

A step toward CNO solar neutrino detection in liquid scintillators

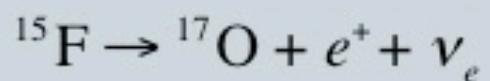
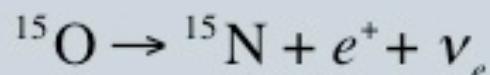
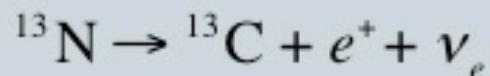


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F.L. Villante, A. Ianni, F. Lombardi, G. Pagliaroli and F. Vissani,
Phys. Lett. B 701 (2011) 336,
hep-ph:1104.1335.

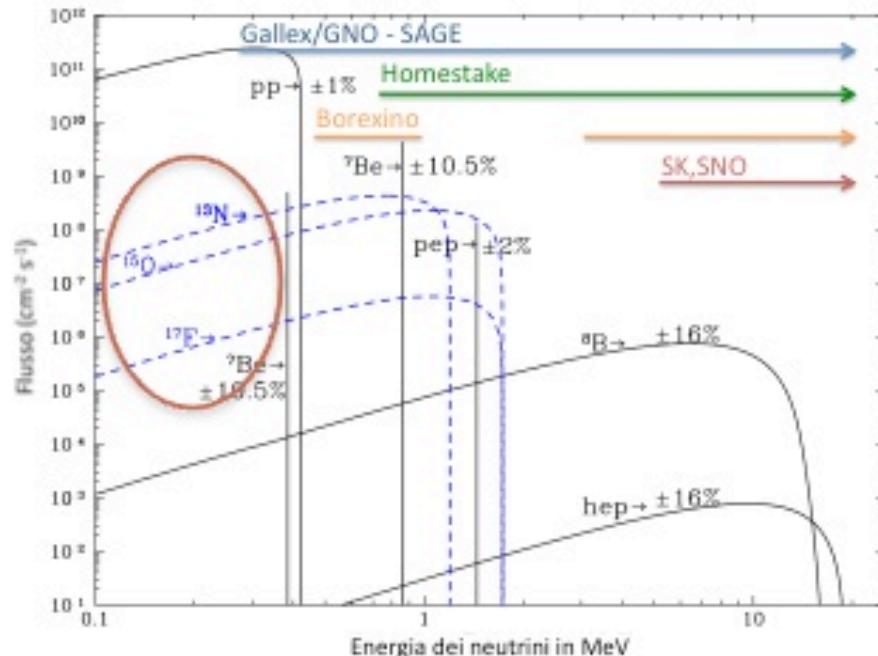
CNO neutrinos

The detection of CNO neutrinos is one of the goals of the solar neutrino experiments



At present, we only have a loose Upper limit on CNO neutrino fluxes:

ν flux	GS98	AGSS09	Solar
^{13}N ($10^8 \text{ cm}^{-2} \text{ s}^{-1}$)	$2.96(1 \pm 0.14)$	$2.17(1 \pm 0.14)$	≤ 6.7
^{15}O ($10^8 \text{ cm}^{-2} \text{ s}^{-1}$)	$2.23(1 \pm 0.15)$	$1.56(1 \pm 0.15)$	≤ 3.3
^{17}F ($10^6 \text{ cm}^{-2} \text{ s}^{-1}$)	$5.52(1 \pm 0.17)$	$3.04(1 \pm 0.16)$	≤ 59

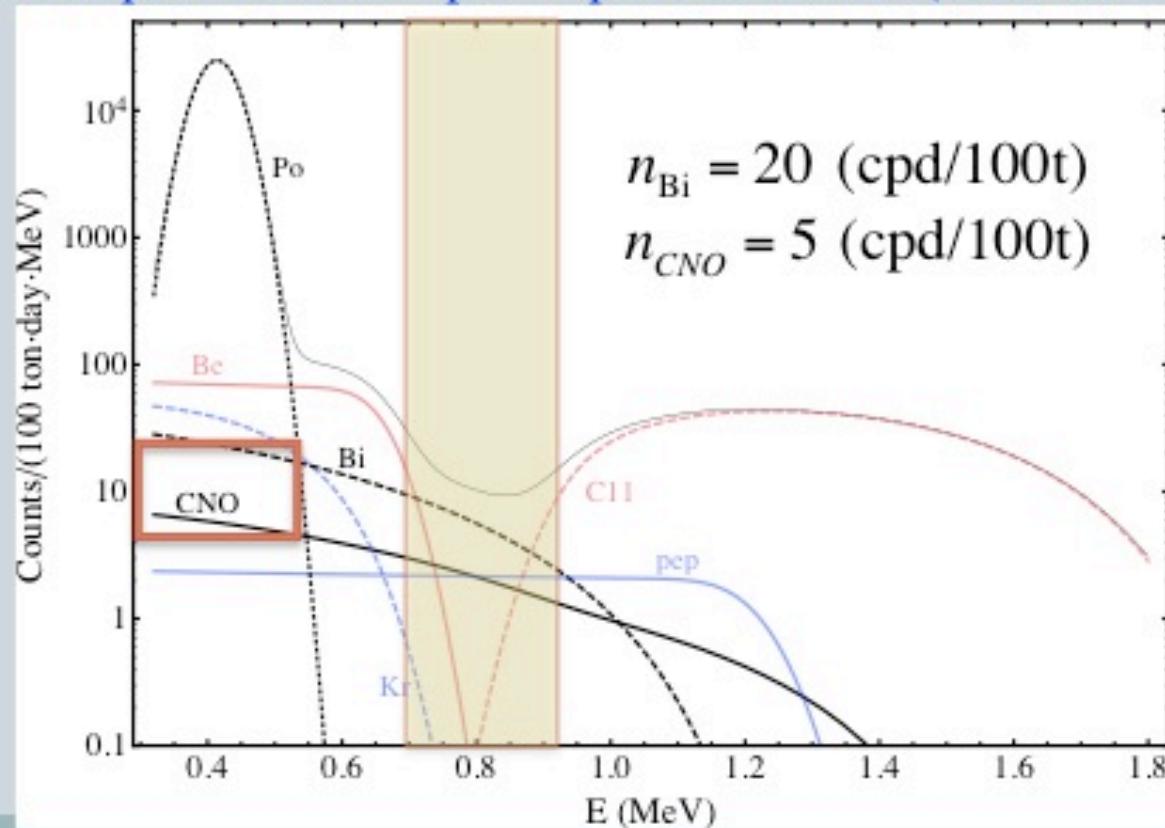


$$\text{GS98} \rightarrow (Z/X)b = 0.0231$$
$$\text{AGSS09} \rightarrow (Z/X)b = 0.0181$$

CNO neutrinos detection

- Low energy neutrinos → endpoint at about 1.5 MeV
- Continuous spectrum → degeneracy with Bi-210

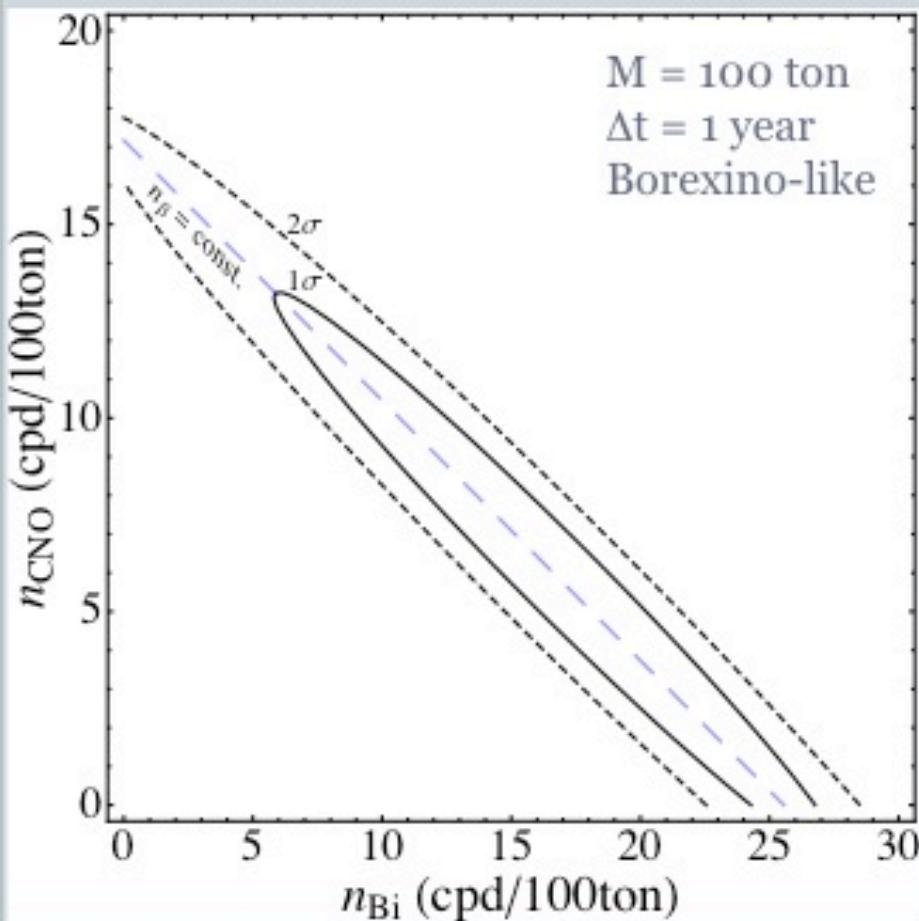
Event spectrum in ultrapure liquid scintillators (Borexino-like)



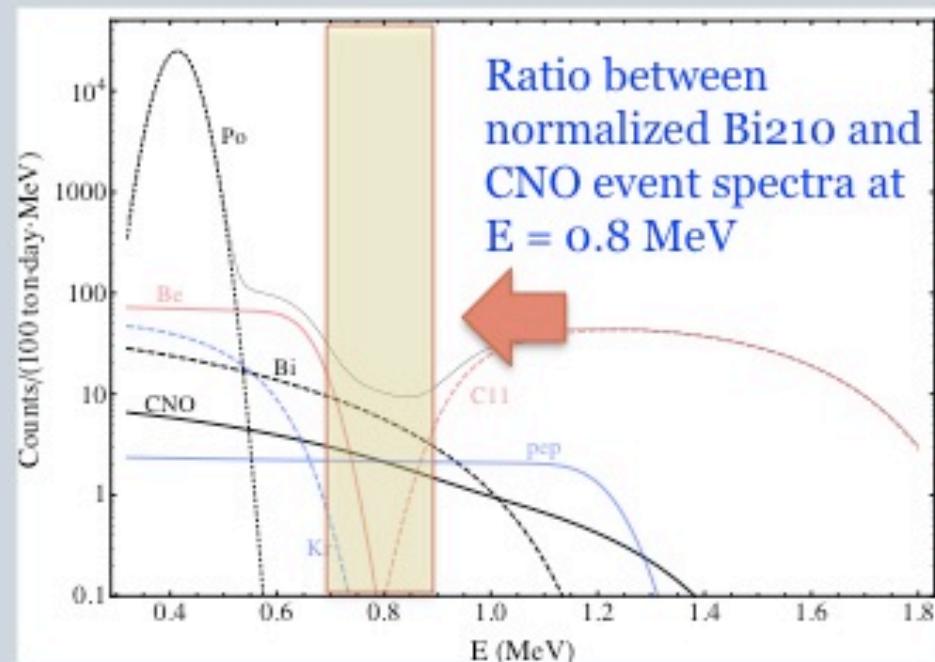
CNO vs Bismuth-210



Spectral fit of simulated data



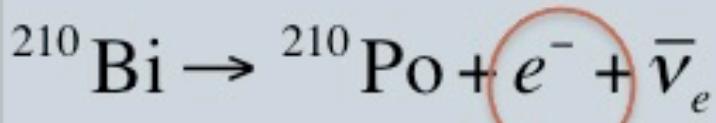
$$n_\beta = n_{\text{CNO}} + 0.67 n_{\text{Bi}}$$



Bismuth-210



$$\tau_{\text{Pb}} \approx 22 \text{ years}$$

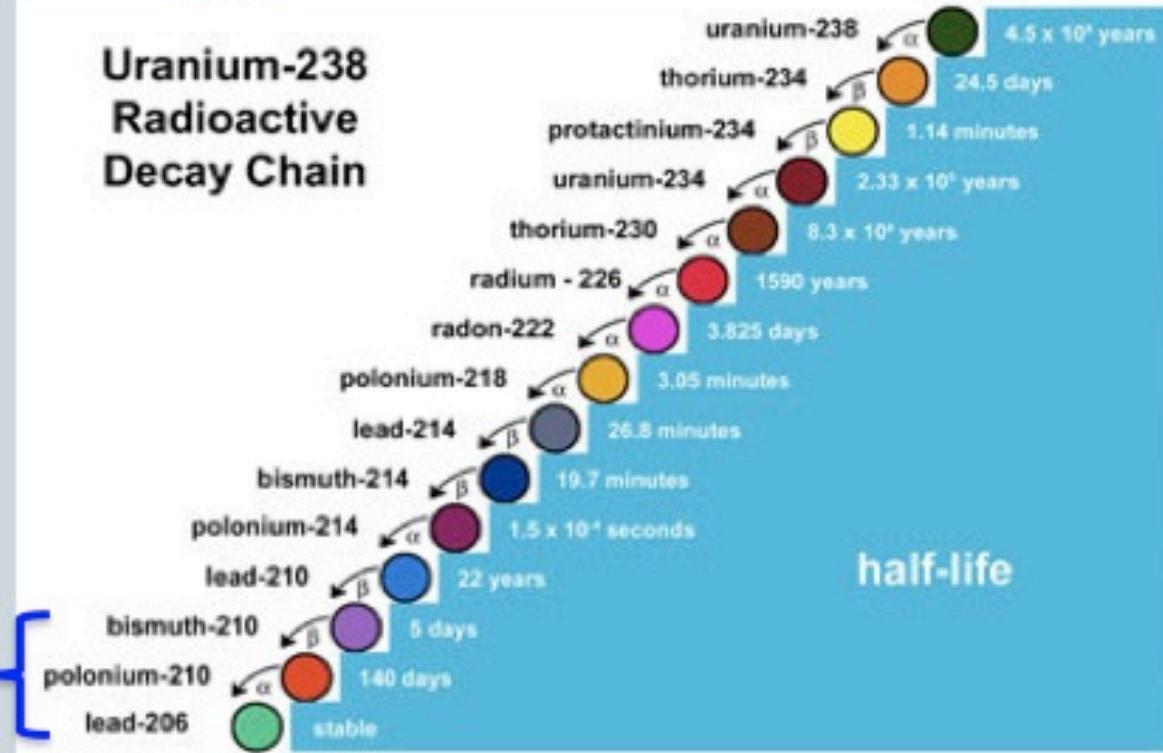


$$\tau_{\text{Bi}} \approx 7 \text{ days}$$



$$\tau_{\text{Po}} \approx 200 \text{ days}$$

Uranium-238 Radioactive Decay Chain



Monochromatic alpha particle easily identified

$$E_\alpha = 5.3 \text{ MeV}$$

Polonium-210 to extract Bismuth-210



$$n_{\text{Po}}(t) = [n_{\text{Po},0} - n_{\text{Bi}}] \exp(-t/\tau_{\text{Po}}) + n_{\text{Bi}}$$

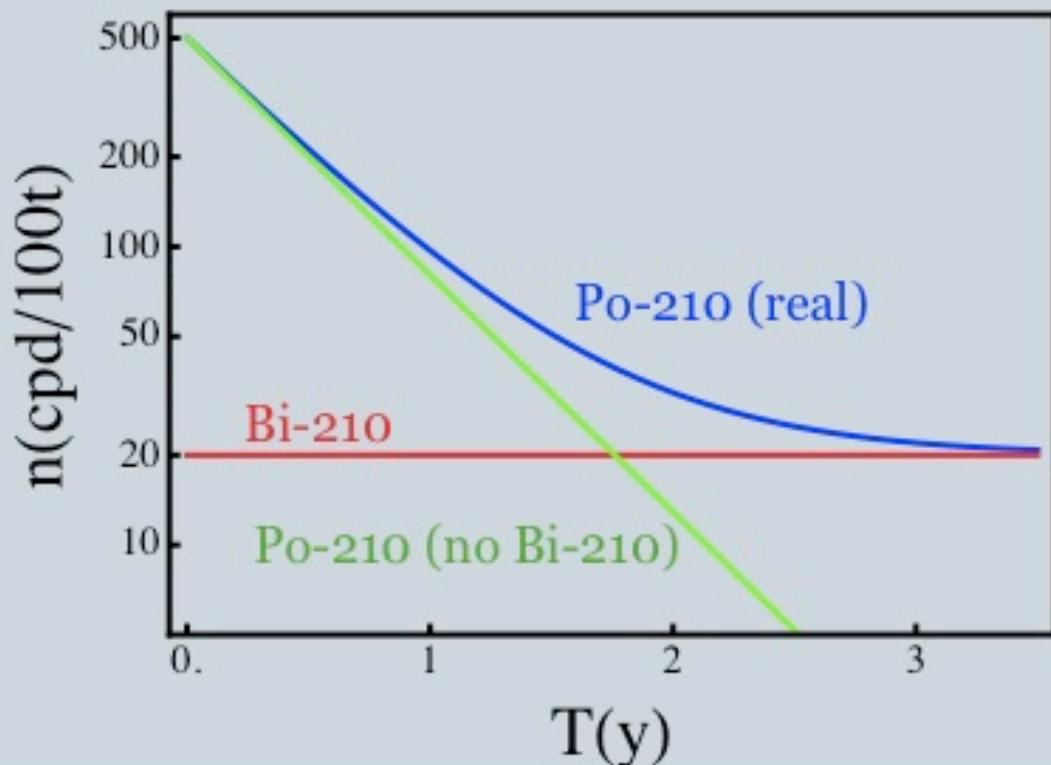
ASSUMPTIONS:

- No other sources of Polonium
- Stability of alpha detection
- Bismuth constant in time

$$n_{\text{Po}}^0 = 500 \text{ (cpd/100t)}$$

$$n_{\text{Bi}} = 20 \text{ (cpd/100t)}$$

Within 3 years Borexino could reach the equilibrium



NOTE



The most general expression is:

$$n_{\text{Po}}(t) = n_{\text{Po}}^0 \exp(-t / \tau_{\text{Po}}) + \langle n_{\text{Bi}}(t) + S_{\text{Po}}(t) \rangle$$

where

$$\langle f(t) \rangle = \frac{1}{\tau_{\text{Po}}} \int_0^t dt' f(t - t') \exp(-t'/\tau_{\text{Po}})$$

NO OTHER SOURCES OF POLONIUM-210

NOTE



The most general expression is:

$$n_{\text{Po}}(t) = n_{\text{Po}}^0 \exp(-t / \tau_{\text{Po}}) + \langle n_{\text{Bi}}(t) \rangle$$

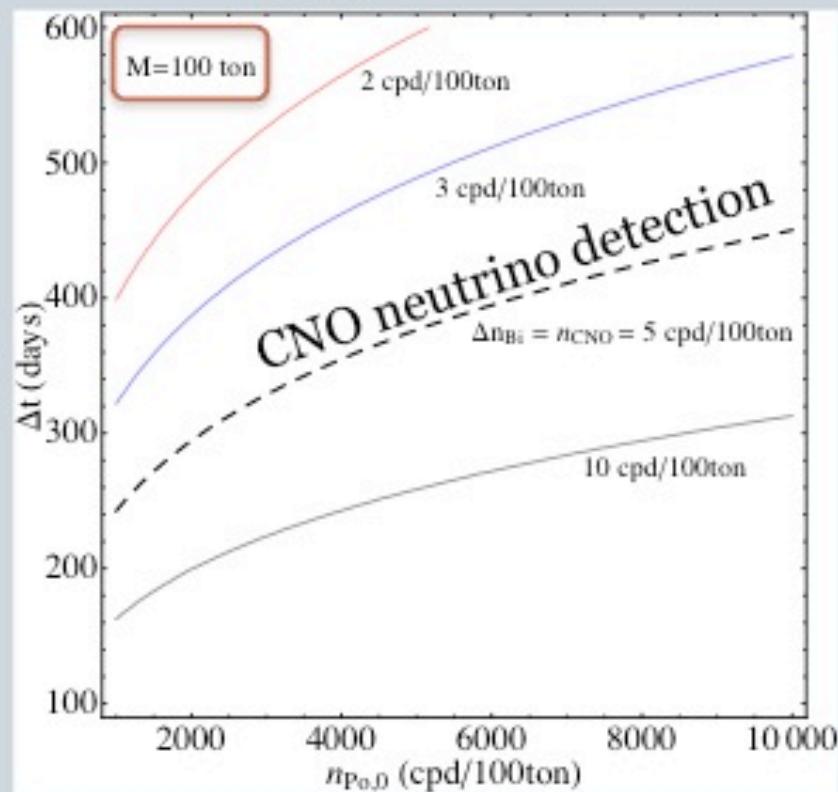
where

$$\langle n_{\text{Bi}}(t) \rangle = \frac{1}{\tau_{\text{Po}}} \int_0^t dt' n_{\text{Bi}}(t - t') \exp(-t'/\tau_{\text{Po}})$$

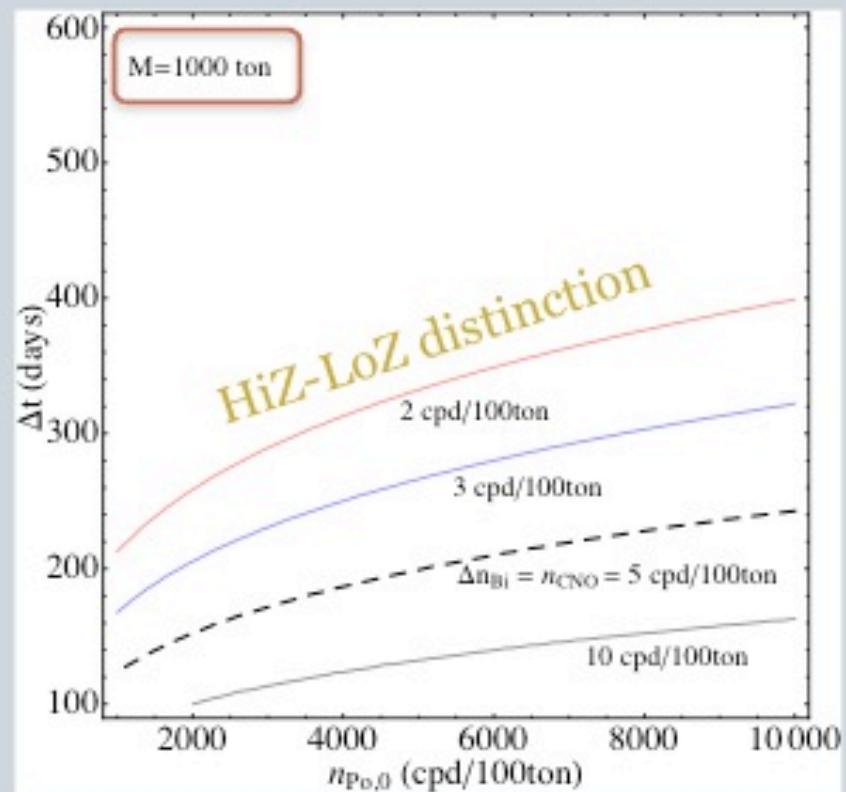
- A time varying Bi-210 contamination does not invalidate the possibility to perform our analysis

Expected Accuracy on Bismuth-210

$$\Delta n_{\text{Bi}} \simeq \sqrt{\frac{n_{\text{Po},0}}{\tau_{\text{Po}} M}} f(\Delta t)$$



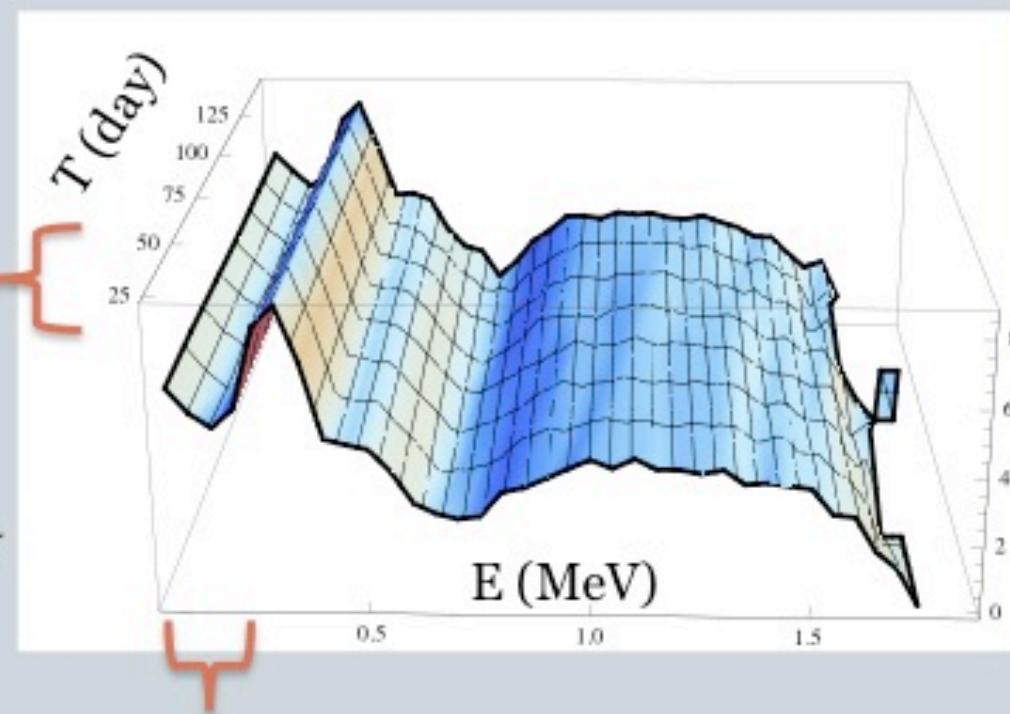
$$f(\Delta t) = \left(\frac{2 \tau_{\text{Po}}}{\Delta t} \right) e^{-\frac{\Delta t}{4 \tau_{\text{Po}}}} \sqrt{\frac{1 + e^{-\frac{\Delta t}{2 \tau_{\text{Po}}}}}{1 - e^{-\frac{\Delta t}{2 \tau_{\text{Po}}}}}}$$



NOTE that Borexino level of Polonium -210 is now only 500 (cpd/100 t)

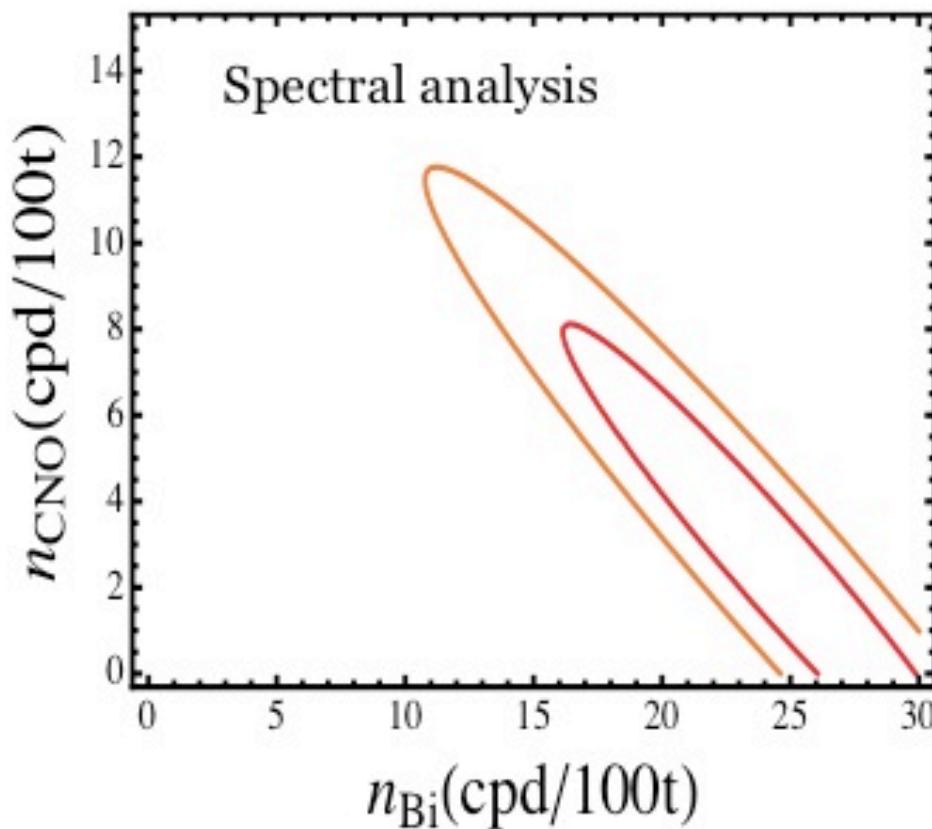
2-Dimensional Analysis

$$\Delta t = 25 \text{ days}$$
$$\Delta E = 0.05 \text{ MeV}$$

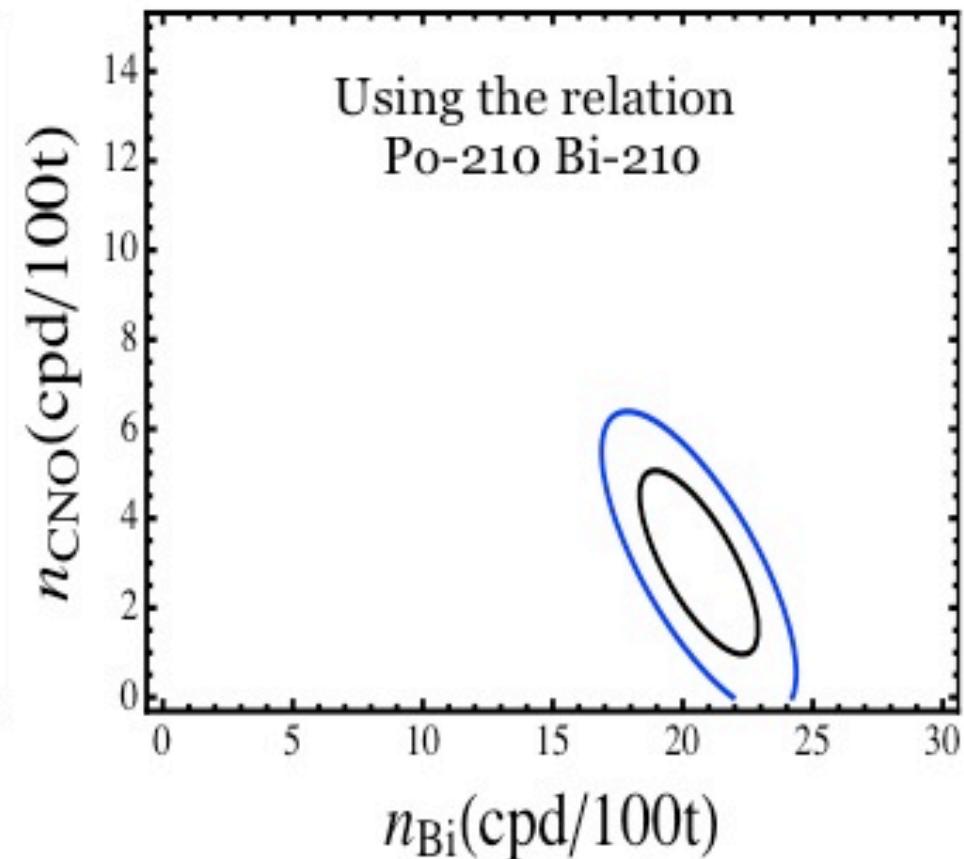


$$\chi^2 \left({}^7\text{Be}, \text{CNO}, {}^{210}\text{Bi}, {}^{210}\text{Po}, {}^{11}\text{C} \right) = \sum_i \frac{\left(n_i(\Delta E, \Delta t) - n_i^{th} \right)^2}{n_i(\Delta E, \Delta t)}$$

Borexino 1 year analysis

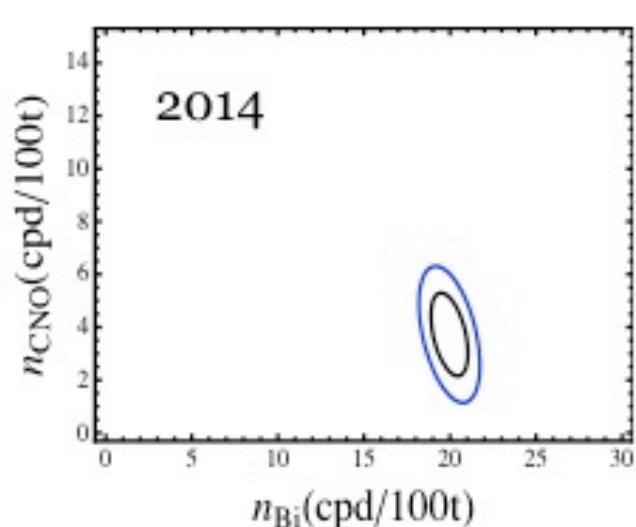
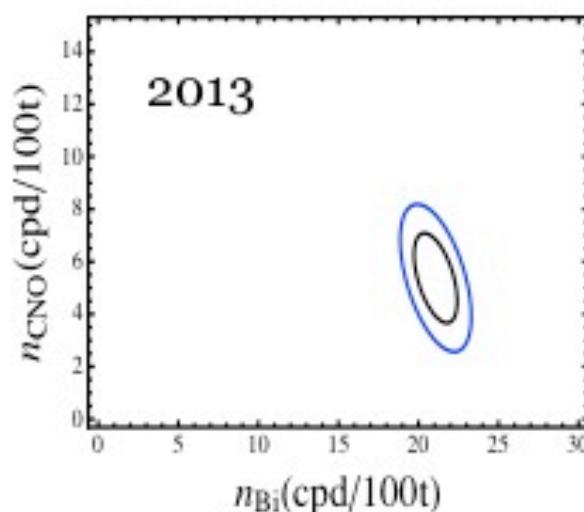
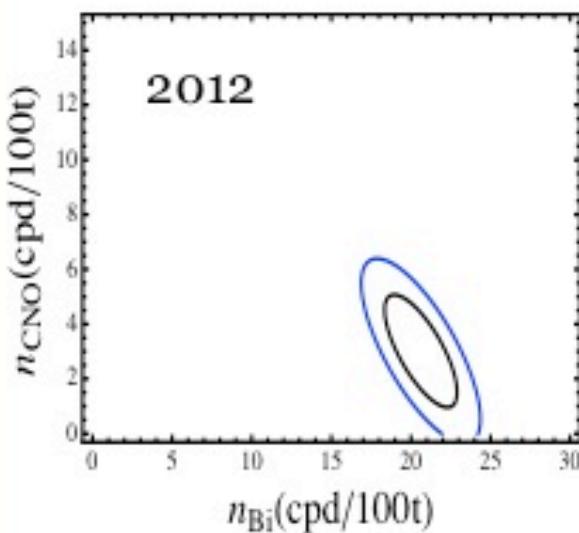


$$n_{\text{CNO}} = 2.4 \pm 3.7 \text{ (cpd/100t)}$$



$$n_{\text{CNO}} = 2.9 \pm 1.4 \text{ (cpd/100t)}$$

CNO sensitivity



$$n_{\text{CNO}}^{1y} = 2.9 \pm 1.4 \text{ (cpd/100t)}$$

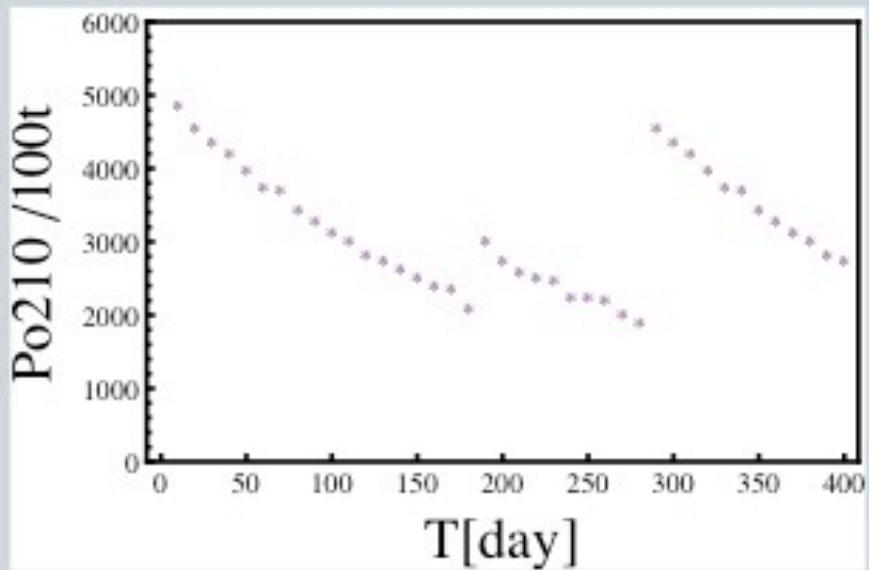
$$n_{\text{CNO}}^{2y} = 5.4 \pm 1.1 \text{ (cpd/100t)}$$

$$n_{\text{CNO}}^{3y} = 3.7 \pm 1.0 \text{ (cpd/100t)}$$

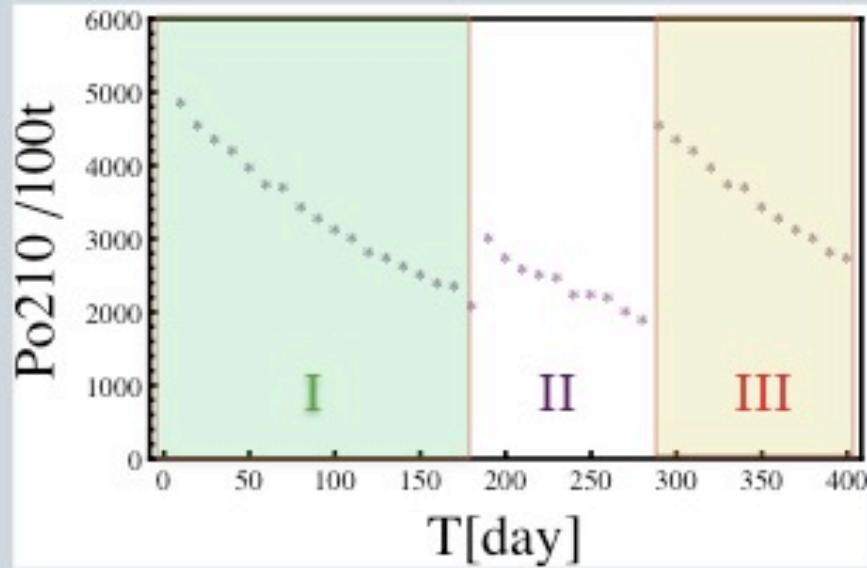
Combined analysis of next three years of data

$$n_{\text{CNO}}^{\text{TOT}} = 4.1 \pm 0.7 \text{ (cpd/100t)}$$

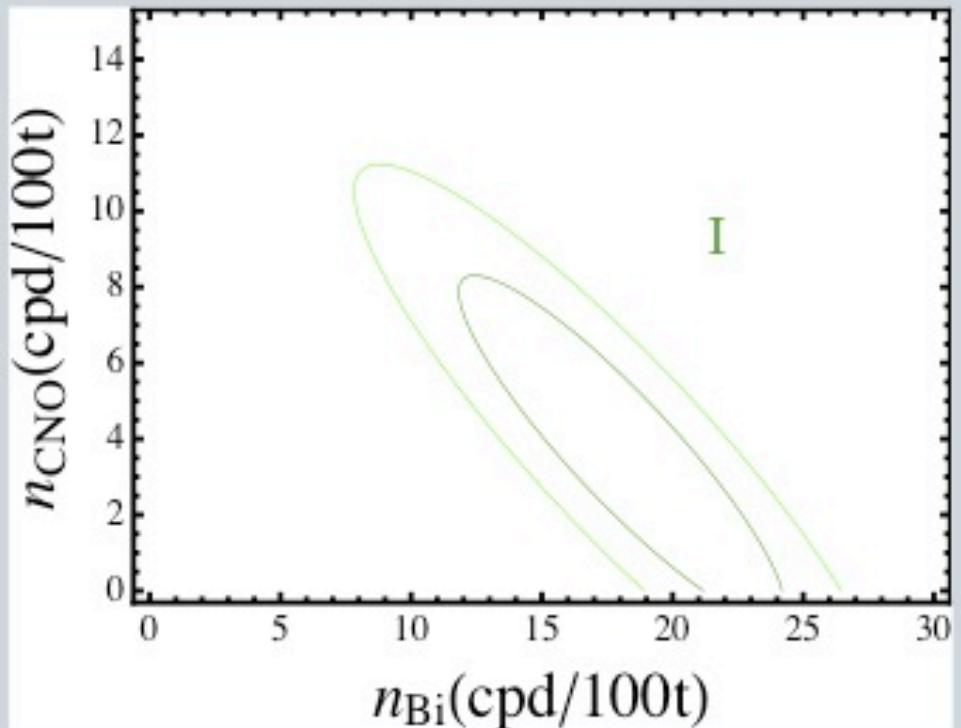
Polonium Fluctuations



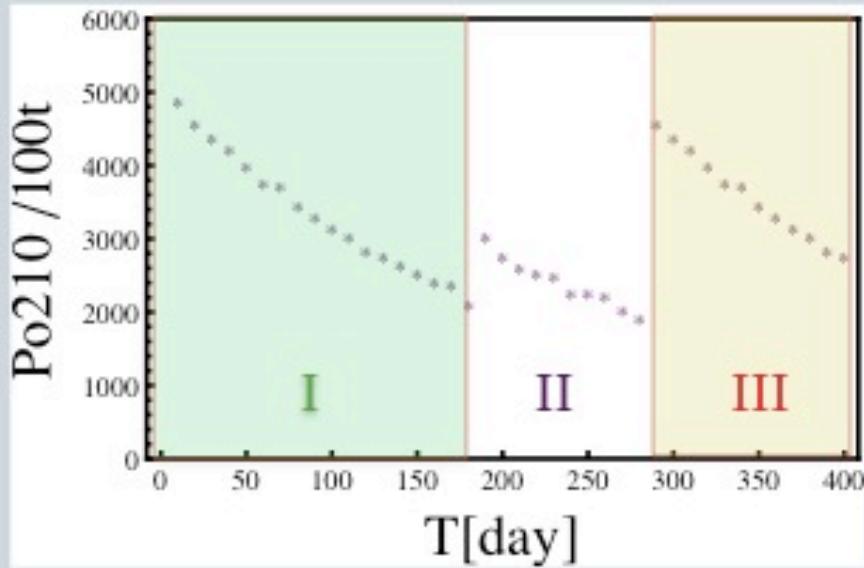
Polonium Fluctuations



$$n_{\text{CNO}}^I = 3.7 \pm 3.0 \text{ (cpd/100t)}$$

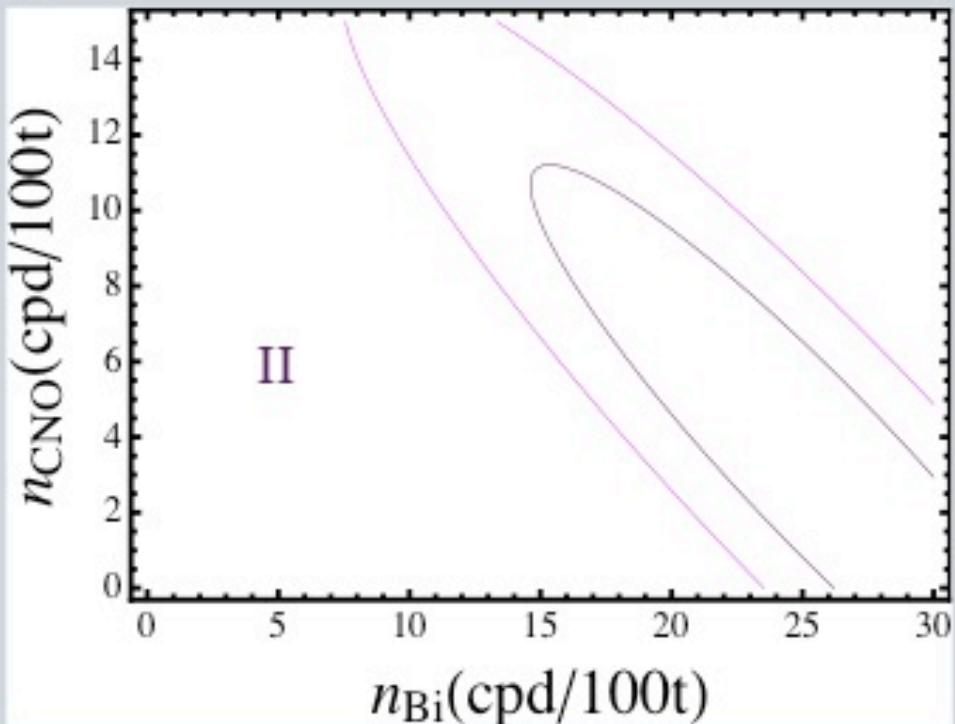


Polonium Fluctuations

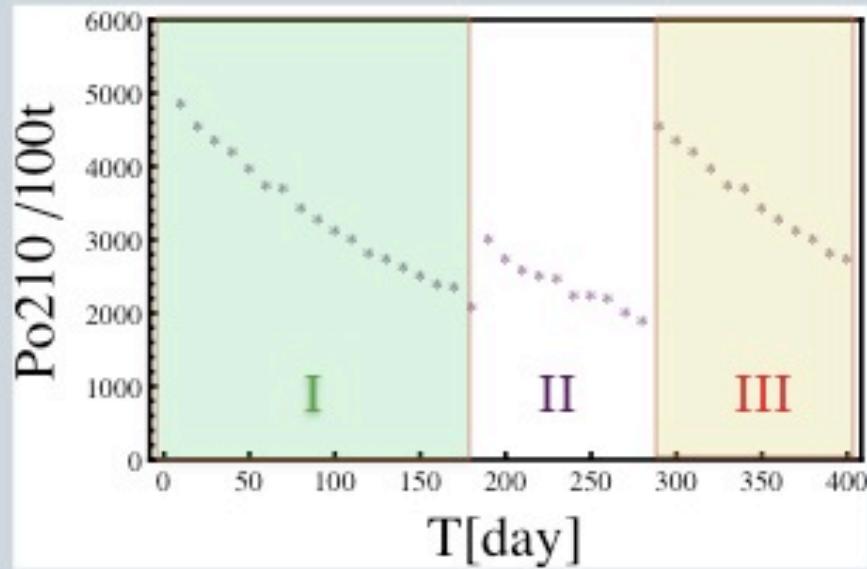


$$n_{\text{CNO}}^I = 3.7 \pm 3.0 \text{ (cpd/100t)}$$

$$n_{\text{CNO}}^{II} = 3.2 \pm 5.3 \text{ (cpd/100t)}$$



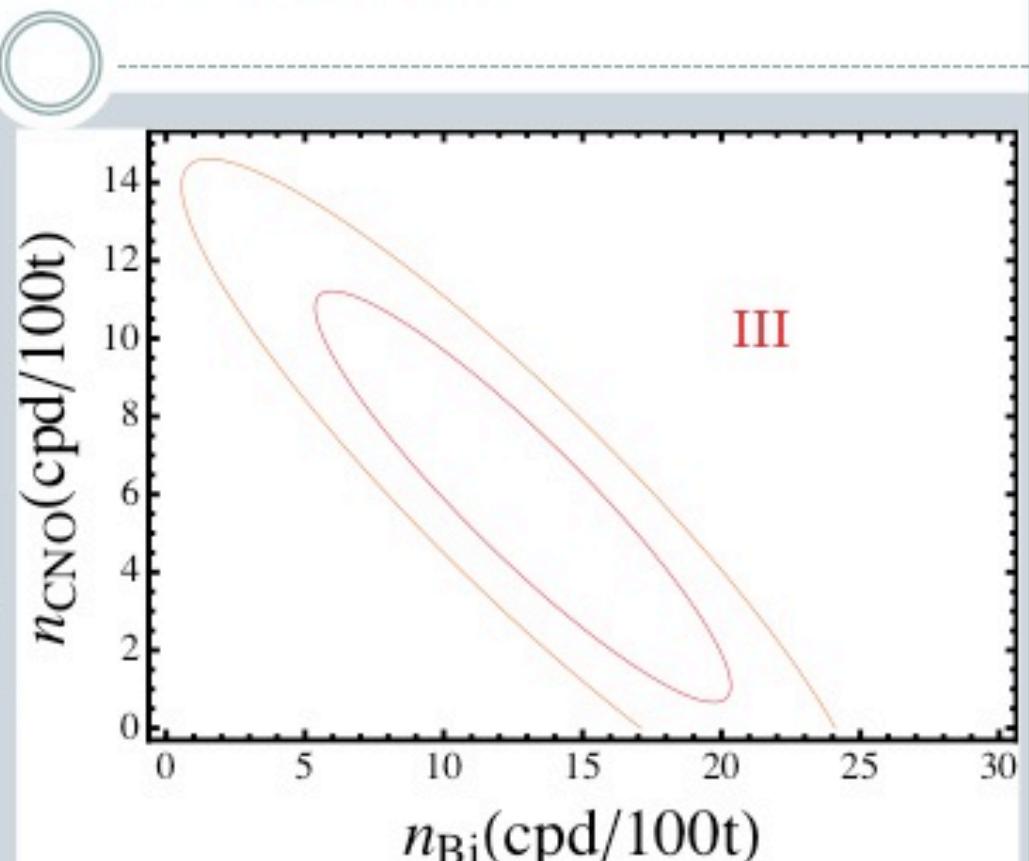
Polonium Fluctuations



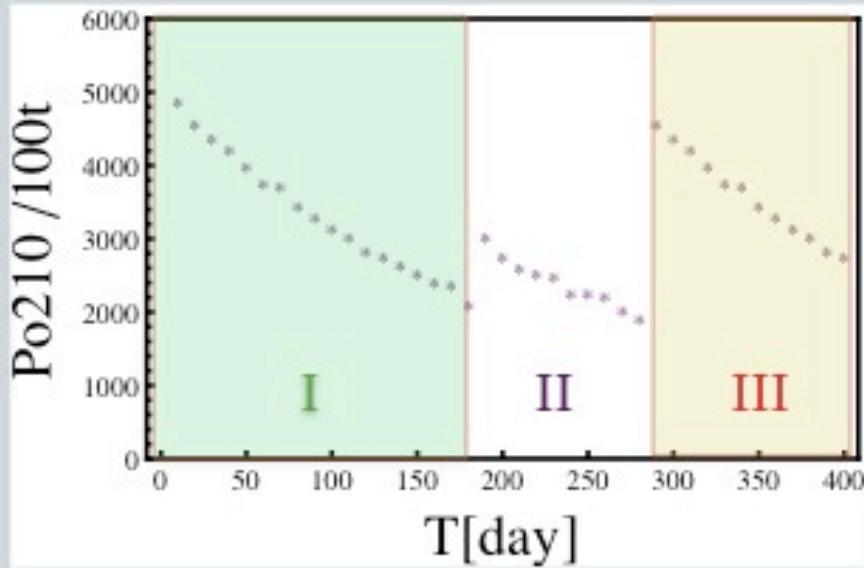
$$n_{\text{CNO}}^I = 3.7 \pm 3.0 \text{ (cpd/100t)}$$

$$n_{\text{CNO}}^{II} = 3.2 \pm 5.3 \text{ (cpd/100t)}$$

$$n_{\text{CNO}}^{III} = 5.9 \pm 3.5 \text{ (cpd/100t)}$$



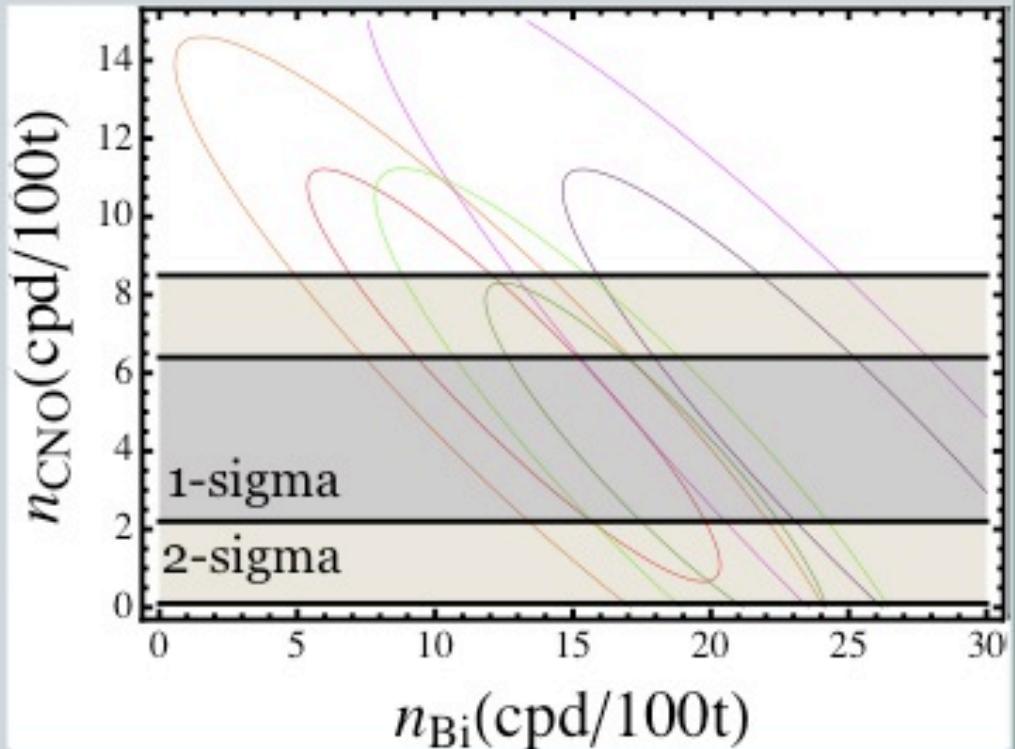
Polonium Fluctuations



$$n_{\text{CNO}}^I = 3.7 \pm 3.0 \text{ (cpd/100t)}$$

$$n_{\text{CNO}}^{II} = 3.2 \pm 5.3 \text{ (cpd/100t)}$$

$$n_{\text{CNO}}^{III} = 5.9 \pm 3.5 \text{ (cpd/100t)}$$



$$n_{\text{CNO}}^{TOT} = 4.3 \pm 2.1 \text{ (cpd/100t)}$$

CONCLUSIONS

- Bismuth-210 decay spectrum is degenerate with the CNO neutrino signal
- Polonium-210 decay rate is related with the one of the Bismuth-210
- Taking into account this relation the degeneracy is broken and CNO can be extracted
- The sensitivity actually reached from Borexino is unique and the CNO detection could be close in time