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

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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?**

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
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**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**

![Graph showing predicted spectral shapes for various isotopes](image-url)
TOWARDS THE CNO SOLAR-$\nu$ 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 $\nu \sim 4$-$5$ cpd/100 ton
- pep $\nu \sim 3$ cpd/100 ton
- $^{210}$Bi $\sim 15$-$20$ 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.
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Still, the $^{210}\text{Bi}$ spectrum is quasi-degenerate with the CNO neutrino one.....
The Bismuth-210 Constraint

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

$$^{210}\text{Pb} \xrightarrow{\beta^-} 23\text{ y} \quad ^{210}\text{Bi} \xrightarrow{\beta^-} 5\text{ d} \quad ^{210}\text{Po} \xrightarrow{\alpha} 138\text{ d} \quad ^{206}\text{Pb} \text{ (stable)}$$
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.

$$\mathcal{L}_{MV} = \mathcal{L}^{11}_{\text{sub}} \cdot \mathcal{L}^{11}_{\text{tag}} \cdot \mathcal{L}_{\text{rad}}$$
CNO NEUTRINOS: THE RESULT

\[ \mathcal{R}(\text{CNO}) = 7.2^{+2.9}_{-1.7} \text{ cpd/100 t (stat)} \]
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