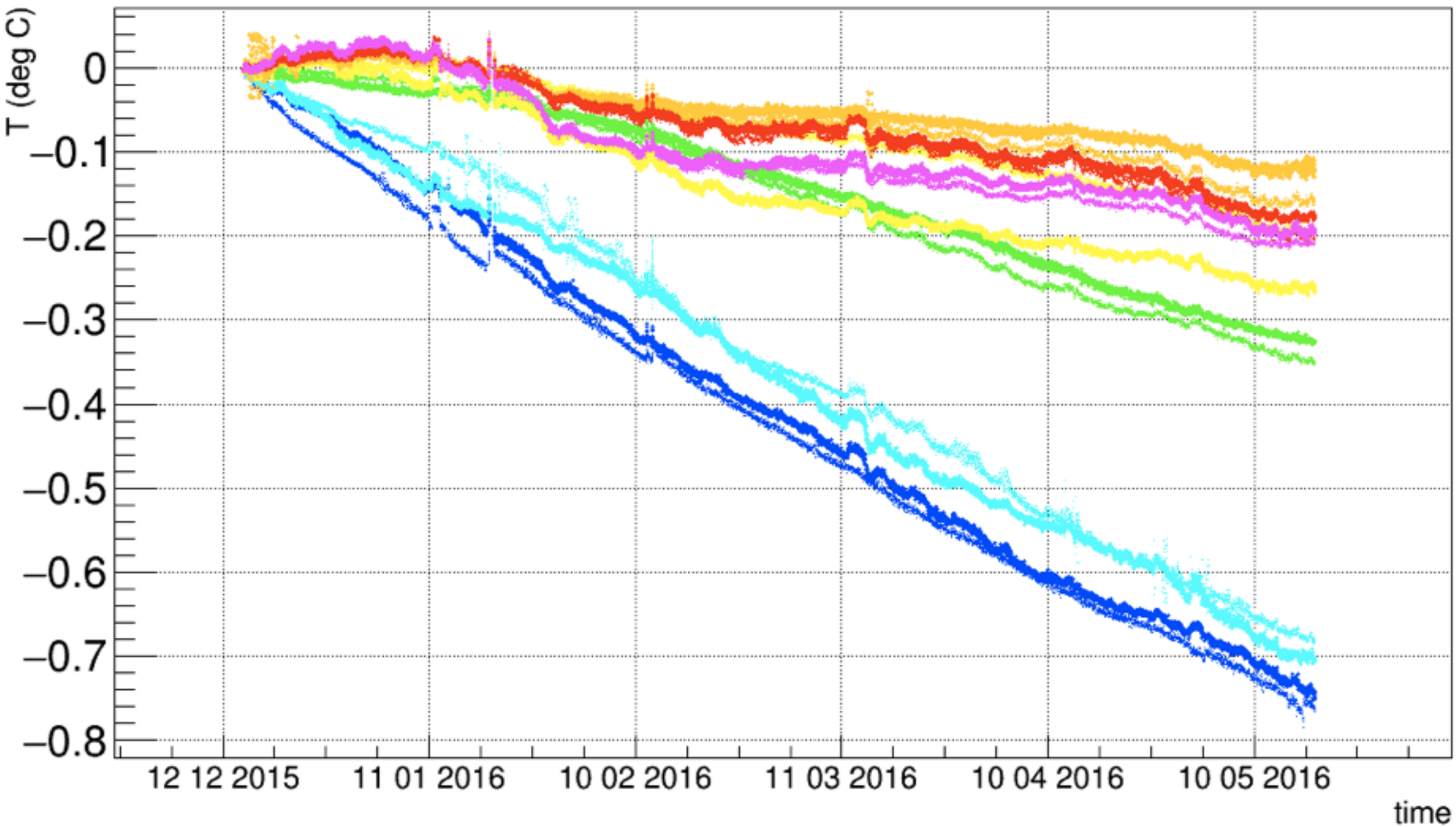
This work is possible thanks to all the Borexino Collaboration

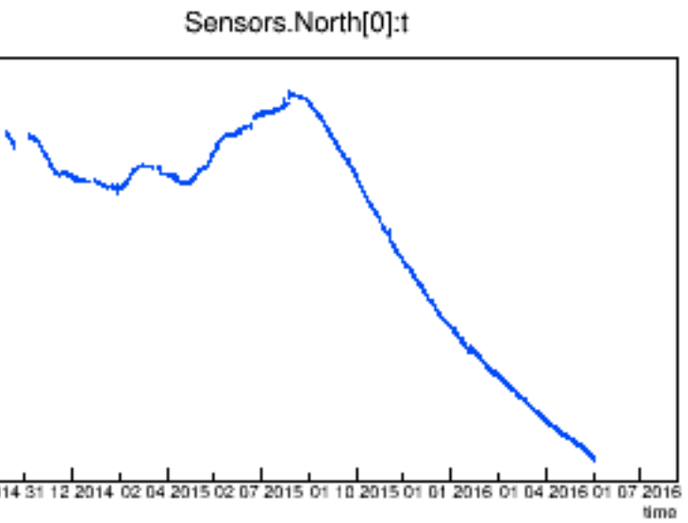
Astroparticle and Cosmology Laboratory - Paris, France
INFN Laboratori Nazionali del Gran Sasso - Assergi, Italy
INFN e Dipartimento di Fisica dell'Università degli Studi - Genova, Italy
INFN e Dipartimento di Fisica dell'Università degli Studi - Milano, Italy
INFN e Dipartimento di Chimica dell'Università degli Studi - Perugia, Italy
Institute for Nuclear Research - Gatchina, Russia
Institute of Physics, Jagellonian University - Cracow, Poland
Joint Institute for Nuclear Research - Dubna, Russia
Kurchatov Institute - Moscow, Russia
St. Petersburg Nuclear Physics Institute, Gatchina, Russia
Max Planck Istitute fuer Kernphysik - Heidelberg, Germany
Institut für Experimentalphysik - Hamburg, Germany
Princeton University - Princeton, NJ, USA
Technische Universität - München, Germany
University of Massachusetts - Amherst, MA, USA
Lomonosov Moscow State University - Moscow, Russia
Skobeltsyn Institute of Nuclear Physics - Moscow, Russia
University of California, Los Angeles (UCLA) - Los Angeles, CA, USA
Virginia Tech - Blacksburg, VA, USA

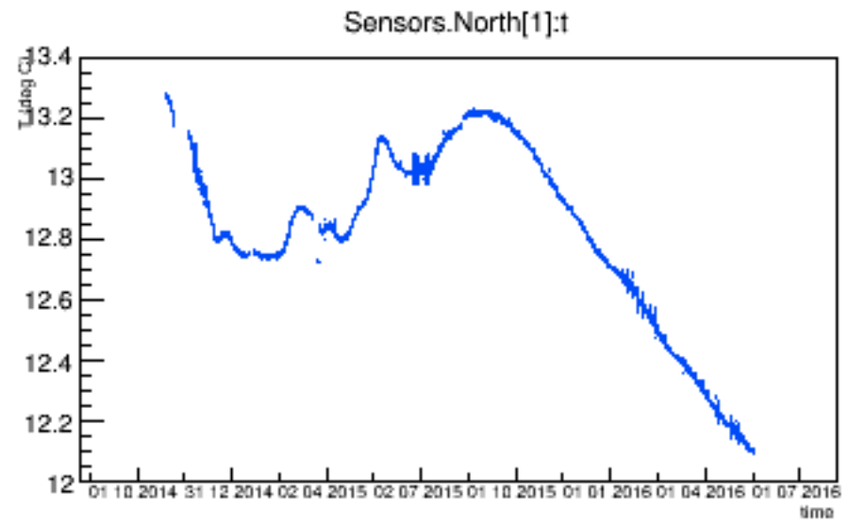
Thank you for your attention!

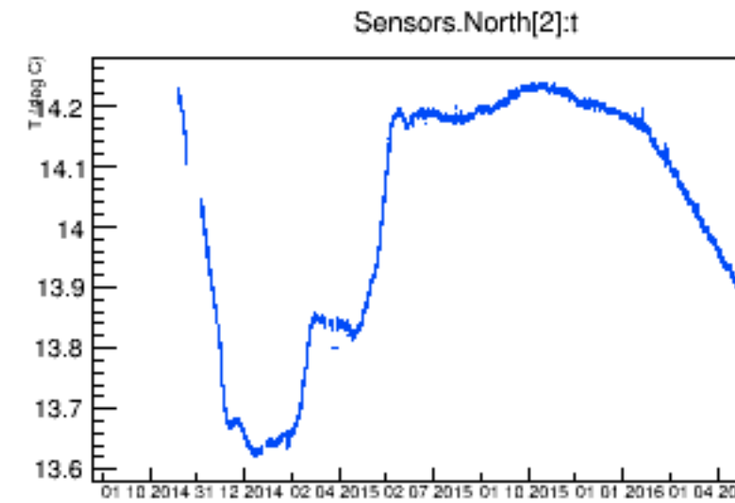
EVEN MORE BOREXINO!
(BACKUP)

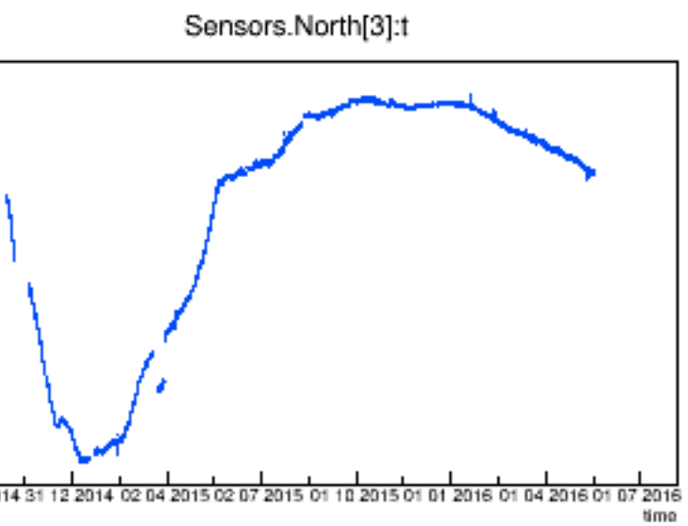
Blue=-67 purple=+67 thicker=North slimmer=South

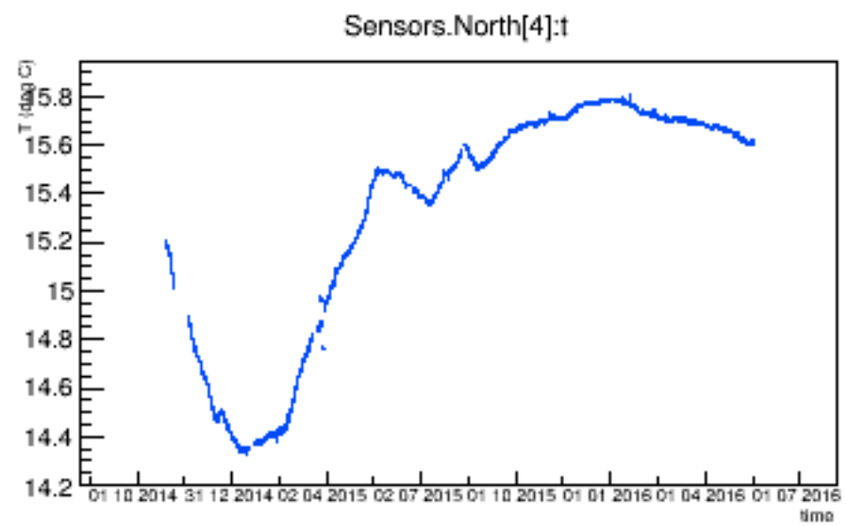


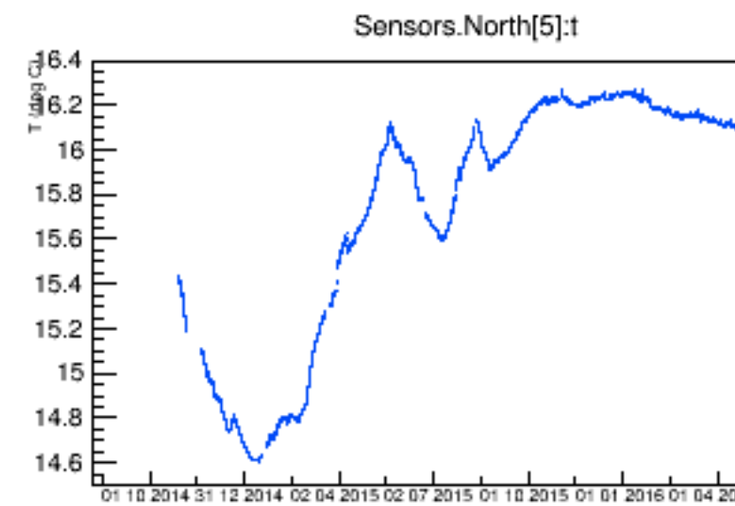

Sensors.North[0]:t
01 10 2014 31 12 2014 02 04 2015 02 07 2015 01 10 2015 01 01 2016 01 04 2016 01 07 2016
time

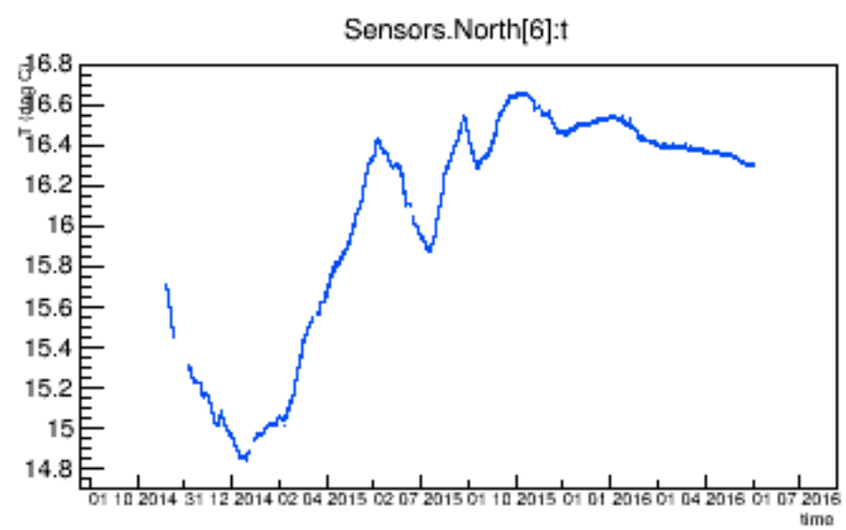

Sensors.North[1]:t
T (deg C)
13.4
13.2
13
12.8
12.6
12.4
12.2
12
01 10 2014 31 12 2014 02 04 2015 02 07 2015 01 10 2015 01 01 2016 01 04 2016 01 07 2016
time

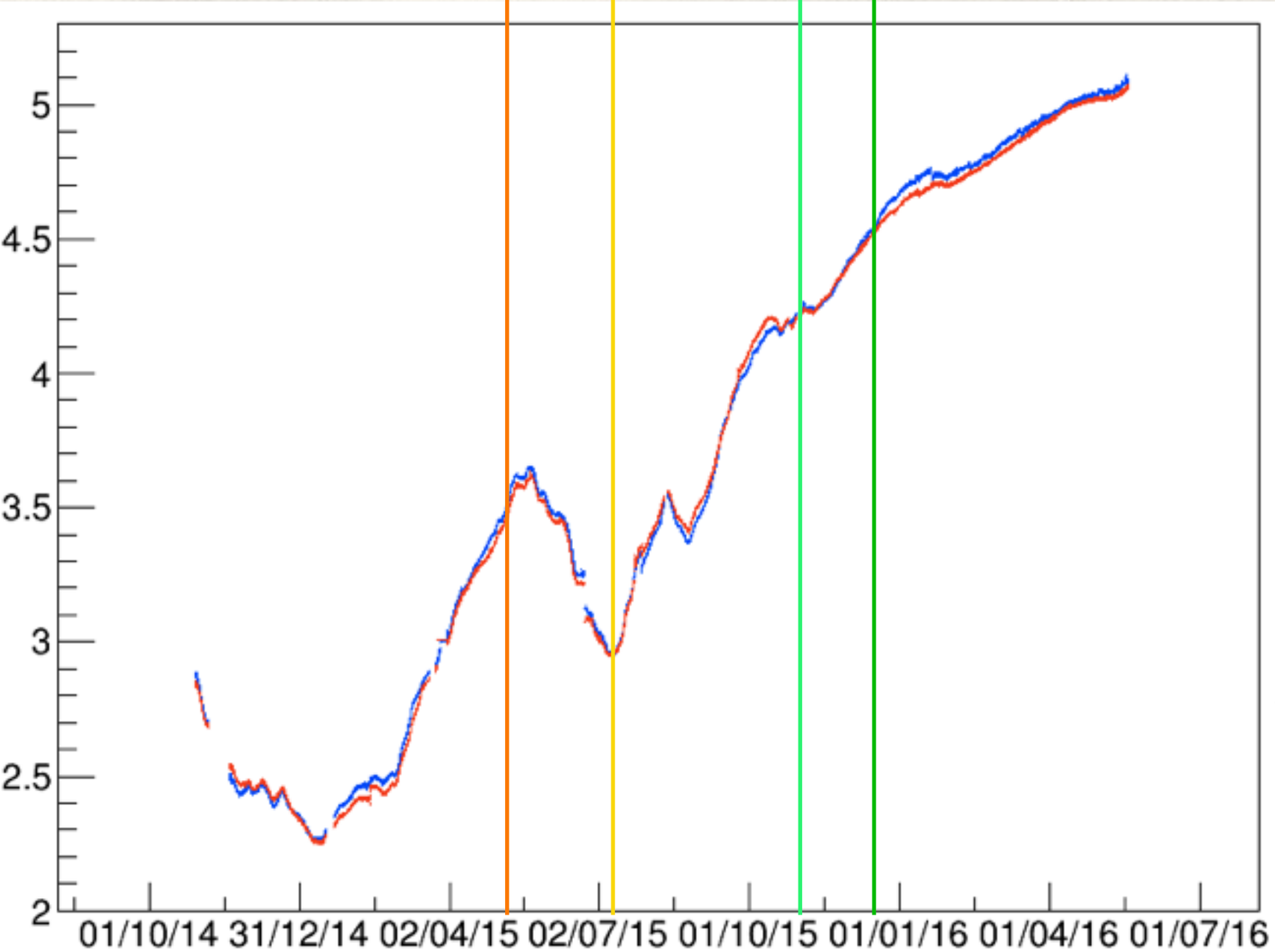

Sensors.North[2]:t
T (deg C)
14.2
14.1
14
13.9
13.8
13.7
13.6
01 10 2014 31 12 2014 02 04 2015 02 07 2015 01 10 2015 01 01 2016 01 04


Sensors.North[3]:t
01 10 2014 31 12 2014 02 04 2015 02 07 2015 01 10 2015 01 01 2016 01 04 2016 01 07 2016
time


Sensors.North[4]:t
T (deg C)
15.8
15.6
15.4
15.2
15
14.8
14.6
14.4
14.2
01 10 2014 31 12 2014 02 04 2015 02 07 2015 01 10 2015 01 01 2016 01 04 2016 01 07 2016
time


Sensors.North[5]:t
T (deg C)
16.4
16.2
16
15.8
15.6
15.4
15.2
15
14.8
14.6
01 10 2014 31 12 2014 02 04 2015 02 07 2015 01 10 2015 01 01 2016 01 04


Sensors.North[6]:t
T (deg C)
16.8
16.6
16.4
16.2
16
15.8
15.6
15.4
15.2
15
14.8
01 10 2014 31 12 2014 02 04 2015 02 07 2015 01 10 2015 01 01 2016 01 04 2016 01 07 2016
time



Insulation start

Cylindrical walls

All tank surfaces

TIS finished