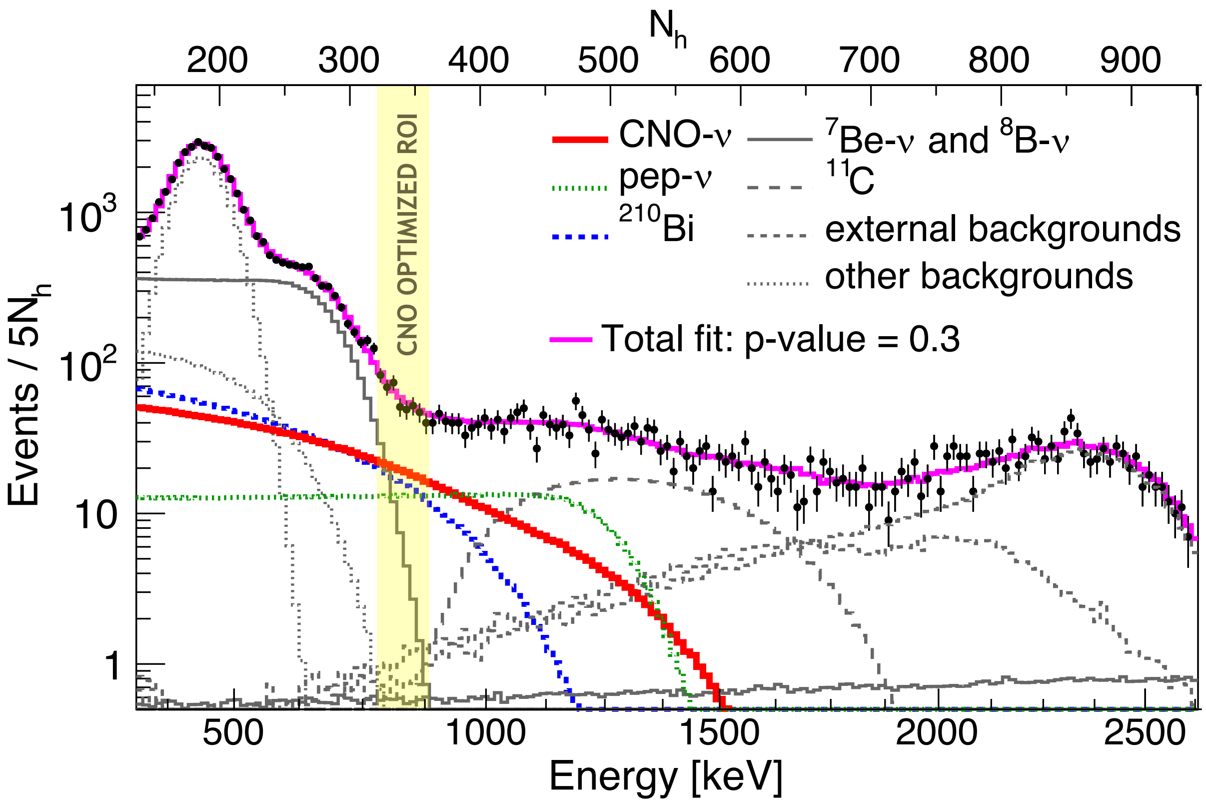
A successful strategy for the CNO measurement with Borexino: the MultiVariate Fit

Alessandra Carlotta Re

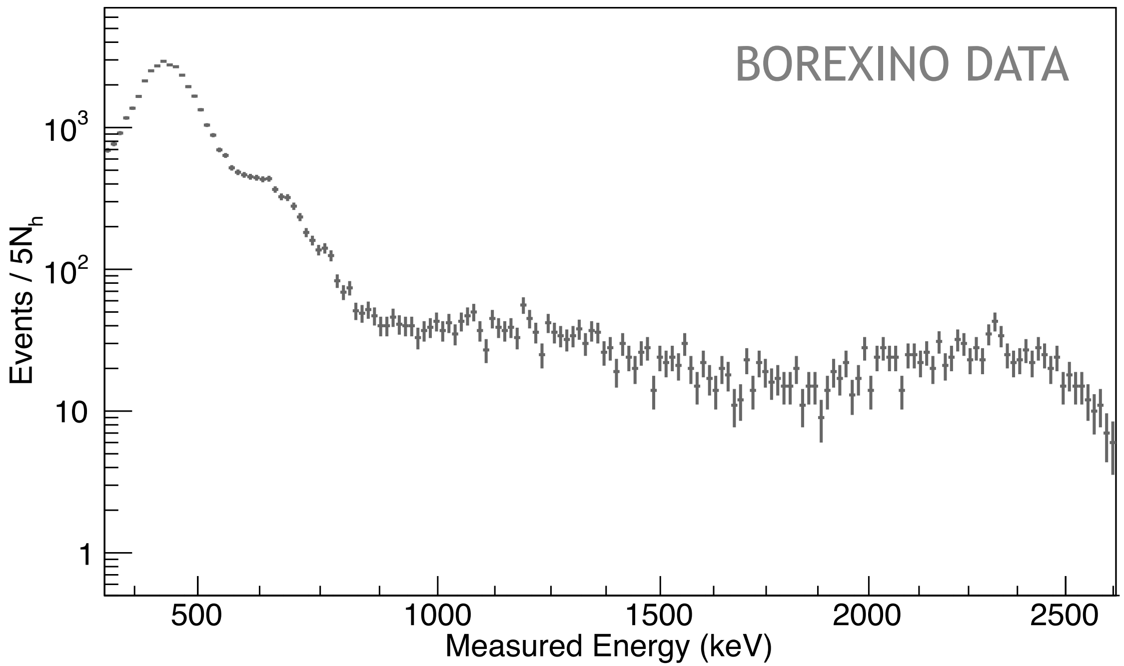
Università degli Studi & INFN, Milano (Italy)

On behalf of the Borexino Collaboration

“Experimental evidence of neutrinos produced in the CNO fusion cycle in the Sun”.
Nature 587 (2020), 577



How to extract the CNO neutrino signal?



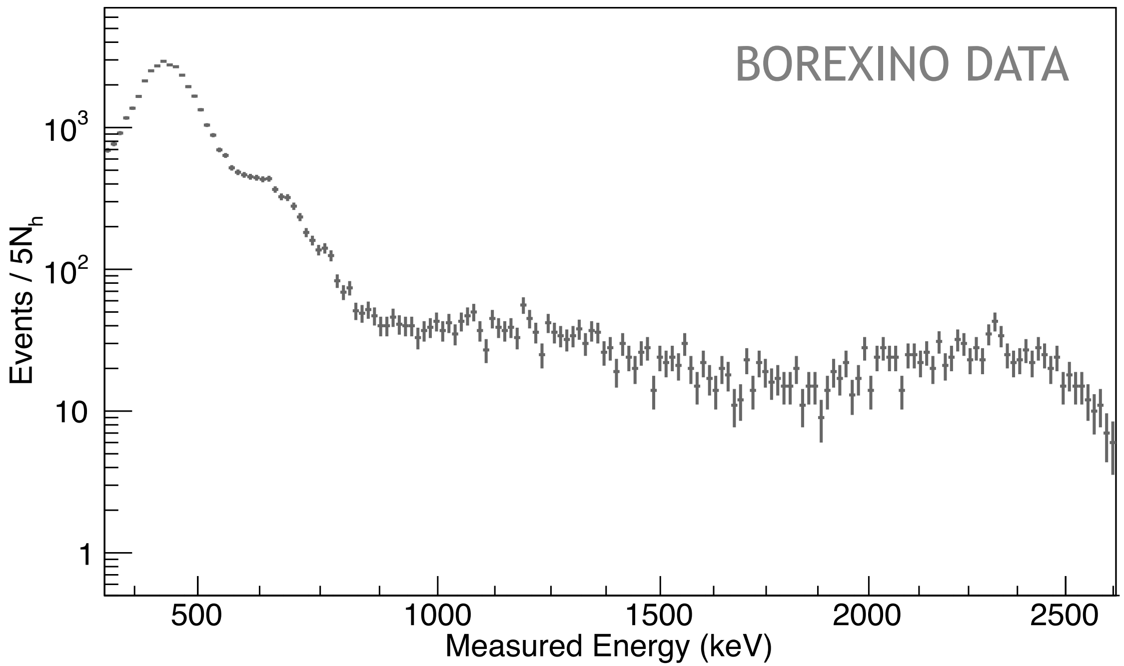
STARTING POINT

Data-set: Phase-III (July 2016 - February 2020) --> Exposure: 1072 days x 71.3 t

Fit range: 0.32 – 2.64 MeV.

Software cuts: 1) Removing muons
2) Selecting a fiducial volume ($r < 2.8$ m, -1.8 m $< z < 2.2$ m)
3) Tagging/Subtracting ^{11}C background

How to extract the CNO neutrino signal?



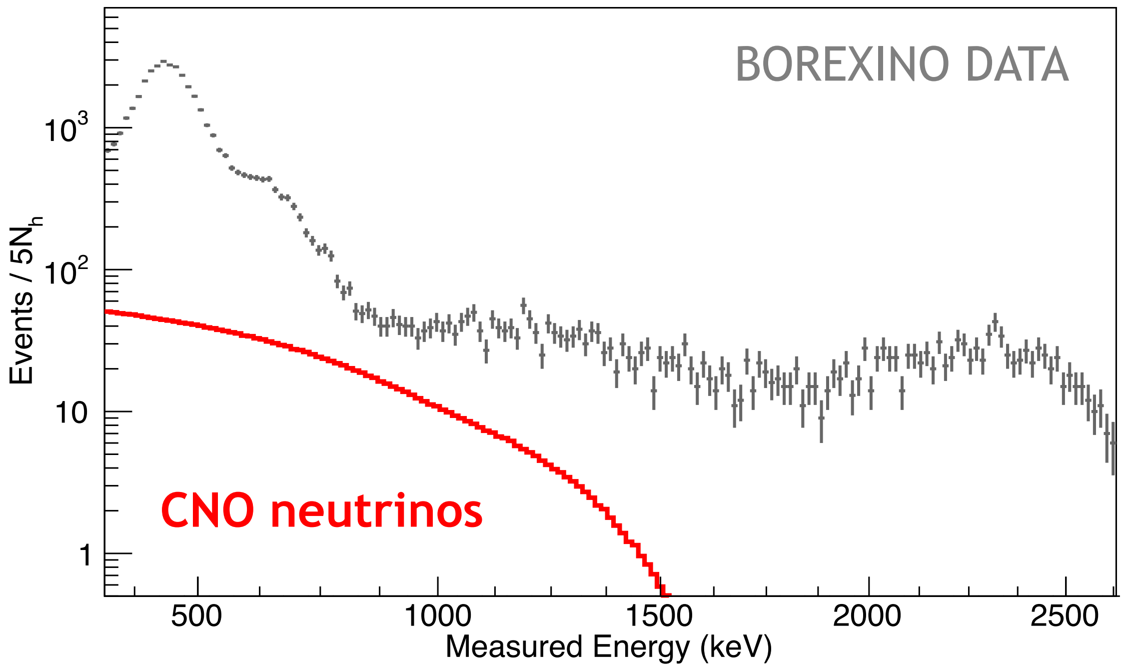
Where are CNO neutrinos?

Data-set: Phase-III (July 2016 - February 2020) --> Exposure: 1072 days x 71.3 t

Fit range: 0.32 – 2.64 MeV.

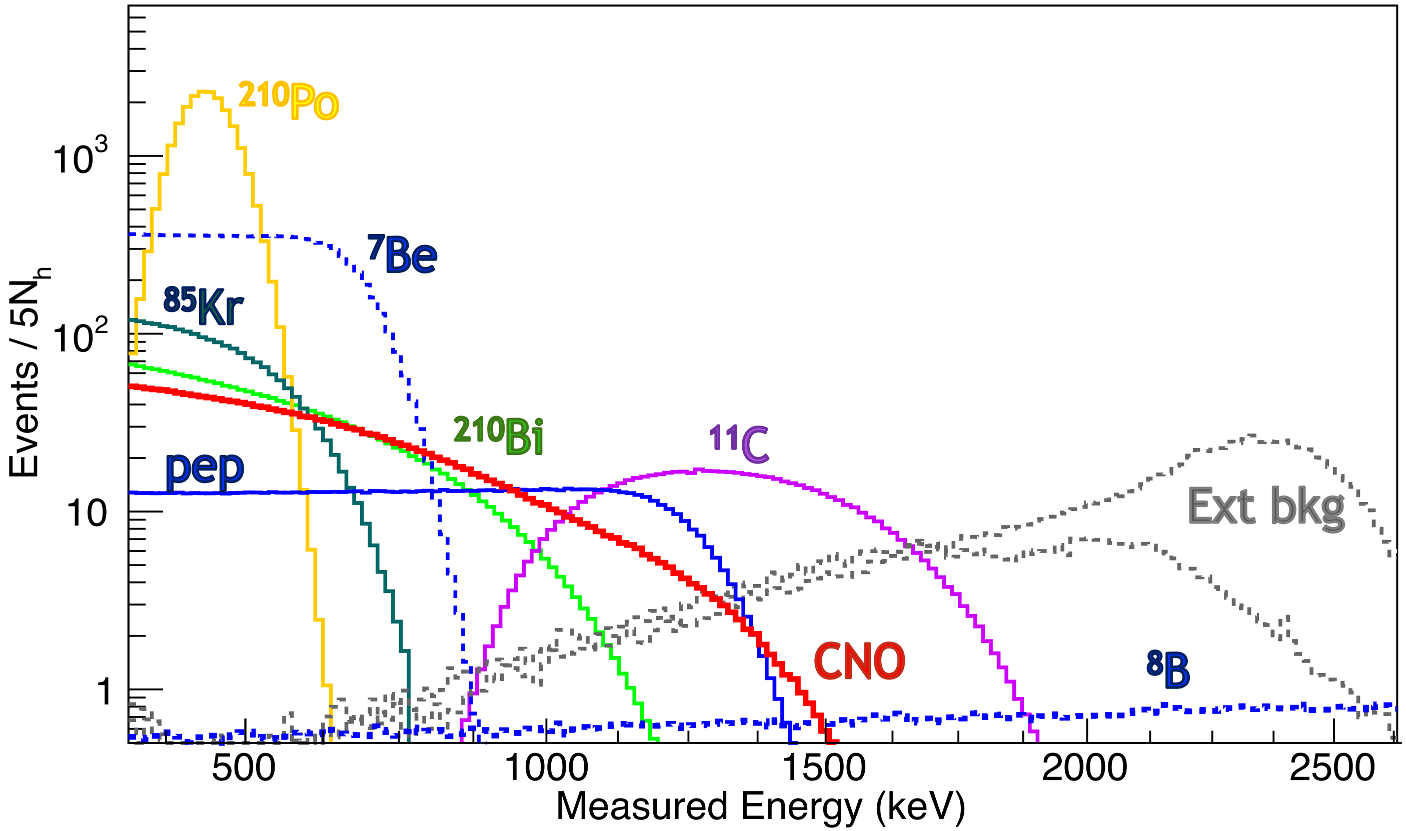
Software cuts: 1) Removing muons
2) Selecting a fiducial volume ($r < 2.8$ m, -1.8 m $< z < 2.2$ m)
3) Tagging/Subtracting ^{11}C background

How to extract the CNO neutrino signal?



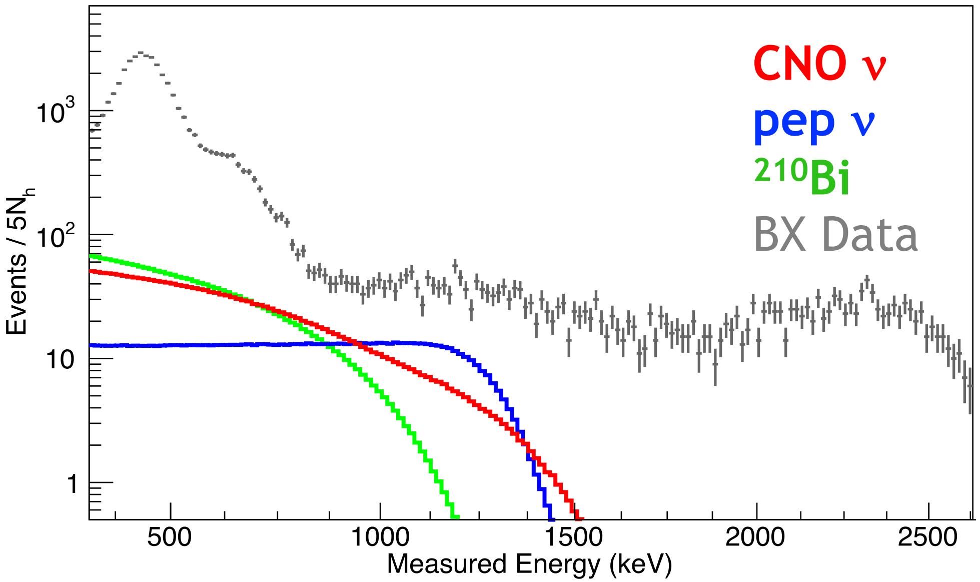
Strategy:
Exploiting the difference in the energy distribution of signal and backgrounds to separate them.
→ The spectral shapes for both components are generated in a Geant4 Borexino-tailored Monte Carlo framework.

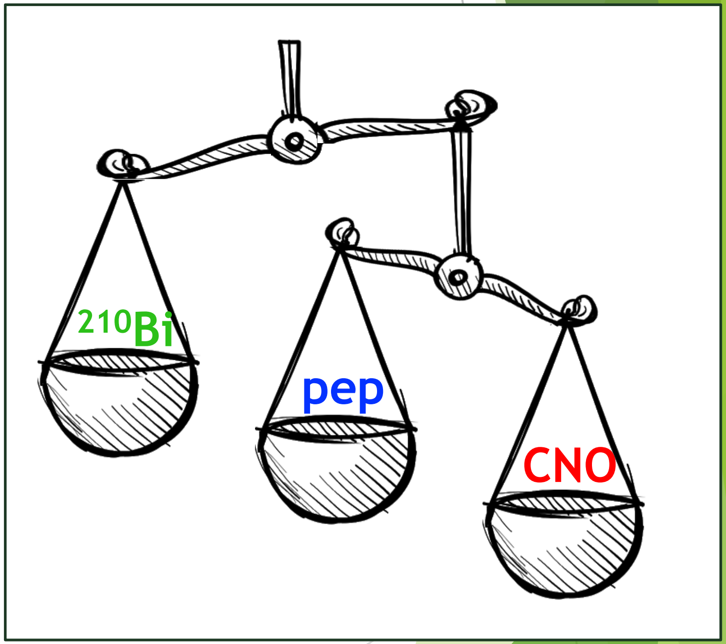
Borexino: The predicted spectral shapes



TOWARDS THE CNO SOLAR-ν MEASUREMENT

The similarity between the CNO, pep and ^{210}Bi spectral shapes limits the sensitivity of Borexino.

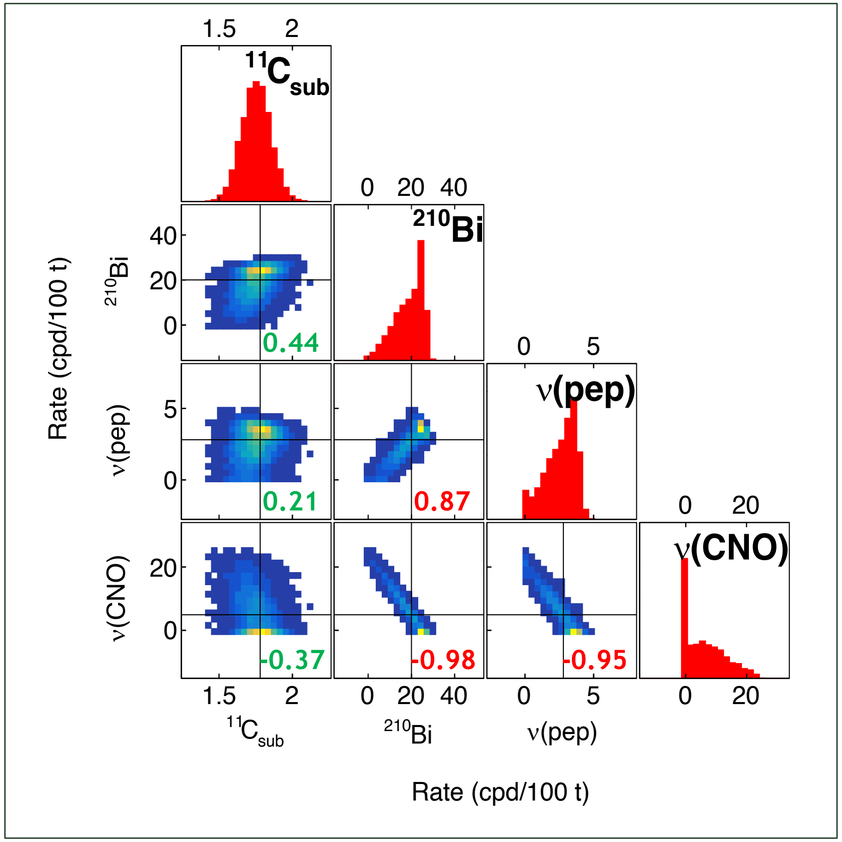




The predicted neutrino rates do not help:

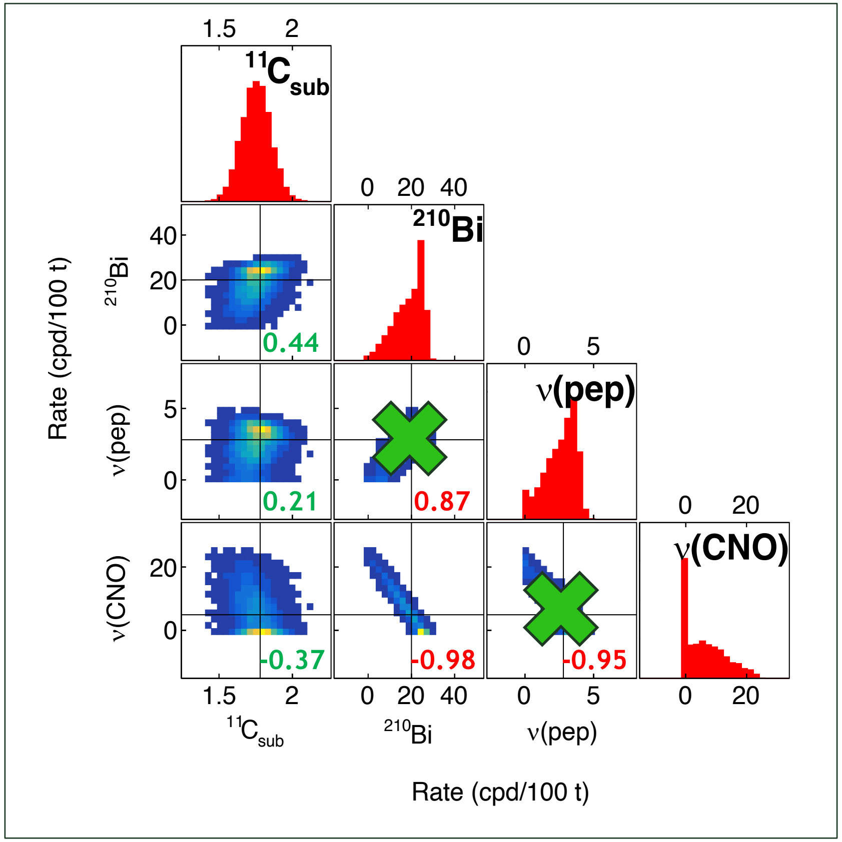
- CNO ν ~ 4-5 cpd/100 ton
- pep ν ~ 3 cpd/100 ton
- ^{210}Bi ~ 15-20 cpd/100 ton

THE PP/PEP RATIO CONSTRAINT



To reduce correlations we put a constraint on the pp/pep ratio following the theoretical predictions as described in *Nature 562 (2018), 505*.

THE PP/PEP RATIO CONSTRAINT



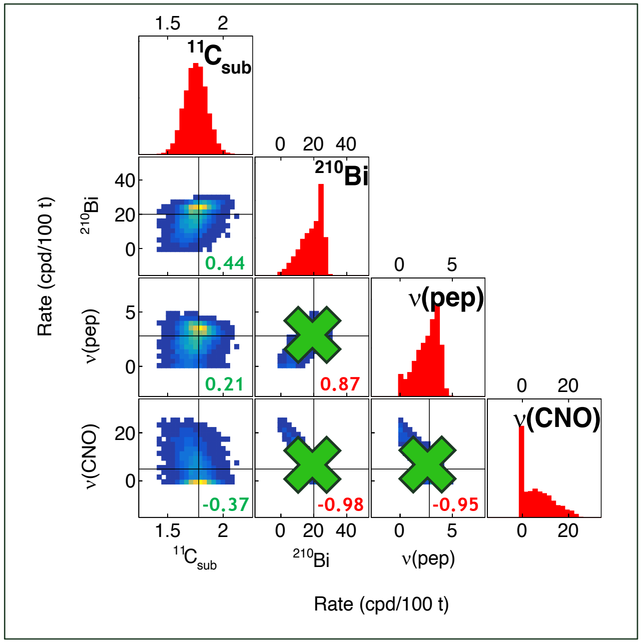
To reduce correlations we put a constraint on the pp/pep ratio following the theoretical prediction as described in *Nature 562 (2018), 505*.

Still, the ^{210}Bi spectrum is quasi-degenerate with the CNO neutrino one…..

THE BISMUTH-210 CONSTRAINT

The ^{210}Bi spectrum is still quasi-degenerate with the CNO neutrino one…..
…. But the ^{210}Bi rate can be constrained by precisely (and indipendently) mapping the ^{210}Po rate!

$$^{210}\mathrm{Pb} \xrightarrow[23\,y]{\beta^-} {}^{210}\mathrm{Bi} \xrightarrow[5\,d]{\beta^-} {}^{210}\mathrm{Po} \xrightarrow[138\,d]{\alpha} {}^{206}\mathrm{Pb}\ (\mathrm{stable})$$

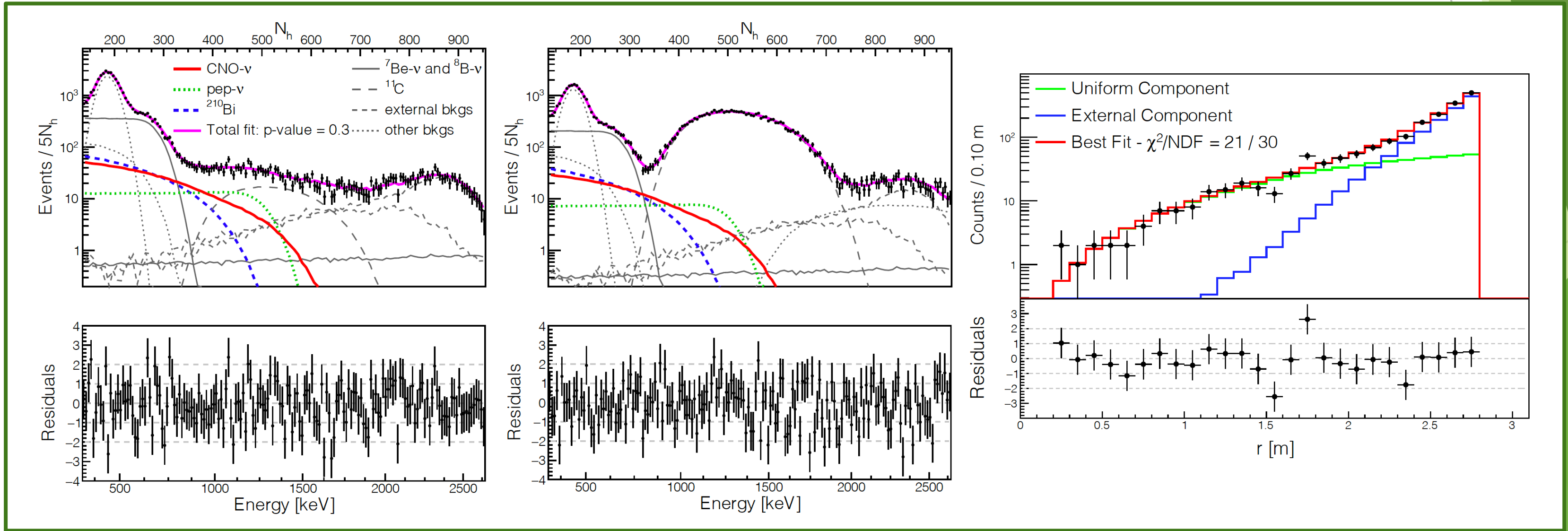


THE MULTIVARIATE FIT

A Multivariate fit is performed and the neutrino interaction rates are obtained by maximizing a binned likelihood function which includes both the ^{11}C-subtracted and ^{11}C-tagged energy spectrum, as well as the radial distribution.

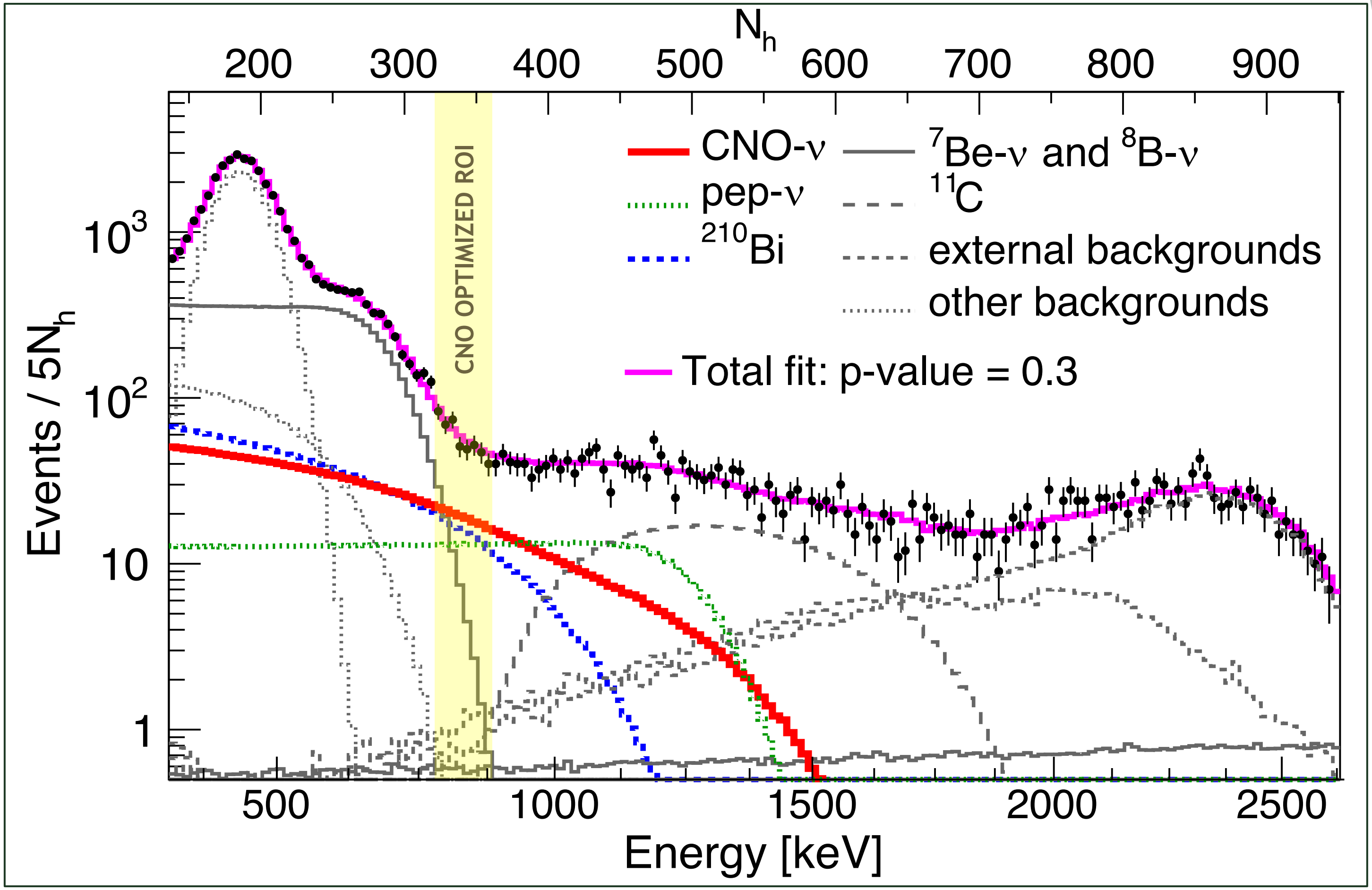
The rate of signals and backgrounds are left free parameters of the fit with the two discussed exceptions: ^{210}Bi and pep.

$$\mathcal{L}_{\mathrm{MV}} = \mathcal{L}_{^{11}\mathrm{C}_{\mathrm{sub}}} \cdot \mathcal{L}_{^{11}\mathrm{C}_{\mathrm{tag}}} \cdot \mathcal{L}_{\mathrm{rad}}$$



CNO NEUTRINOS: THE RESULT

Nature 587 (2020), 577



$$\mathcal{R}(\mathrm{CNO}) = \mathbf{7.2^{+2.9}_{-1.7}}\ \mathrm{cpd/100\,t\ (stat)}$$

THANKS!

Related talks @NeuTel:

Friday 19/02/2021

- **D. Basilico**: How the CNO neutrinos detection can unravel the solar metallicity problem?
- **A. Göttel**: Data analysis of a low Polonium field for the discovery of CNO neutrinos in Borexino

Tuesday 23/02/2021

- **G. Bellini**: Neutrino, Solar and star physics with Borexino

Wednesday 24/02/2021

- **O. Penek**: Sensitivity to CNO cycle solar neutrinos in Borexino