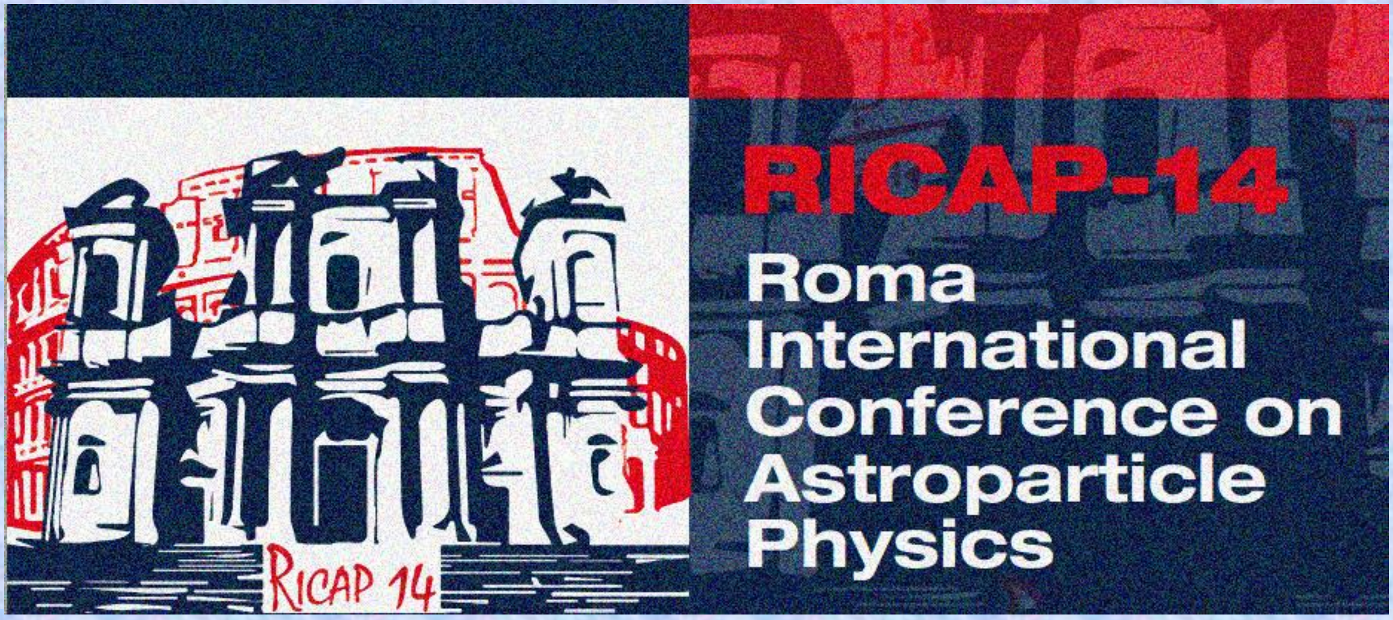


Short Distance Neutrino Oscillations with Borexino

A. Caminata – INFN GENOVA

for the SOX collaboration

Experimental hints

$\nu_e, \bar{\nu}_e$ disappearance

- **Reactor anomaly (~2.5 σ)**
  Re-analysis of flux from reactor short baseline (L~10 m-100 m) shows a small deficit R=0.943±0.023
  *G.Mention et al, Phys.Rev.D83, 073006 (2011), A.Mueller et al.*Phys.Rev.C 83, 054615 (2011);
- **Gallex/SAGE anomaly (~3 σ)**
  Deficit of neutrinos coming from ^{51}Cr and ^{37}Ar sources
  $R = 0.76^{+0.09}_{-0.08}$
  C. Giunti and M. Laveder, Phys.Rev. C83, 065504 (2011), arXiv:1006.3244 [hep-ph].

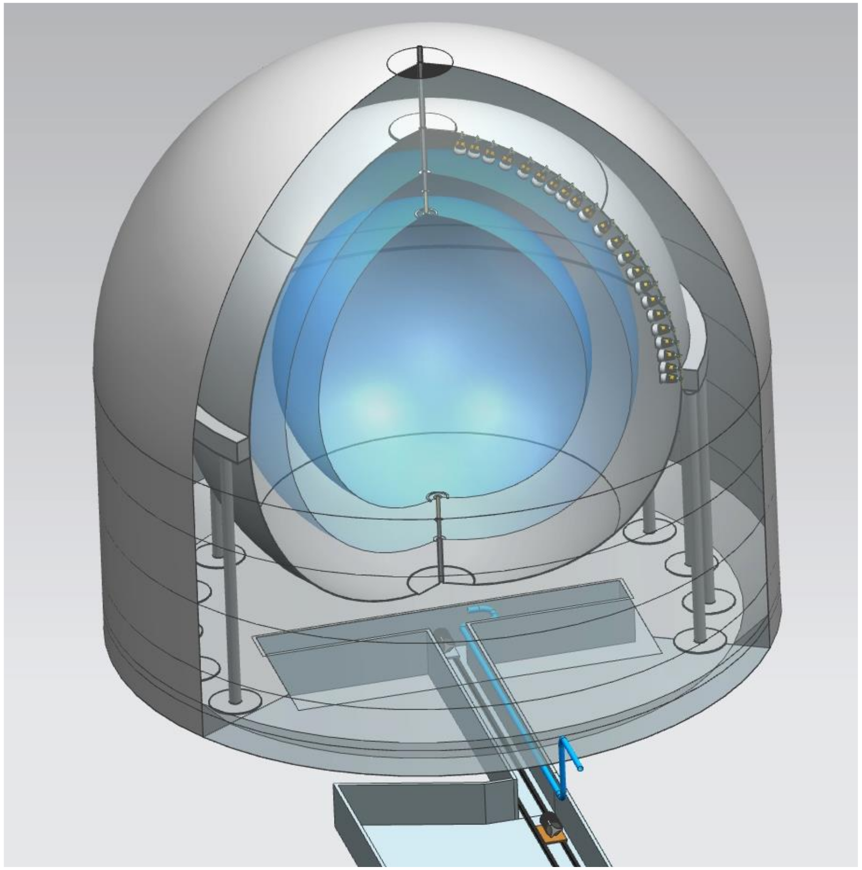
$\nu_e, \bar{\nu}_e$ appearance

- **Accelerator anomaly (~3.8 σ)**
  appearance of $\bar{\nu}_e$ in a $\bar{\nu}_\mu$ beam (LSND), confirmed by miniBooNE (which also sees appearance of ν_e in a ν_μ beam)
  A.Aguilar et al. LSND Collaboration Phys.Rev.D 64 112007 (2001), A.Aguilar et al. (MiniBooNE Collaboration) Phys.Rev.Lett. 110 161801 (2013)

Possible mixing of active flavors with a sterile neutrino Δm^2~1 eV^2

The Borexino Detector

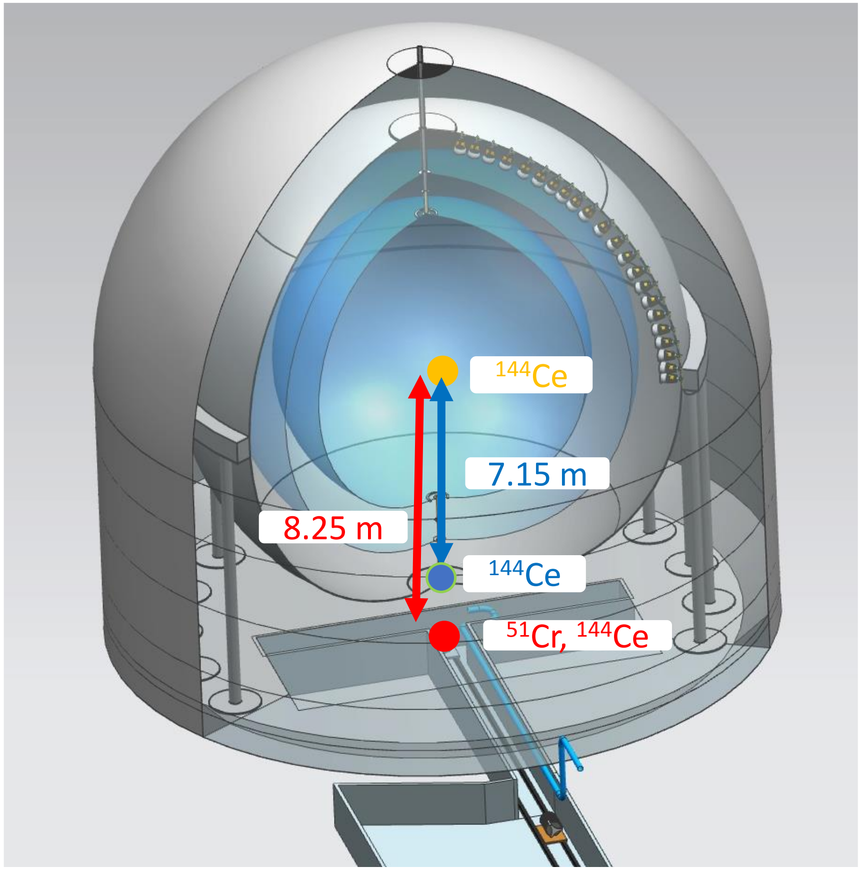
- **Active volume**
  270 t of liquid scintillator in nylon vessel of R=4.25 m
  radiopurity: U/Th<10^{-17} g/g
- **Stainless Steel Sphere**
  radius 6.85 m
  2200 inward-facing PMTs
- **Sox pit**
  R=8.25 m
- **Detector performances at 1 MeV**
  Energy resolution: 5%
  Spatial resolution: 10 cm



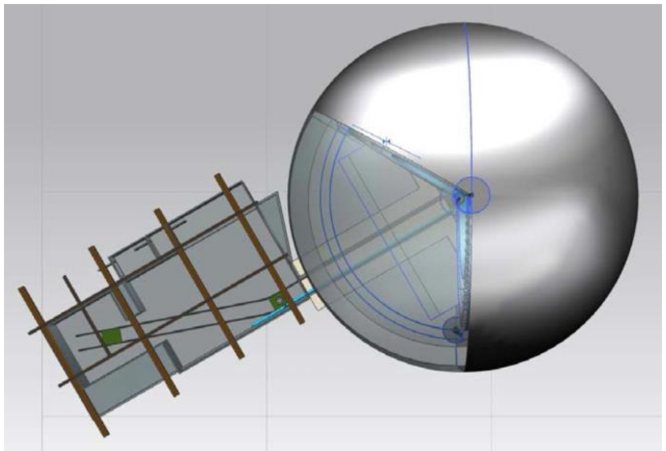
MORE DETAILS AND RESULTS IN M. PALLAVICINI'S TALK

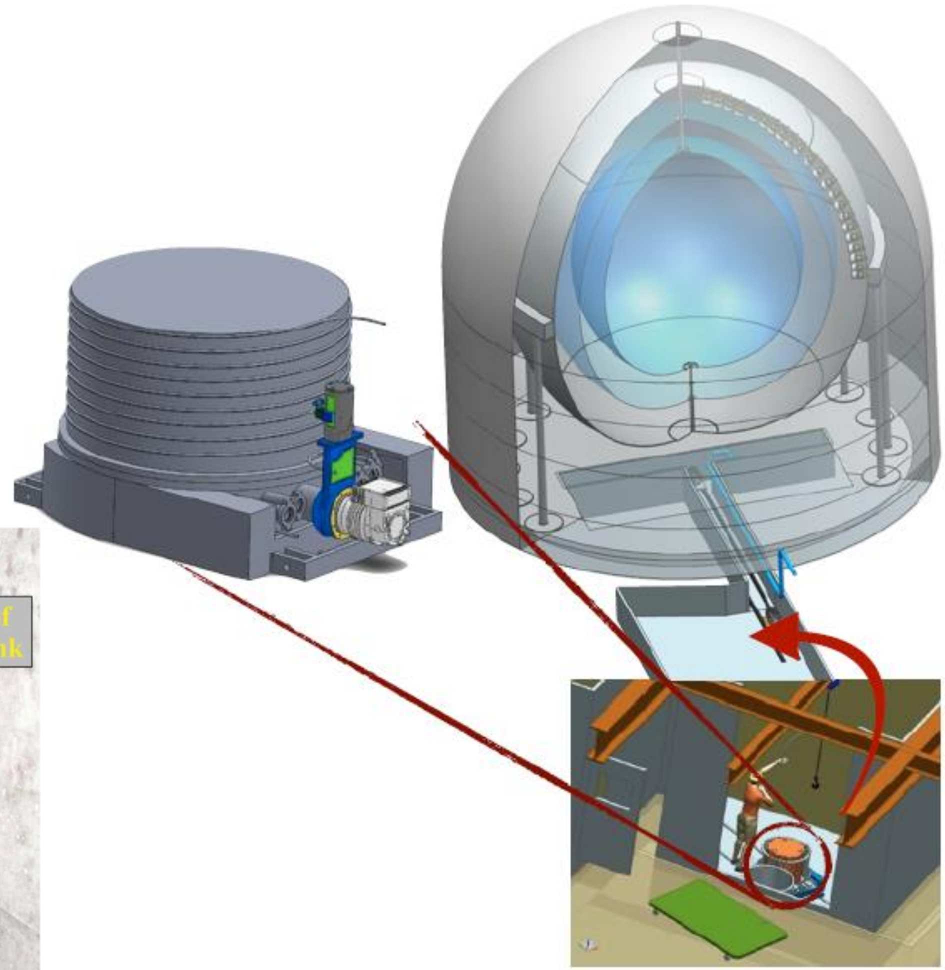
SOX: Short distance neutrino Oscillations with BoreXino

- SOX aims to test the neutrino and antineutrino anomalies using radioactive sources (^{51}Cr, ^{144}Ce);
- Well understood low background detector (Borexino is taking data since 2007);
- Sources in different positions (**SOX-A**, **SOX-B**, **SOX-C**)



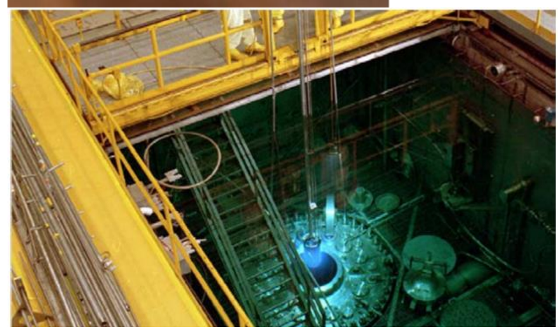
The SOX pit

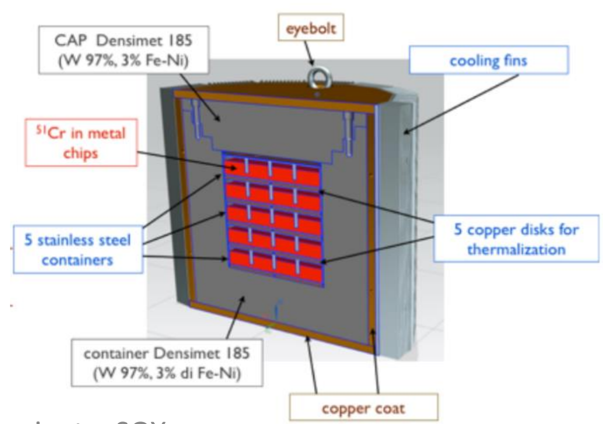


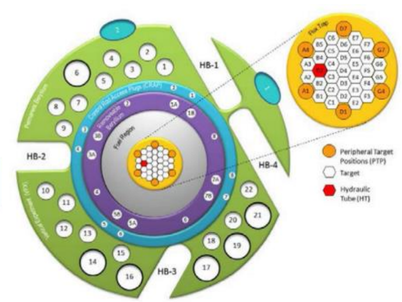


CrSOX

- ^{51}Cr produced by irradiation of ^{50}Cr
- Re-use of Gallex chromium, 38 % enriched in ^{50}Cr.
- Irradiation possible in HFIR (ORNL, Tennessee, USA) or Mayak (Russia);
- Simulations ongoing to optimize activity: 5-6 MCi are reached with two back-to-back cycles at HFIR.
- Tungsten shielding: biological (<200 μSv/h in contact) and background (gammas from activated contaminants)



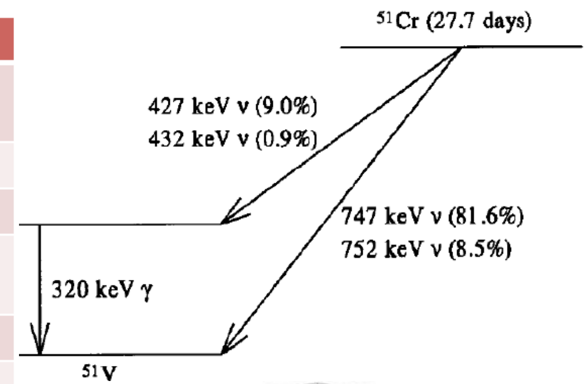


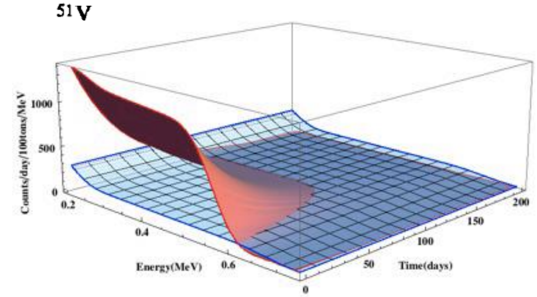


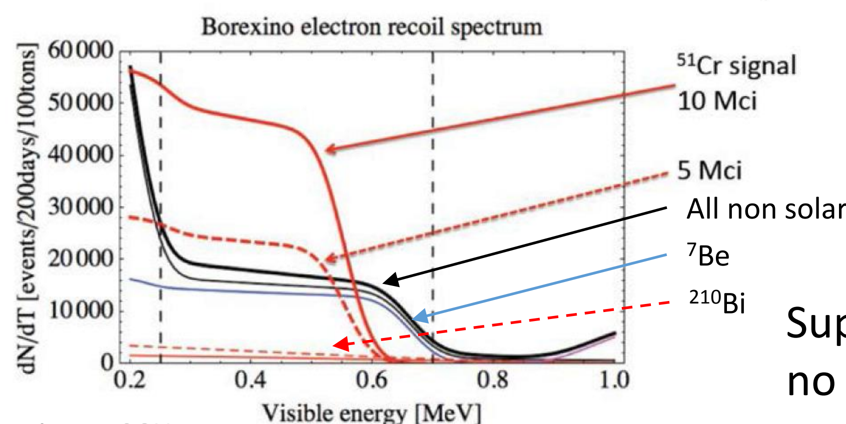
CrSOX

- $^{51}Cr + e^- \rightarrow {}^{51}V + \nu_e$ (τ=27.7 days)
- Short half-life: fast transport to LNGS is needed
- Emission of mono-energetic ν_e's:
  - ~750 keV (90%)
  - ~433 keV (10%)
- Low energy γ-rays in 10% of decays (320 keV γ)
- ν_e detected using elastic scattering on electrons
- Backgrounds: ^{210}Po, ^{210}Bi, ^{7}Be and solar ν_e

Source	^{51}Cr
Production	n-activation of ^{50}Cr at reactor
Decay mode	EC
Neutrino energy	747 keV
Initial activity	2-4 x 10^{17} Bq (5-10 MCi)
Half life	28 d
Exposure	100-180 d
Fiducial mass	130 tons
Events (180 d)	1.1 x 10^4
Oscillation length (Δm^2 = 2 eV^2)	0.9 m
Generated heat	190 W/MCi



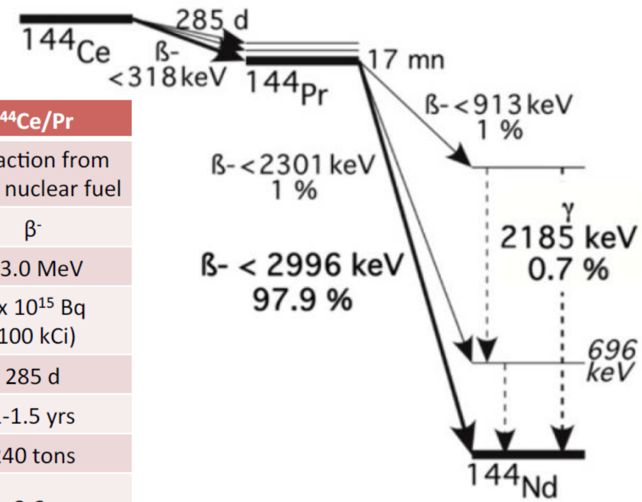




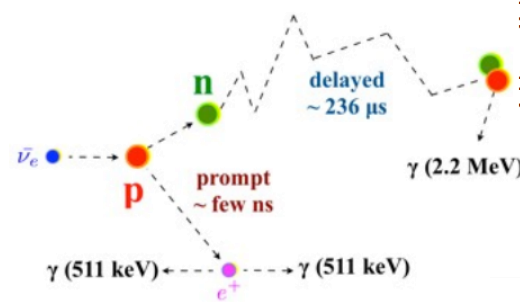
Supposed no ^{210}Po

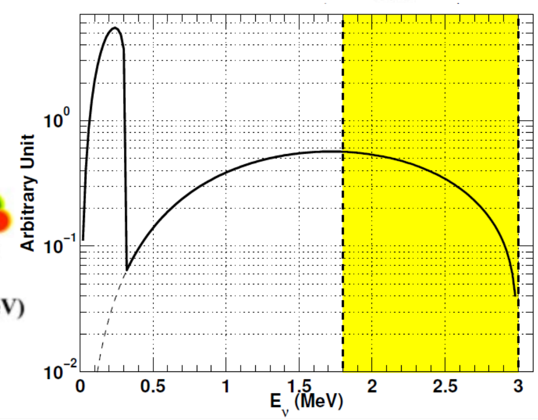
CeSOX

- ^{144}Ce-^{144}Pr antineutrino source:
  - $\tau(^{144}Ce)$ = 285 days
  - $\tau(^{144}Pr)$ = 17 min
- Produced from exhausted nuclear material (Kola Nuclear Power Plant in Murmansk, Russia)
- More shielding required
- Threshold IBD: 1.8 MeV
- No backgrounds except geoneutrinos and reactor neutrinos!

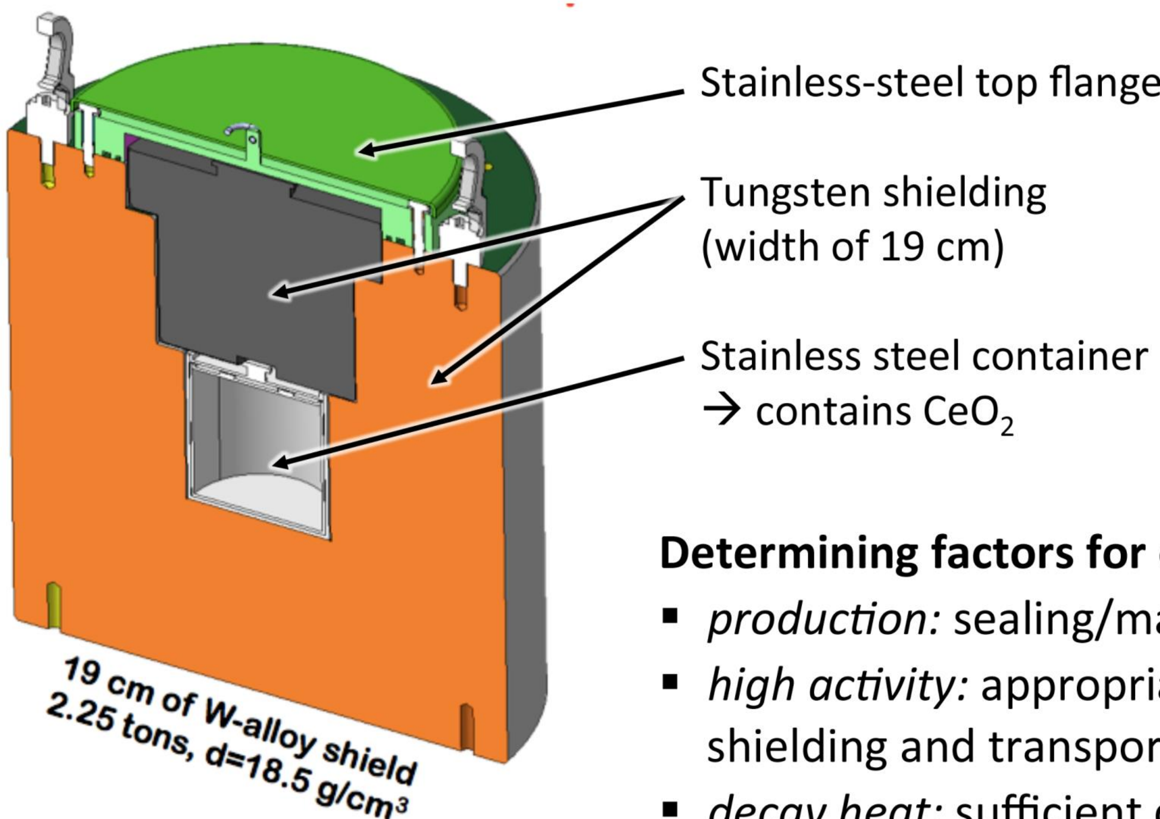


Source	$^{144}Ce/Pr$
Production	extraction from spent nuclear fuel
Decay mode	β^-
Neutrino spectrum	< 3.0 MeV
Initial activity	4×10^{15} Bq (100 kCi)
Half life	285 d
Exposure	1-1.5 yrs
Fiducial mass	240 tons
Oscillation length ($\Delta m^2 = 2\ eV^2$)	< 3.6 m
Events (1.5yrs)	10^4
Generated heat	7.6 W/kCi





CeSOX: source design



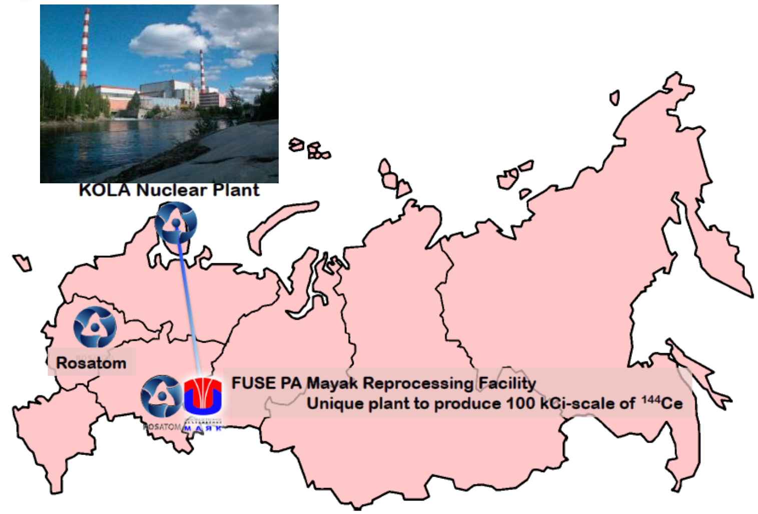
Source diameter: 15cm
Shielding diameter: 54cm

Determining factors for design

- *production:* sealing/manipulation
- *high activity:* appropriate radiation shielding and transportation
- *decay heat:* sufficient cooling
- *mechanics:* dimensions of the tunnel/ calorimeter for heat measurement

CeSOX: long journey from Mayak to LNGS

- Spent nuclear fuel will be shipped from Kola reactor to Mayak ~ end of 2014

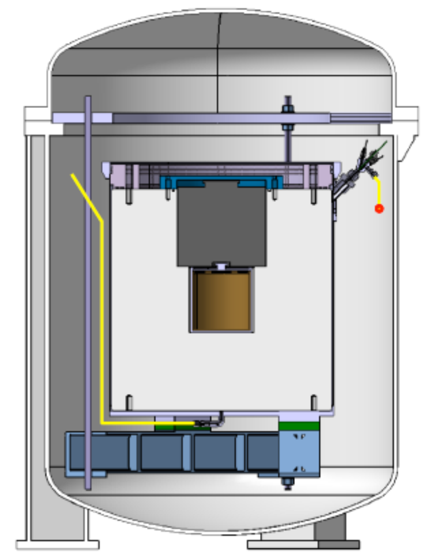


- ^{144}Ce source ready for shipment to Gran Sasso by fall 2015
- Transportation to Gran Sasso in November 2015

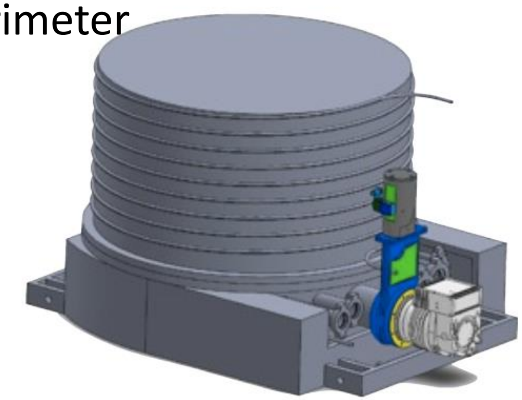
Calorimetry

- An accuracy of about 1% in source activity is needed;
- Ce activity measured before the insertion in the pit both with Ce-calorimeter and with the Cr-calorimeter;
- Cr source will be inserted in the pit wrapped by the Cr-calorimeter.
- Emitted radiations heat up the source and the shield
- Suspended and isolated container: designed as vacuum chamber, controlled water flow measurement
- From the difference of temperature between ingoing and outgoing water and knowing the water flux, the heat released by the source is measured.

Ce-calorimeter

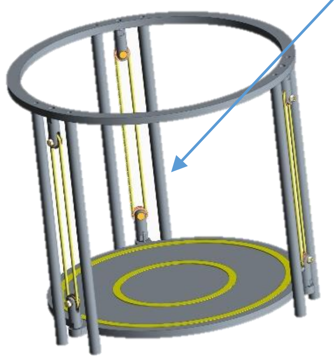


Cr-calorimeter



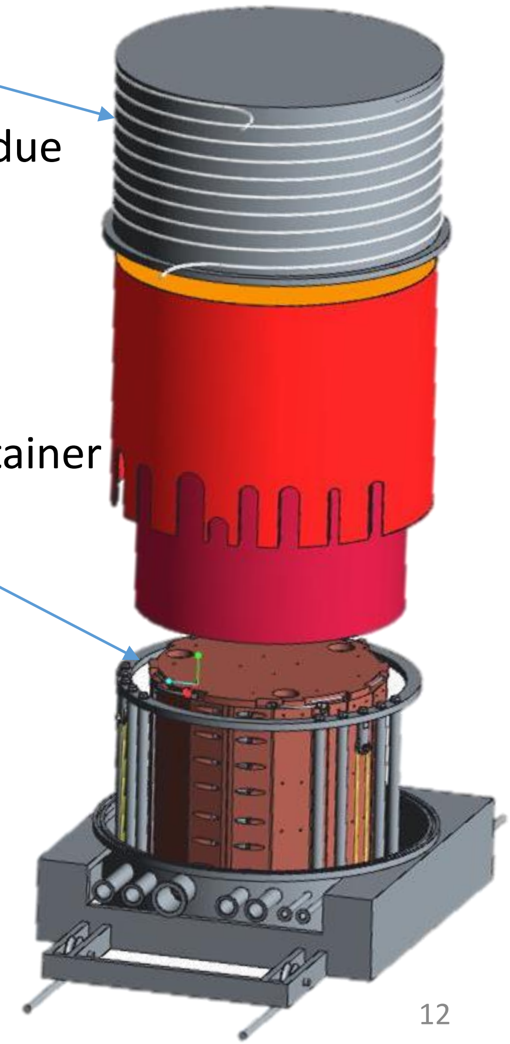
Calorimetry

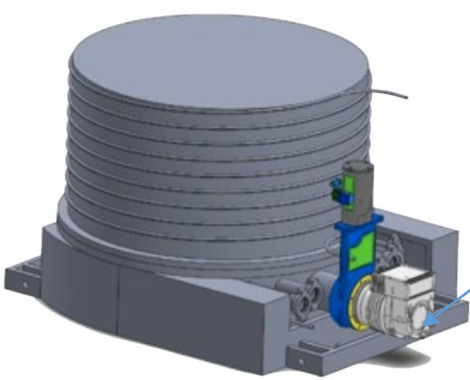
The source is suspended by means of Kevlar rods to avoid thermal losses due to conduction



External shield at the same temperature of the copper container to avoid thermal losses due to radiation

Water flows in small pipes embedded in the copper container



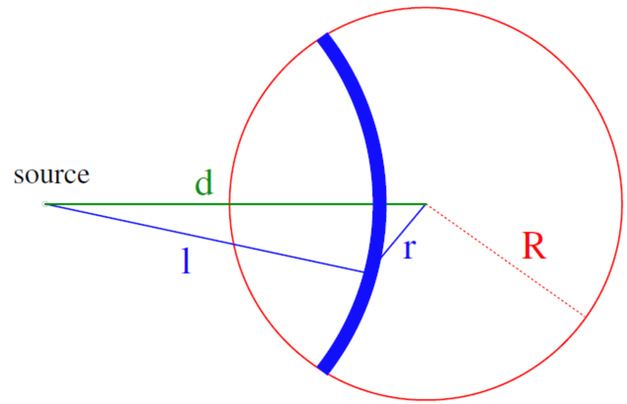


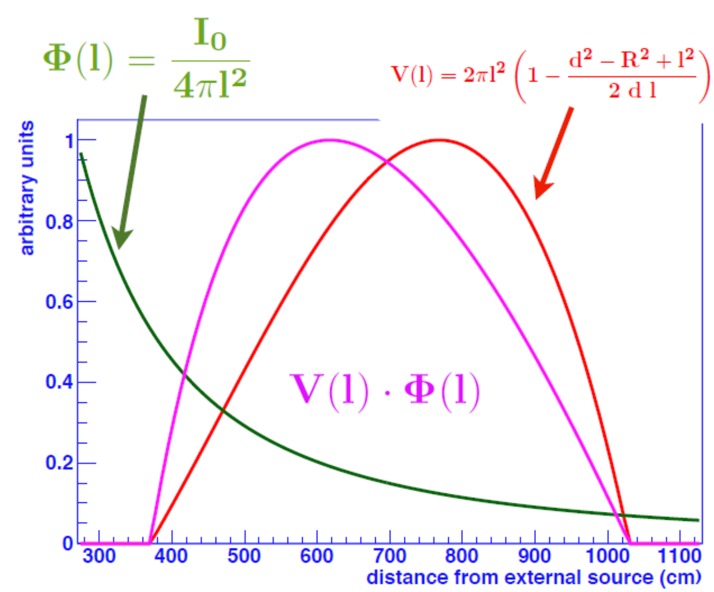
Vacuum is made by means of a turmomolecular pump to avoid convection

Expected signal using an external source

- The expected signal distribution depends on geometry V(l) and flux Φ(l)
- The event distribution is asymmetric even in absence of oscillations!!
- The expected number of events for interaction at distance l from the source is

$$N_0(l, T_1, T_2) = n_e \ \Phi(l) \ V(l) \ P_{ee}(l, E) \int_{T_1}^{T_2} \frac{d\sigma_e(E,T)}{dT} dT$$





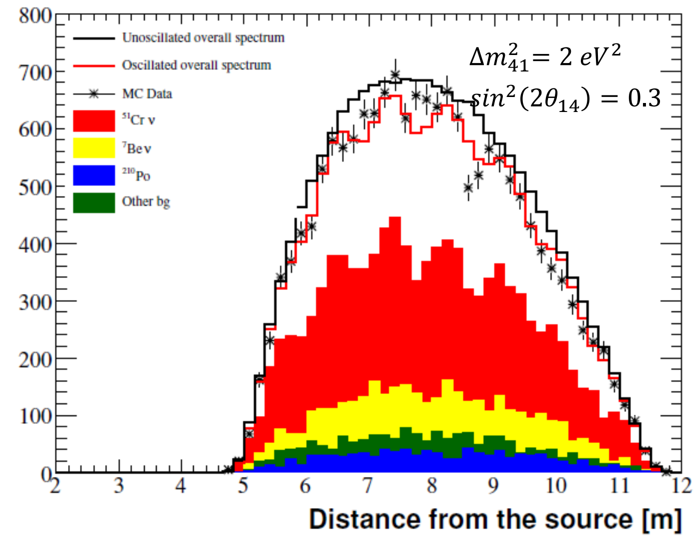
Analysis strategy

- **Rate analysis**
  standard disappearance technique, counts the events in the FV and compares the count rate with the one expected from the source activity
- **Rate + shape analysis**
  searches for spatial oscillations:

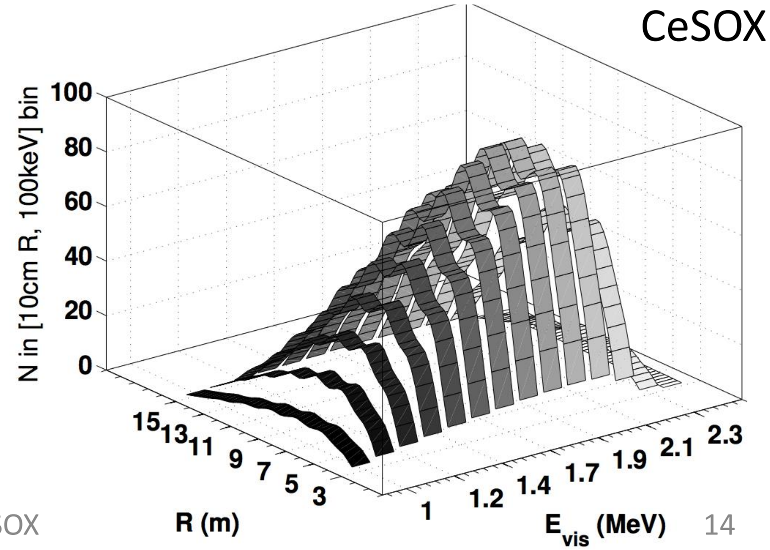
$$P_{ee} = 1 - \sin^2 2\theta_{14} \sin^2 \frac{1.27\Delta m^2_{41}(eV^2)L(m)}{E(MeV)}$$

- $\begin{cases} \Delta m^2_{41} \sim eV^2 \\ E \sim MeV \end{cases} \rightarrow L \sim m$
- wavelength shorter than detector size and bigger than resolution!

CrSOX



CeSOX



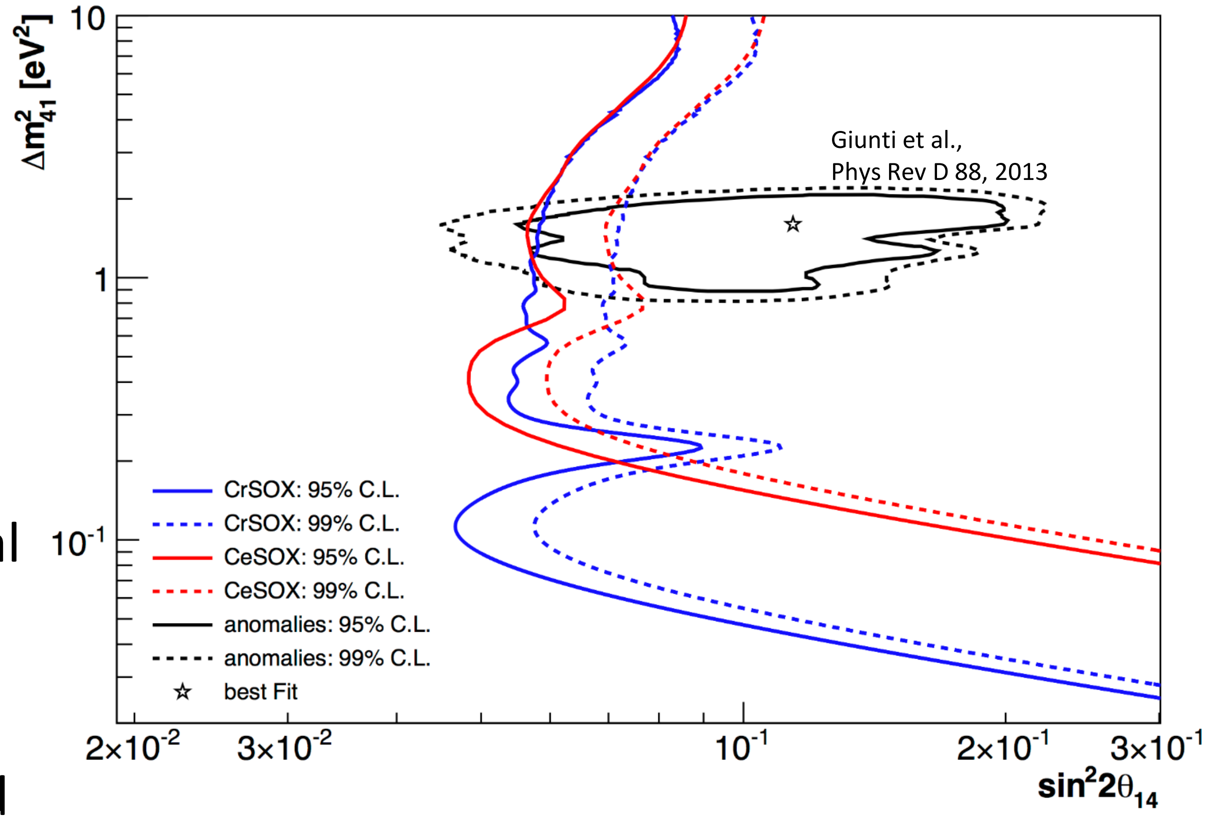
SOX-A: projected sensitivity

CrSOX

Activity: 10MCi
Fiducial Radius: 3.3 m
1% source error
1% FV error
1% background error

CeSOX

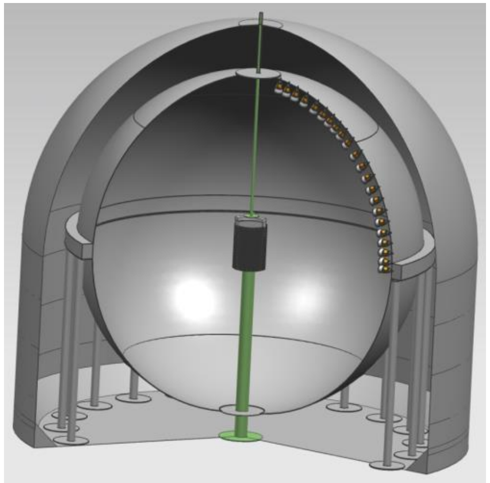
Activity: 100 kCi Fiducial Radius: 4 m
1% source error
1% FV error
no relevant background



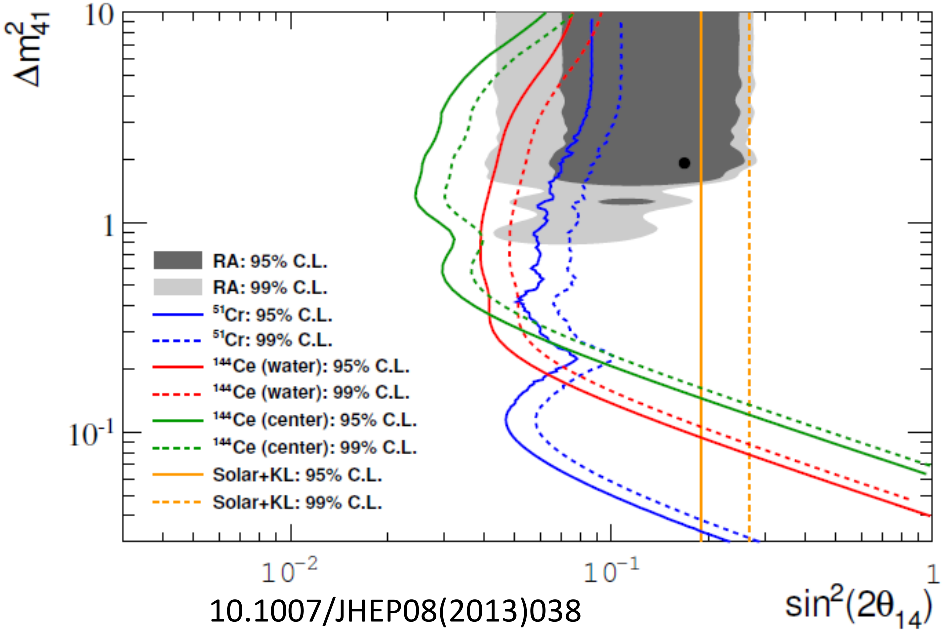
Sox could discover/exclude best fit value at > 5 σ
95% C.L. region of anomalies can be covered

Schedule and perspectives

- February 2015: arrival of fresh nuclear fuel at Mayak;
- November 2015: delivery of Ce source by Mayak;
- December 2015: start of data-taking at LNGS



- 2015-2016: Chromium irradiation and CrSOX
- Future: SOX-B (after the end of the solar program) and SOX-C (major detector upgrade needed)



10.1007/JHEP08(2013)038

Summary

- Thanks to the sensitivity of Borexino to electron neutrino and antineutrino, it is possible to investigate the most favored region of today’s global fit;
- Sources will be placed under the detector (SOX pit)
- Their activity will be measured using calorimetry (~1% accuracy)
- Start of data-taking at the end of 2015

Thank you for your attention!

The SOX collaboration

- APC, University Paris Diderot;
- Joint Institute for Nuclear Research, Dubna;
- INFN Genoa and Physics Department of Genoa University;
- Smoluchowski Institute of Physics, Jagellonian University, Krakow;
- Kiev Institute for Nuclear Research;
- NRC Kurchatov Institute, Moskow;
- INFN Milan and Physics Department of Milan University;
- Physics Department Princeton University;
- Physik Department, Technische Universität München;
- Physics Department, Virginia Polytechnic Institute and State University;
- Lomonosov Moscow State University Skobeltsyn Institute of Nuclear Physics;
- Cea Centre de Saclay;
- Institut für Physik, Johannes Gutenberg Universität, Mainz;
- Physikalisches Institut, Eberhard Karls Universität, Tübingen.

Further reading

- *G. Bellini et al,*
  SOX: Short distance neutrino Oscillations with BoreXino,
  JHEP08 (2013)
- *C. Giunti et al,*
  Pragmatic View of Short-Baseline Neutrino Oscillations,
  Phys. Rev. D 88 (2013)
- *B. Caccianiga,*
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