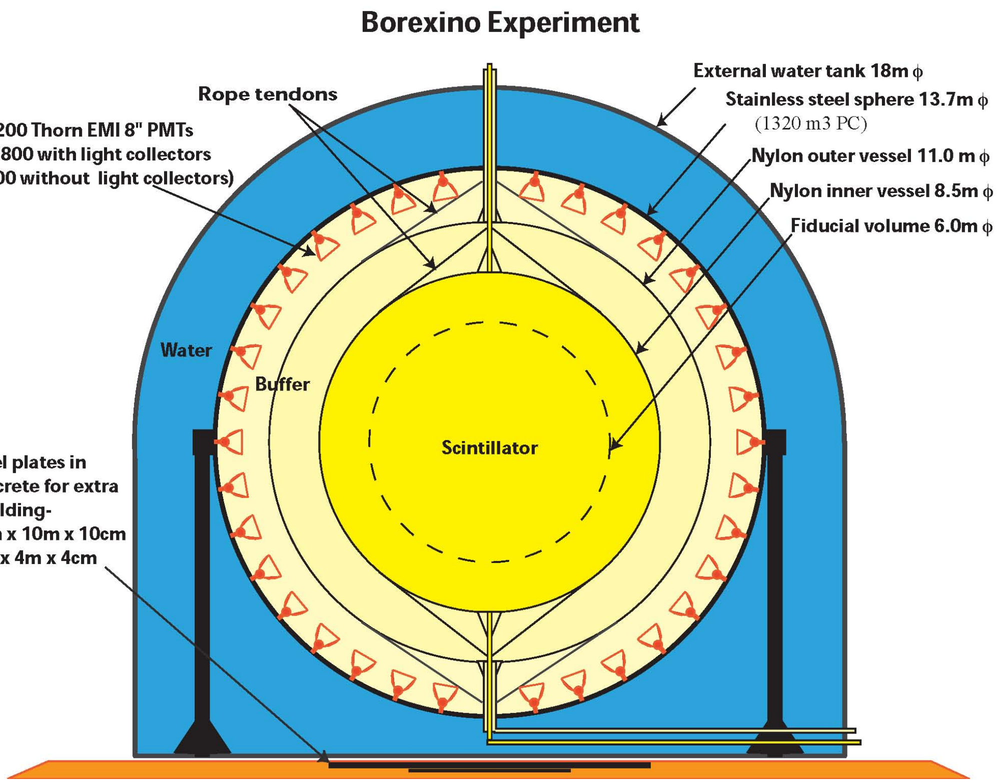
Evidence of large potassium abundance in the Earth from new Borexino data

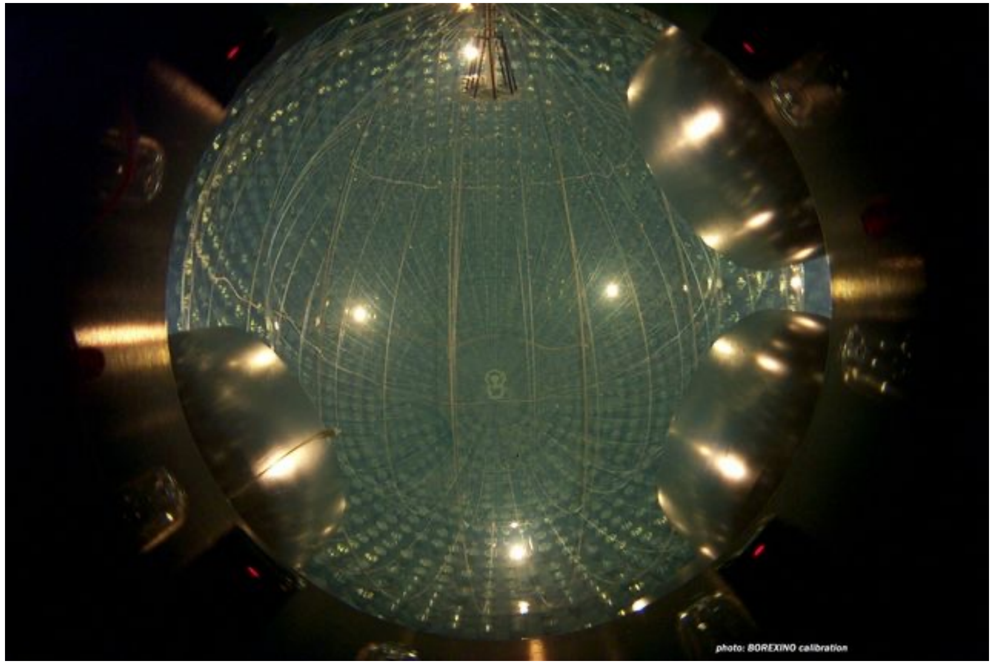
Valery Sinev[1,2], Leonid Bezrukov[1], Ivan Karpikov[1]

[1] Institute for Nuclear Research RAS

[2]National Research Nuclear University (MEPhI)

Borexino experiment





View from inner camera

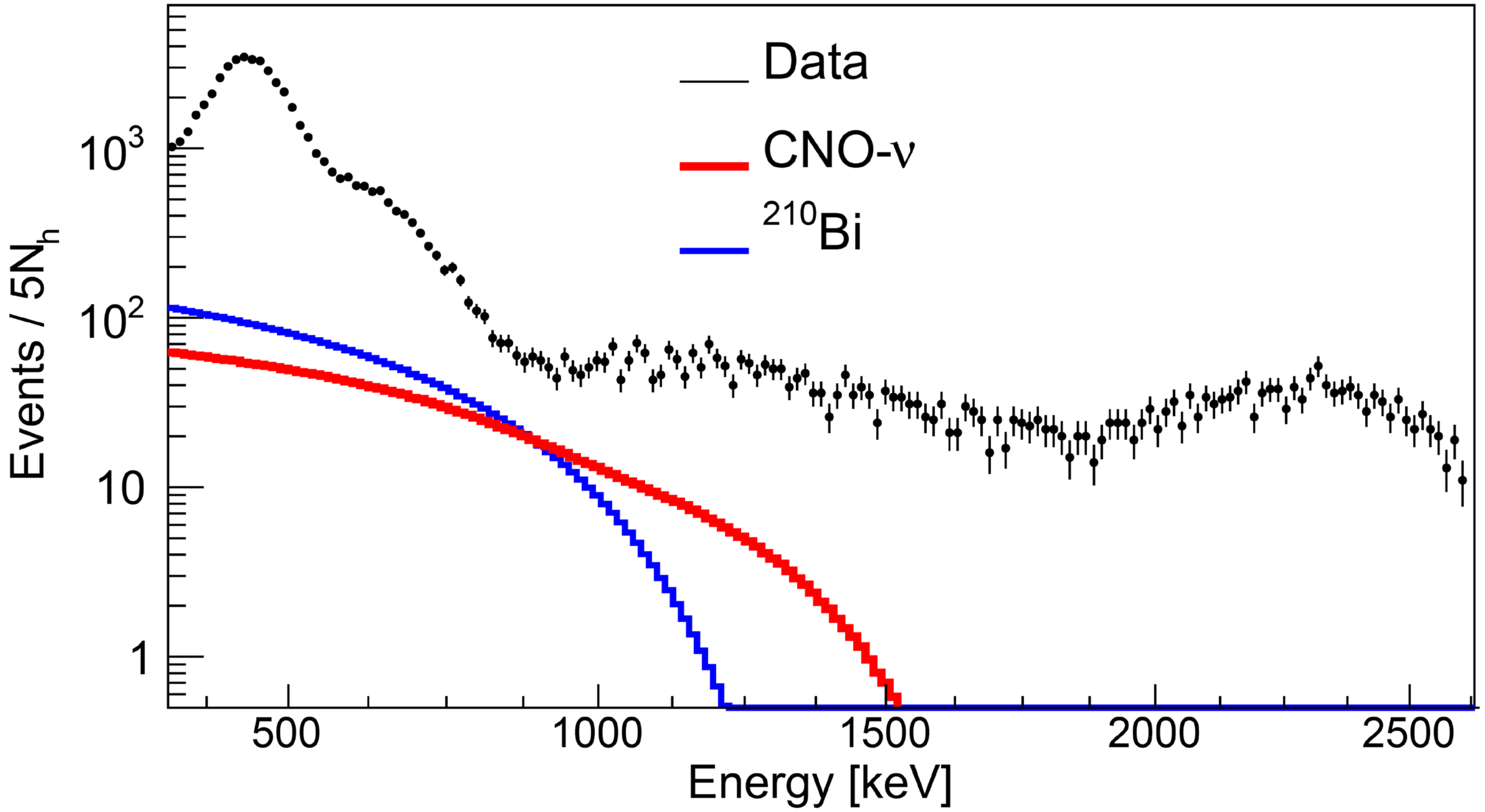
Borexino detects single events from electrons, gammas and alphas

Что меряет Борексино?

- Рассеяние нейтрино на электроне. А значит и антинейтрино тоже.
- Есть возможность оценить антинейтринные потоки, например геонейтрино от калия (^{40}K).
- Сколько калия в Земле и какой поток он производит?
- 0.024% дает 0.05 событий в сутки в 100 т
- 1% - 2 события в сутки.
- В коре 1.5-2.5% калия по массе. Сколько внутри – неизвестно.

Final single events spectrum from Borexino done for 871.37 day of live time measurements

Final Phase-III dataset: Jan 2017-Sep 2021; N_{ev}= 110000



year	N_{events}
2020	42037
2022	53732

How to analyze the Borexino spectrum?

There is a set of calculated spectra that are applied to fit the experimental spectrum.

Solar neutrinos spectra:

^{8}B, ^{7}Be, *pep*, CNO (^{13}N, ^{15}O, ^{17}F)

Backgrounds:

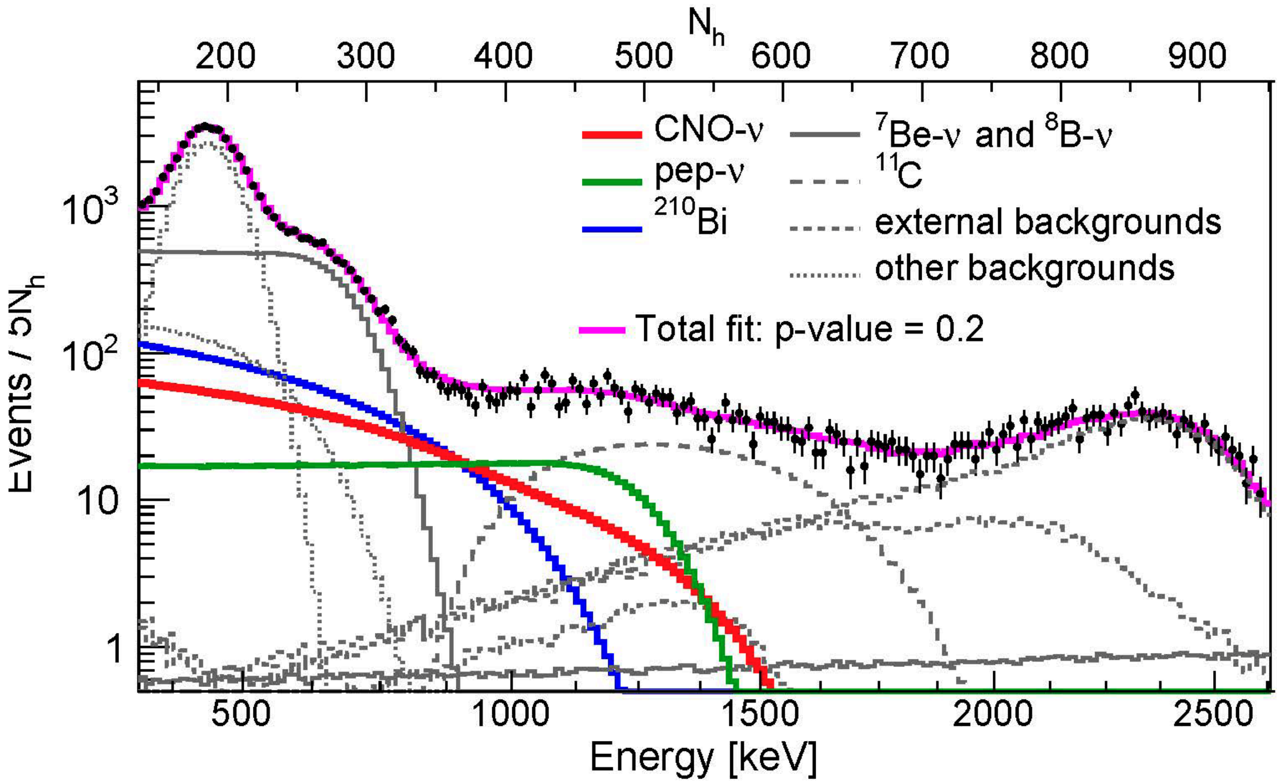
^{210}Po, ^{210}Bi, ^{85}Kr, ^{11}C – inner inside the scintillator

^{208}Tl, ^{214}Bi, ^{40}K – coming from outside

Each component has an individual spectrum that is calculated and normalized by unit. It is pdf – probability density function.

When fitting experimental spectrum one founds coefficients for pdf-s that are integrals of components.

Fit of Borexino spectrum



R(CNO) = $6.7^{+2.0}_{-0.8}$

R(^{7}Be) = 48 +- 2.0

R(^{210}Bi) <= 10.8 ± 1.0

R(^{85}Kr) <= 8.5 ± 2.0

R(^{210}Po) = 42 ± 2.0

R(^{11}C) = 1.4 ± 0.2

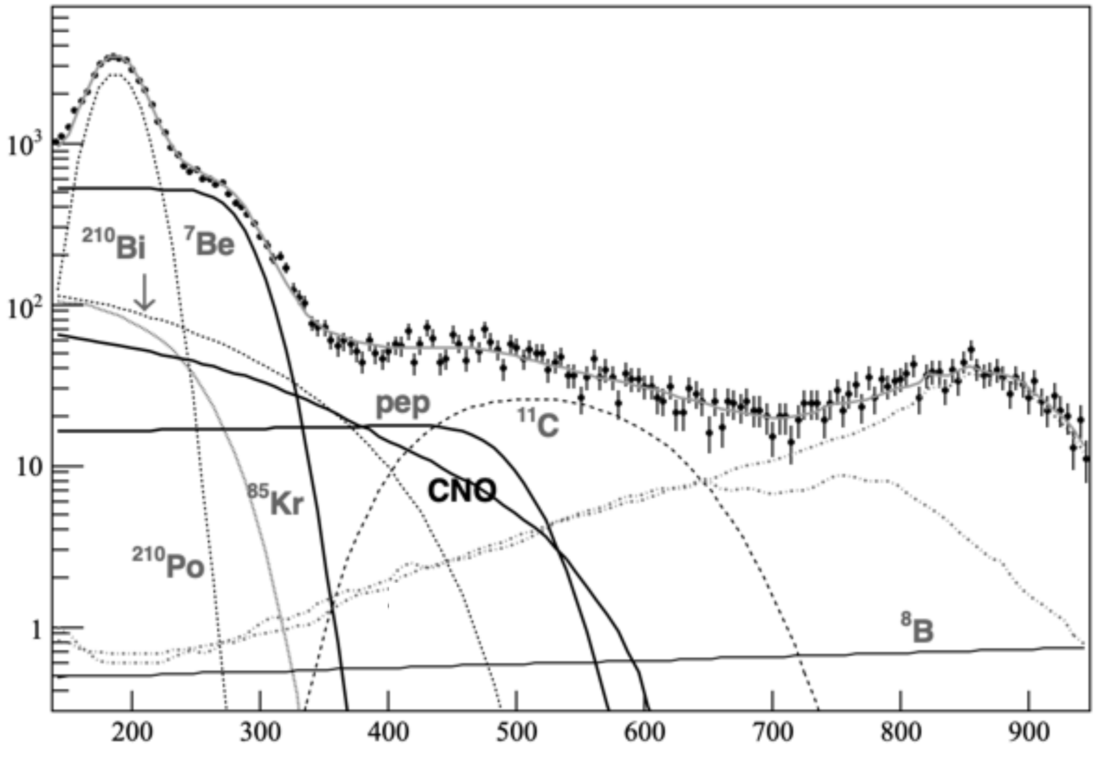
R(*pep*) = 1.74 ± 0.04

R(^{214}Bi) = 1.8 ± 0.2

R(^{208}Tl) = 4.4 ± 0.2

We have reproduced the analysis of Borexino data the same way

Our fit of Borexino data



R(CNO) = 6.7 ± 1.6

$R(^{7}Be)$ = 48 +- 2.0
$R(^{210}Bi)$ = 10.8 ± 1.0
$R(^{85}Kr)$ = 8.5 ± 2.0
$R(^{210}Po)$ = 42 ± 2.0
R(^{11}C) = 1.7 ± 0.8
$R(pep)$ = 1.74 ± 0.04
$R(^{214}Bi)$ = 1.8 ± 0.2
$R(^{208}Tl)$ = 4.4 ± 0.2

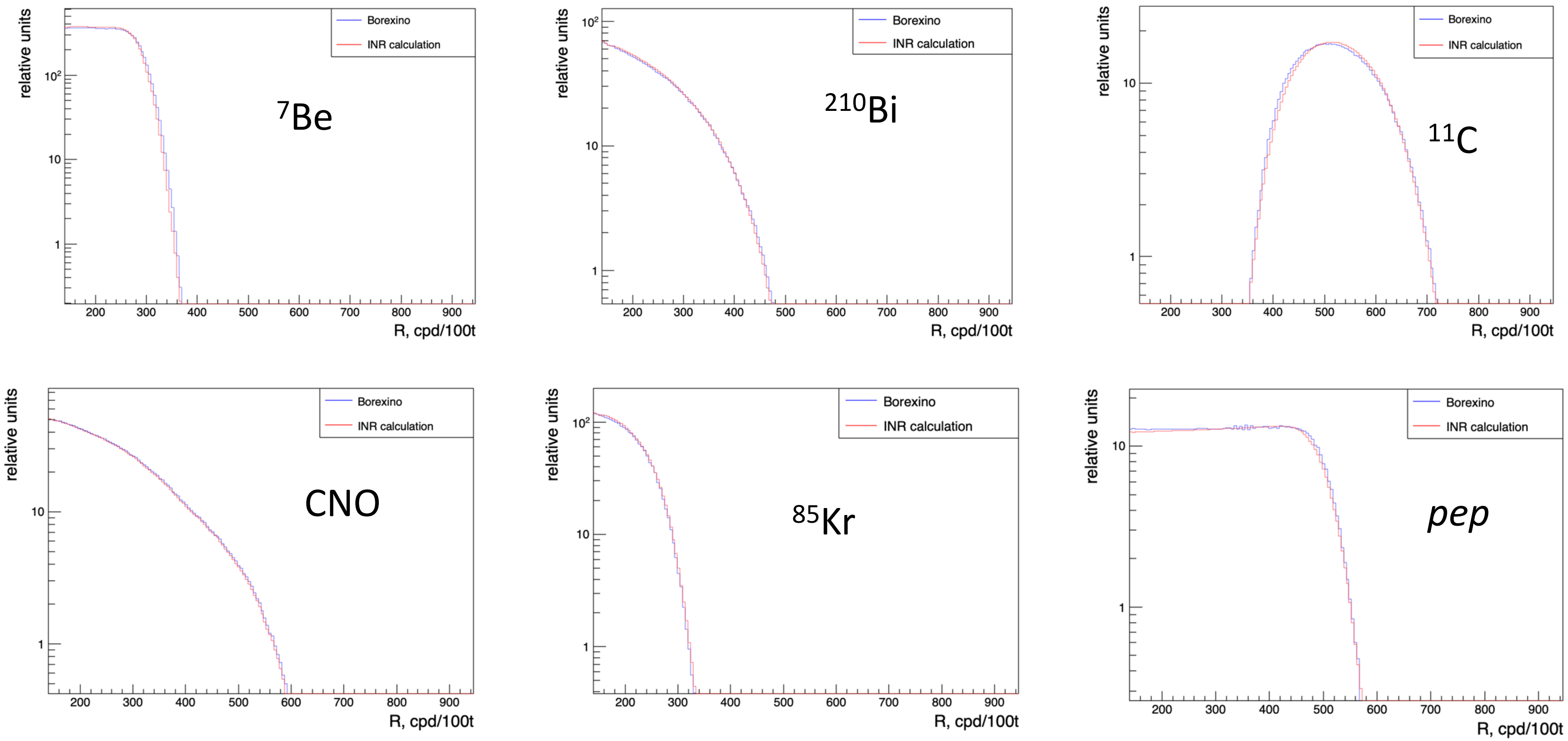
χ^2 = 199

Potassium problem

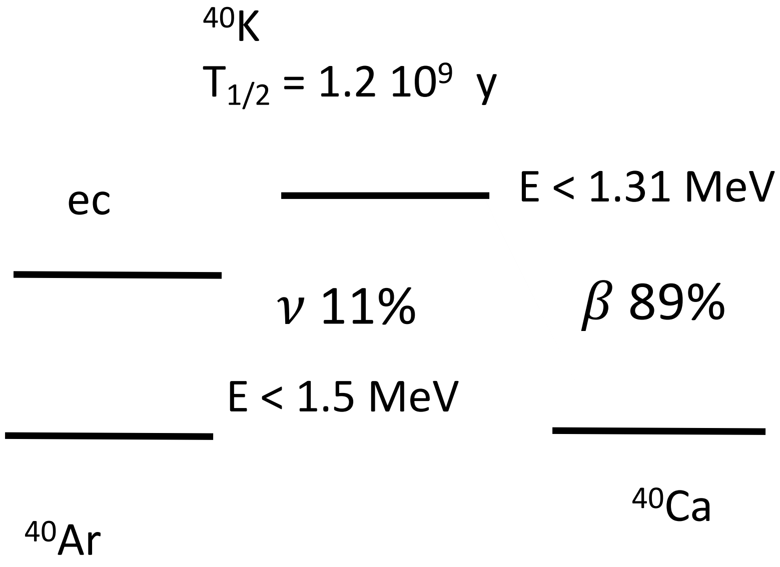
- Potassium abundance in the crust a_K = (1.5 – 2.5)%
- To explain the fact that the Earth is not melted now, they proposed that it was melted some time ago, and while cooling the crust was formed and all potassium comes into the crust (lithophilic element). Then mean abundance became a_K = 0.024%.
- BUT. Large potassium abundance can explain climate changes taking place on the Earth from time to time.
- There is no evidence of the Earth being melted in the past, it is just hypothesis.
- Neutrino detection can setup an upper limit on potassium abundance.

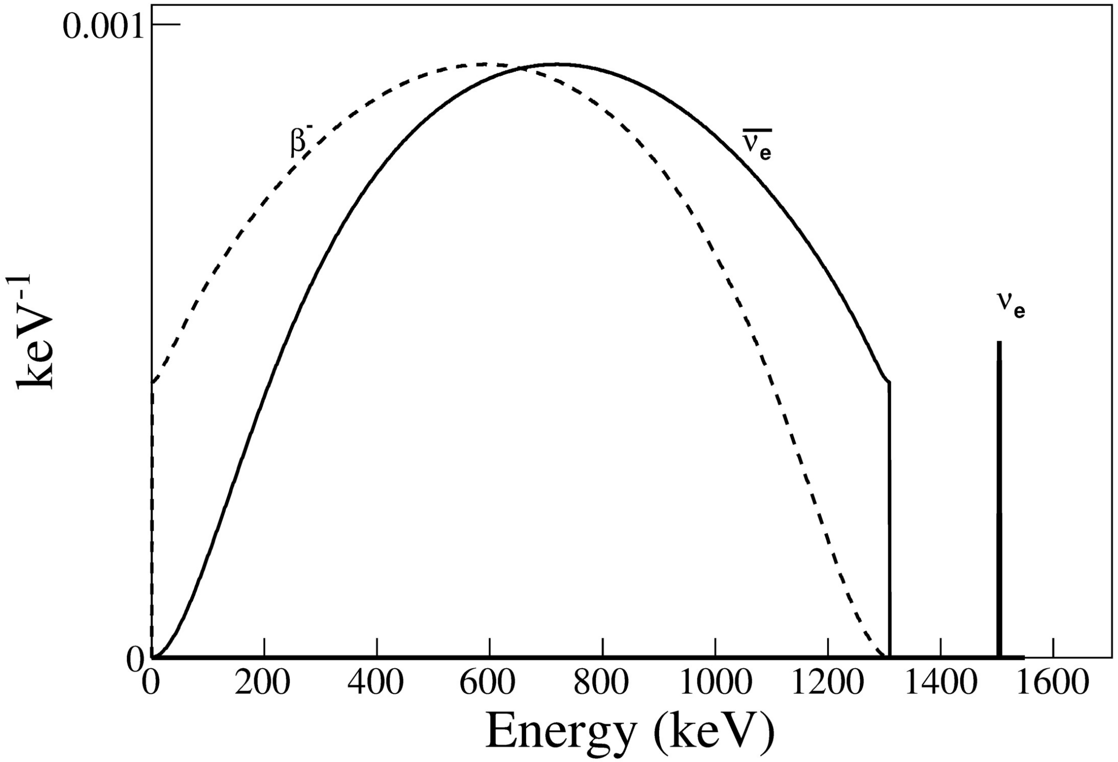
We did our own analysis of Borexino data

Comparison of our pdf-s with Borexino Collaboration ones

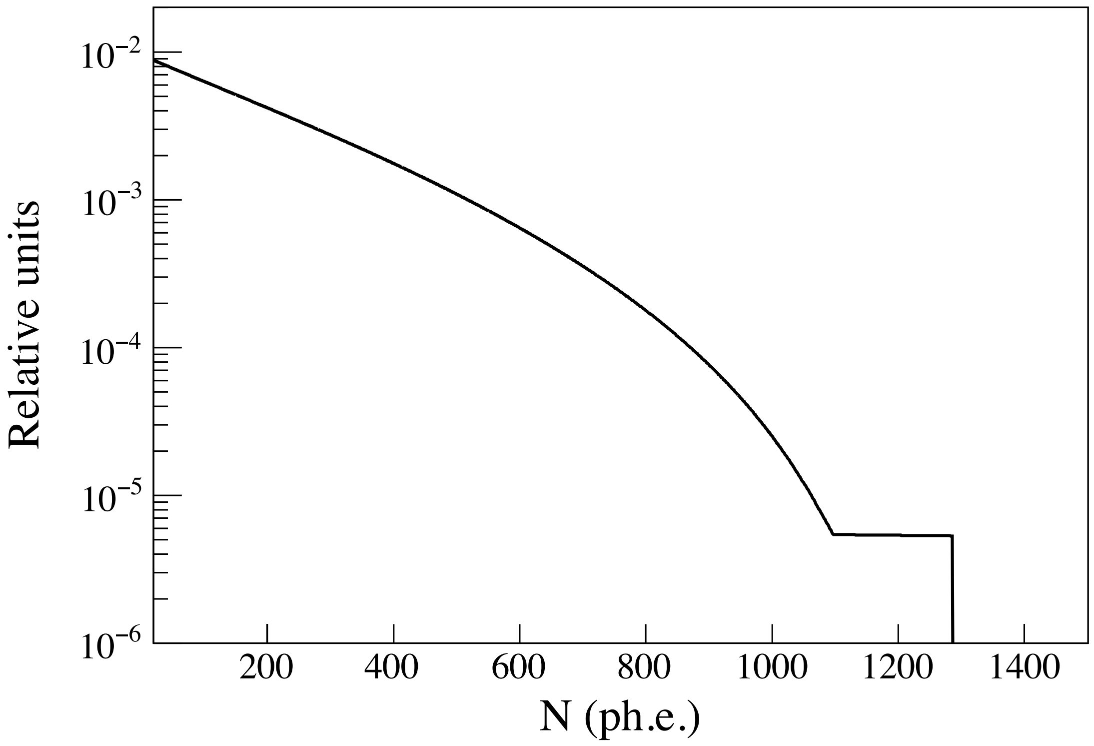


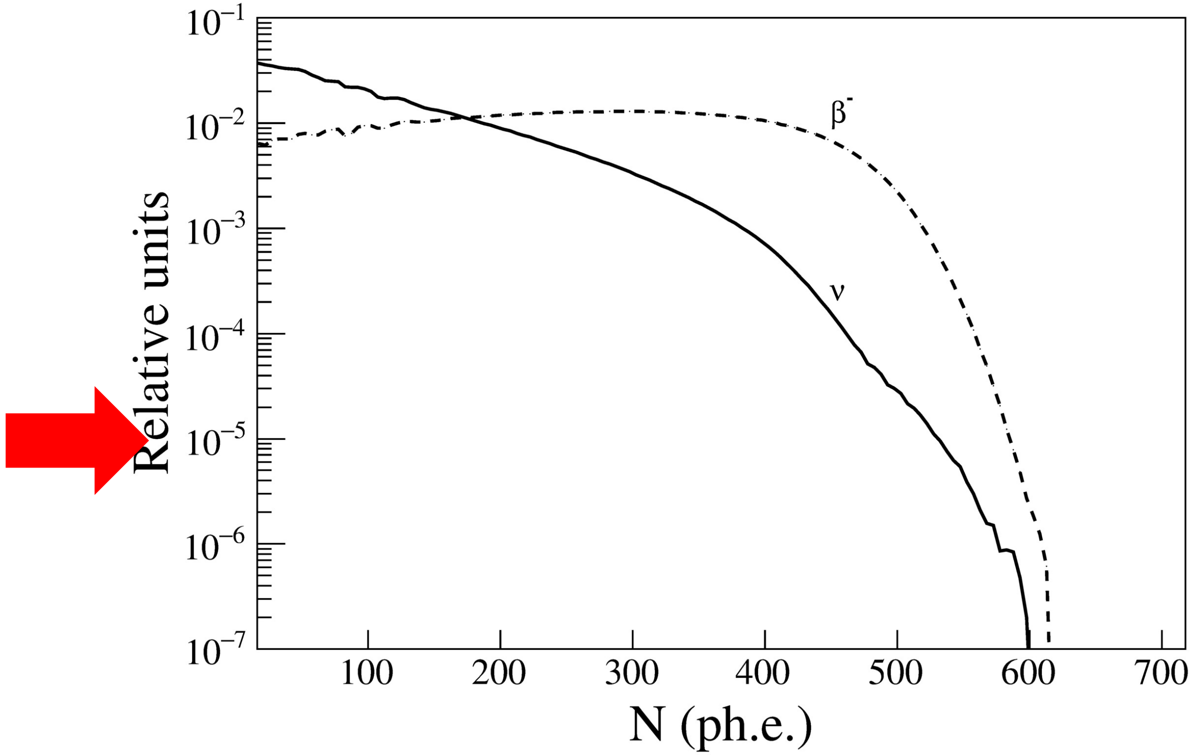
^{40}K antineutrino and neutrino spectra





^{40}K antineutrino and neutrino spectra transformed into pdf for the analysis. ^{40}K beta spectrum was transformed too

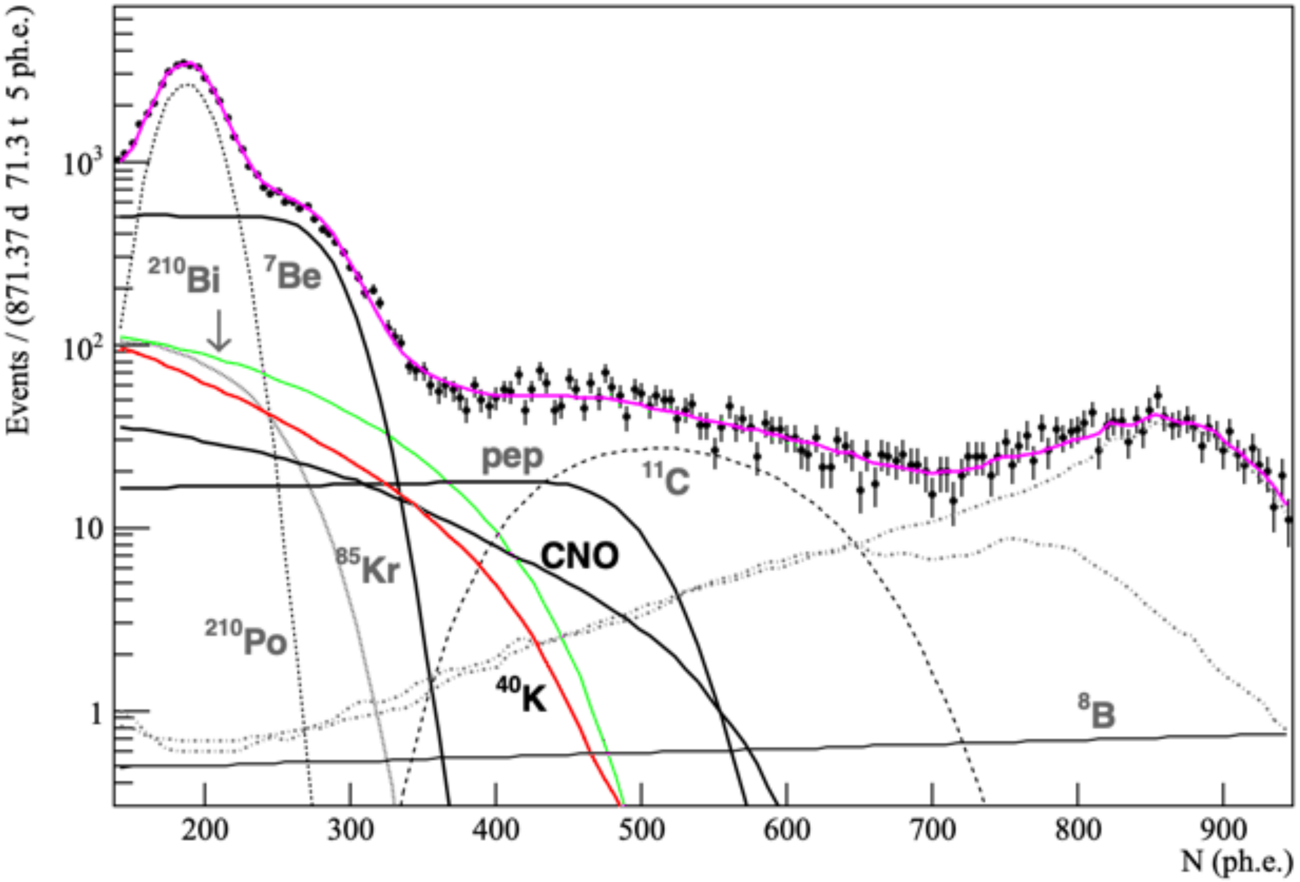




Fit of Borexino spectrum with ^{40}K pdf

Analysis was performed independently by two persons.

1. ROOT
2. Python



$R(CNO) = 3.9 \pm 0.4$

$R(^{7}Be) = 47 \pm 0.2$

$R(^{210}Bi) = 10.7 \pm 0.3$

$R(^{85}Kr) = 8.5 \pm 0.4$

$R(^{210}Po) = 41 \pm 0.5$

$R(^{11}C) = 1.75 \pm 0.08$

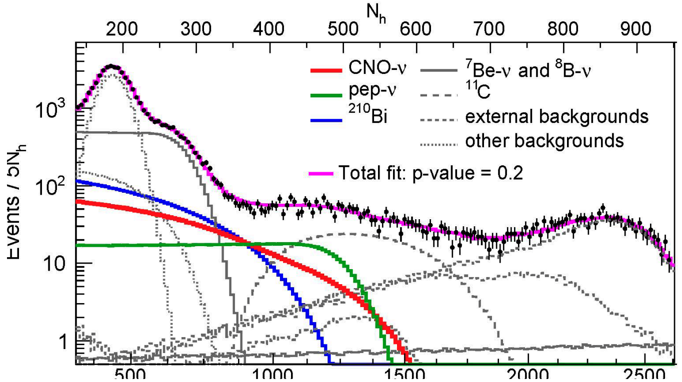
$R(pep) = 1.74 \pm 0.04$

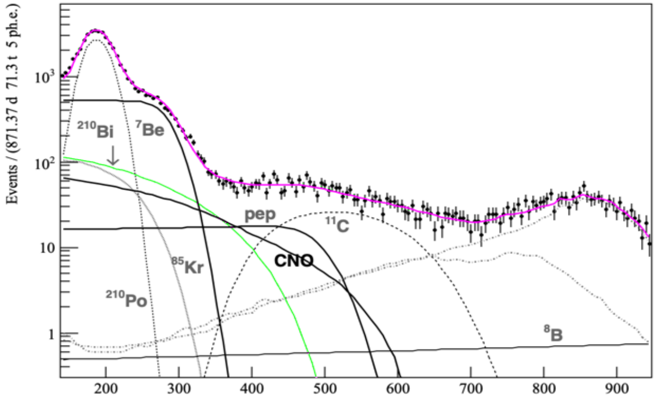
$R(^{214}Bi) = 1.8 \pm 0.2$

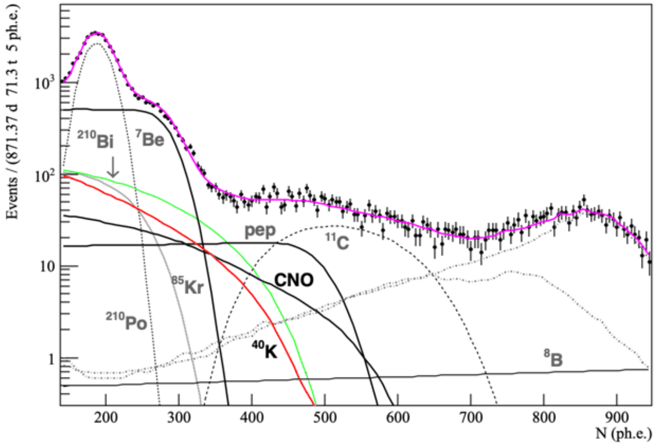
$R(^{208}Tl) = 4.7 \pm 0.2$

$R(^{40}K) = 11.0 \pm 1.2$

$\chi^2 = 175.7$





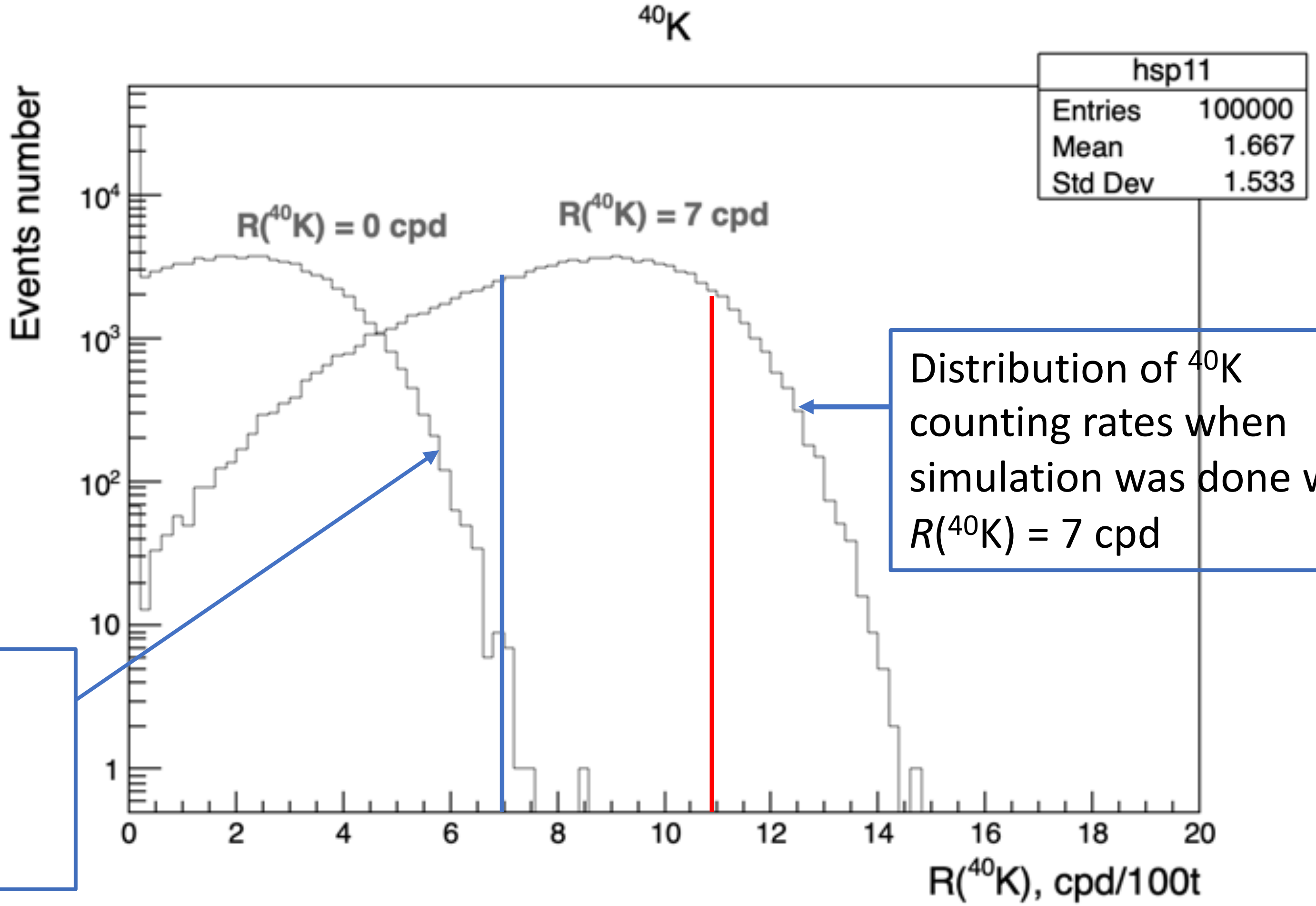


Borexino analysis	INR analysis: No ^{40}K	INR analysis: with ^{40}K
R(CNO) = $6.7^{+2.0}_{-0.8}$	R(CNO) = 6.7 ± 1.6	R(CNO) = 3.9 ± 0.4
R(^{7}Be) = 48 +- 2.0	R(^{7}Be) = 48 +- 2.0	R(^{7}Be) = 47 ± 0.2
R(^{210}Bi) <= 10.8 ± 1.0	R(^{210}Bi) = 10.8 ± 1.0	R(^{210}Bi) = 10.7 ± 0.3
R(^{85}Kr) <= 8.5 ± 2.0	R(^{85}Kr) = 8.5 ± 2.0	R(^{85}Kr) = 8.5 ± 0.4
R(^{210}Po) = 42 ± 2.0	R(^{210}Po) = 42 ± 2.0	R(^{210}Po) = 41 ± 0.5
R(^{11}C) = 1.4 ± 0.2	R(^{11}C) = 1.7 ± 0.8	R(^{11}C) = 1.75 ± 0.08
R(*pep*) = 1.74 ± 0.04	R(*pep*) = 1.74 ± 0.04	R(*pep*) = 1.74 ± 0.04
R(^{214}Bi) = 1.8 ± 0.2	R(^{214}Bi) = 1.8 ± 0.2	R(^{214}Bi) = 1.8 ± 0.2
R(^{208}Tl) = 4.4 ± 0.2	R(^{208}Tl) = 4.4 ± 0.2	R(^{208}Tl) = 4.7 ± 0.2
	R(^{40}K) = 0	R(^{40}K) = 11.0 ± 1.2
χ^2 = ?	χ^2 = 200	χ^2 = 175

What is probability to find ^{40}K if it is absent? Monte Carlo simulated distributions of counting rate

$P(R_{40K} > 7$ cpd/100t$) = 3\times10^{-5}$ in case of ^{40}K absence

And in contrast
$P(R_{40K} <= 11$ cpd/100t$) = 0.93$
in case of ^{40}K presence



Distribution of ^{40}K counting rates when simulation was done with $R(^{40}K) = 7$ cpd

Distribution of ^{40}K counting rates when simulation was done without ^{40}K

Conclusion

- We learned how to make the analysis of Borexino Collaboration data data.
- We reproduced Borexino result in case of ^{40}K absence.
- We introduced in our analysis ^{40}K pdf.
- In the analysis with ^{40}K the χ^2-value is smaller (175) than the one without it (200).
- There was performed virtual experiment (M-C) with and without ^{40}K.
- Probability to find large value of ^{40}K counting rate (>7 cpd) in case of its absence $5 \cdot 10^{-5}$.
- Found large value can signal about ^{40}K presence in analyzed spectrum of Borexino single events. This means high enough mass of potassium in the Earth, but surely > 0. Evidence at level 6σ that K abundance > 0.

Выводы

Обнаружение возможного большого содержания калия в Земле по данным Борексино требует дополнительных исследований.

Теоретико-расчетное. Проверка влияния компонент друг на друга; Определение вероятности большого значения скорости счета ^{40}K. Изучение модели Солнца.

В БНО ИЯИ РАН можно:

Независимое измерение спектра CNO в другом эксперименте (например с ^{115}In).

Разработка детектора типа Борексино с чистой пленкой, большим чувствительным объемом и меньшим фоном ^{210}Po, ^{210}Bi, ^{11}C и без ^{85}Kr.