DETECTING NEUTRINO SIGNALS FROM THE DEEP EARTH WITH BOREXINO

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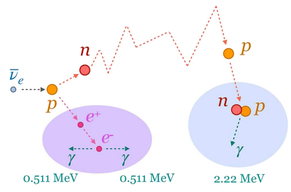
Updated statistics and improved analysis techniques

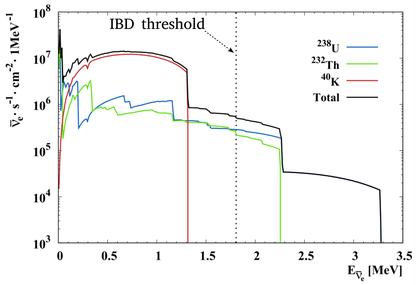
~18% precision in Borexino's geoneutrino measurement

no-mantle signal rejected at 99% C.L.

INTRODUCTION

Inverse Beta Decay (IBD)





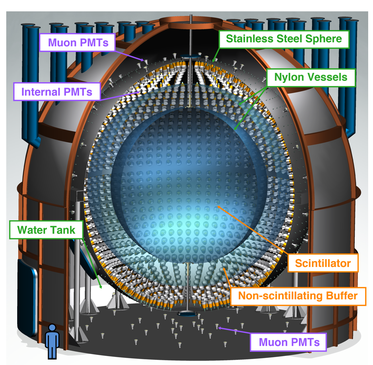
$^{238}\mathrm{U} \rightarrow {}^{206}\mathrm{Pb} + 8\alpha + 8e^- + \boxed{6\bar{\nu}_e} + 51.7\,\mathrm{MeV}$

$^{235}\mathrm{U} \rightarrow {}^{207}\mathrm{Pb} + 7\alpha + 4e^- + \boxed{4\bar{\nu}_e} + 46.4\,\mathrm{MeV}$

$^{232}\mathrm{Th} \rightarrow {}^{208}\mathrm{Pb} + 6\alpha + 4e^- + \boxed{4\bar{\nu}_e} + 42.7\,\mathrm{MeV}$

$^{40}\mathrm{K} \rightarrow {}^{40}\mathrm{Ca} + e^- + \boxed{\bar{\nu}_e} + 1.31\,\mathrm{MeV}\ (89.3\%)$

Measured in Terrestrial Neutrino Units (TNU). 1 TNU corresponds to 1 antineutrino event detected via IBD over 1 year by a detector with 100% detection efficiency containing 10^{32} free target protons (roughly corresponds to 1kton of LS)



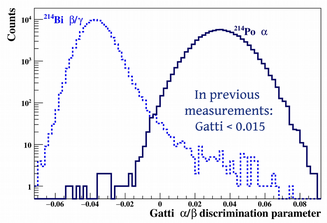
ANALYSIS TECHNIQUES

Selection cuts

- **Charge of prompt**
  408 p.e. (2 x 511 keV γs)
- **Charge of delayed**
  n-capture on ^{1}H → 700 – 1300 p.e. enlarged
  n-capture on ^{12}C → 1300 – 3000 p.e. new
- **dt:** 5 times n-capture time
  2 – 12.5 μs (double cluster events) new
  20 – 1280 μs (single cluster events)
- **dR:** < 1.3 m between prompt and delayed enlarged

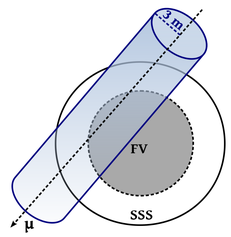
- **Cosmogenic vetoes** improved
  2 s, 1.6 s and 2 ms after internal muons
  2 ms after external muons
  3 m cylindrical veto for one category of internal muons
- **Dynamic Fiducial Volume (DFV) cut** enlarged
  distance of prompt to inner vessel > 10 cm
- **Pulse shape discrimination** improved
  Multi-Layer Perceptron (MLP) > 0.8
  deep learning technique to reject α-like delayed
- **Multiplicity cut**
  to reject neutrons 2 ms before or after prompt or 2 ms after delayed

Better pulse shape discrimination



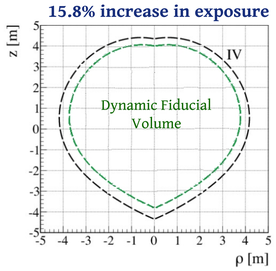
Improved cosmogenic vetoes

In previous measurements → 10-11% exposure loss
Now→ 2.2% exposure loss



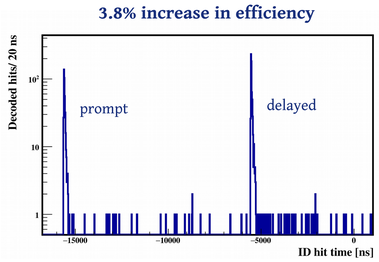
Enlarged fiducial volume

Distance to prompt: 30 cm → 10 cm
15.8% increase in exposure

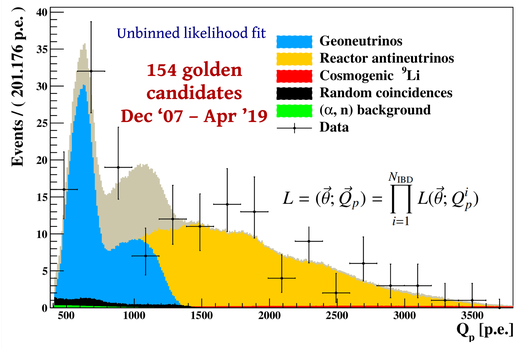


Inclusion of double cluster events

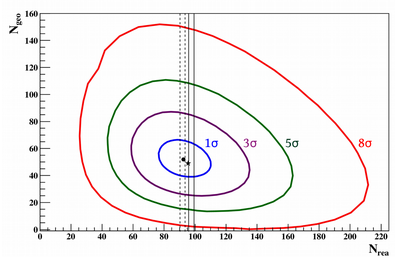
3.8% increase in efficiency



RESULTS



Reactor antineutrino background



- Reactor antineutrino expectation with excess at 5 MeV
- Reactor antineutrino expectation without excess at 5 MeV
- Measured reactor antineutrinos – Th/U ratio fixed
- Measured reactor antineutrinos – Th & U as free parameters

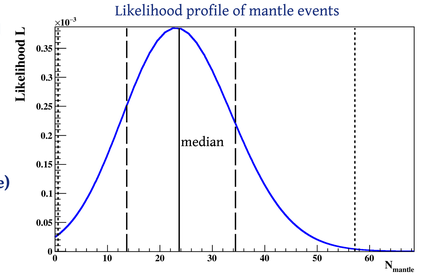
Other backgrounds

Background type	No. of events
^{9}Li background	3.6 ± 1.0
Untagged muons	0.023 ± 0.007
Fast n's (from rock)	<0.013
Fast n's (from WT)	<1.43
Accidental coincidences	3.846 ± 0.01
(α, n) in scintillator	0.81 ± 0.13
(α, n) in buffer	<2.6
(γ, n)	<0.34
Fission in PMTs	<0.057
^{214}Bi-^{214}Po	0.003 ± 0.001
TOTAL	**8.28 ± 1.01**

INTERPRETATIONS

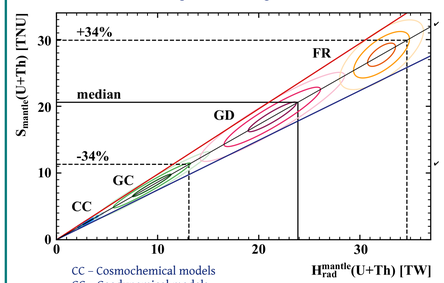
99% C.L. exclusion of the null-hypothesis of the mantle signal

- Relatively well-known lithosphere constrained to $28.8^{+5.5}_{-4.6}$ events using knowledge of the local crust
- Th/U mass ratio (lithosphere) = 3.5
- Th/U mass ratio (mantle) = 3.7
- $S_{mantle} = 21.2^{+9.7}_{-9.0}$ TNU



2.4σ tension with Earth models that predict lowest amount of heat-producing elements inside the mantle

Mantle signal vs Radiogenic heat

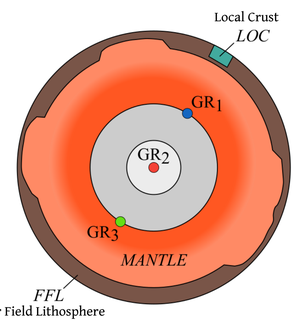


CC – Cosmochemical models
GC – Geodynamical models
GD – Geodynamical models
FR – Full Radiogenic model

- Radiogenic heat: $H(U+Th+K) = 38.2^{+13.6}_{-12.7}$ TW (Lithospheric contribution + measured mantle heat + expected 18% from ^{40}K in mantle)
- Convective Urey Ratio: $UR_{CV} = \frac{H_{rad} - H^{CC}_{rad}}{H_{tot} - H^{CC}_{rad}} = 0.78^{+0.41}_{-0.28}$

Upper limits on a hypothetical georeactor (95% C.L.)

- **Three different locations:**
  < 0.5 TW – Core-mantle boundary (d = 2900 km) – GR1
  < 2.4 TW – Core (d = R_{Earth}) – GR2
  < 5.7 TW – Core-mantle boundary (d = 9842 km) - GR3
- **Georeactor fuel → ^{235}U & ^{238}U**
- **Spectra similar to reactor antineutrinos which are constrained to the expected 97.6 ± 5.5 events**



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