Performances and Calibrations of the Borexino Detector

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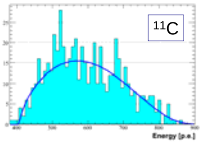
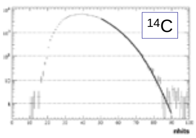
Borexino is a real-time detector for low energy Solar neutrino spectroscopy installed in the underground laboratories (3800 mwe depth) at Gran Sasso, Italy (LNGS). Borexino is specifically designed to measure the mono-energetic (862 keV) 7Be flux via neutrino-electron elastic scattering in ultra-pure organic scintillation liquid. The separation of signal and background relies on the identification of the Compton-like edge in the recoil electron energy spectrum at 667 keV. The physics potential of Borexino strongly depends on the **unprecedented requirements of low level background**. The exceptional radio-purity reached by the Borexino, in order to guarantee the success of the experiment, must be complemented with the identification and discrimination of the residual intrinsic contaminants, as well as of the external and cosmogenic backgrounds. Crucial in this respect are the energy and spatial reconstruction capabilities of the detector, which thus require a careful and precise calibration. Identified background sources can represent optimal sample for **auto-calibrating** the detector. We report on the Borexino performances after 1 year of data taking in **reconstructing event energy and position**, in discriminating on the nature of the contaminant with the **pulse shape** analysis and in the identification of fast coincidences looking at **time and space correlations**.

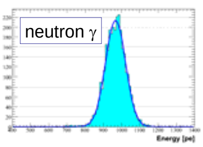
Energy Scale

The calibration of energy scale requires well defined sample of a known source. The best candidates are: **^{14}C** decays, whose activity is dominant below 0.2 MeV, 2.2 MeV gammas from capture of cosmogenic **neutrons**, tagged in coincidence with the muon parent, and cosmogenic **^{11}C** β^+ events, identified with the three fold coincidence with the muon parent and the associated neutron emission.

The energy distortion due to the **quenching effect** is formalized with the **Birks model**. The expected quenching factors for β and α are energy dependent and belong to the [1.02-1.05] and [10-13] ranges, respectively. Even if the effect in the β case is smaller, it is amplified in the Compton electron gamma induced showers: γ energy can be reduced by a factor up to 1.3, introducing a bias in the analysis. 2.2 MeV γ induced by neutrons and the 0.511 MeV γ from the positron annihilation in the ^{11}C decay, are optimal calibration candles for determining the **kB parameter**.

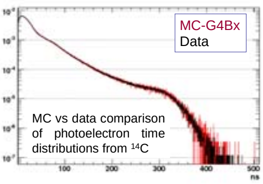






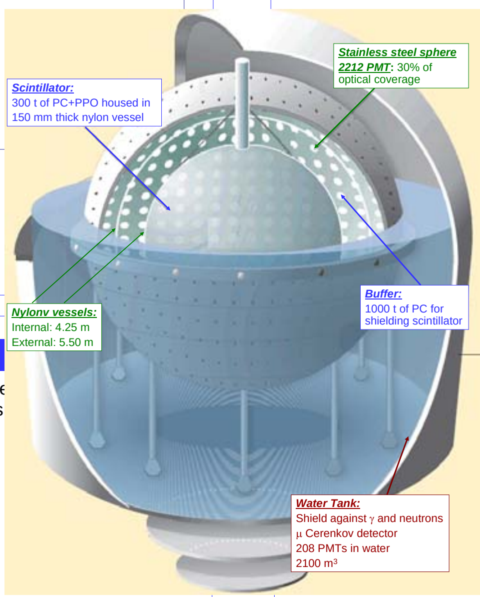
LY = 500 (1%) p.e./MeV
kB = 0.018 (15%) cm/MeV
Ph.Y. ~ 9000 photons/MeV
(from MC comparison)

Monte Carlo Simulations



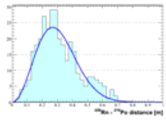
The Borexino Geant-4 based code (G4Bx) provides a detailed description of the detector geometry and materials, electromagnetic and hadronic processes and the scintillator optical properties. Moreover, G4Bx interacts with simpler code based on FLUKA, to study the neutron physics.

A complete simulation of the electronic chain, produce an output file that can be processed by the Borexino reconstruction code. A strict validation of the simulation package is in progress.

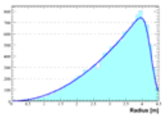


Position Reconstruction and Vessel Shape

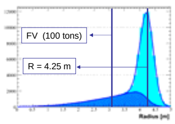
The event spatial reconstruction is based on the time information of each single photons. The arrival time t_a^i of the first photon of the i-electronic channel is equal to: $t_a^i = t_0 + t_d^i + t_f^i + t_j^i$, where t_0 is the absolute time of the event, t_d^i the scintillator decay time, t_f^i the time of flight, and t_j^i is the jitter time proper of the PMT. Spatial position results from the maximum likelihood fit of the time distribution.



Fast coincidence (τ = 216 ms) between **^{220}Rn** and **^{216}Po** (^{232}Th chain): both alphas are produced at the same position and their distance is affected only by the spatial resolution. The fit results σ ~ 18 cm at ~ 250 photoelectrons (500 keV)

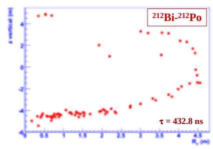


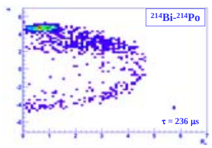
Gammas from muon induced **neutron** captures are an optimal sample to tune the bulk distribution, which is formalized with a convolution between the spherical distribution and the detector response (Rayleigh distribution). σ ~ 15 cm at ~ 800 hits (2200 keV)



Radial fit in the **^{7}Be energy region**. (blue is the bulk component and ligh blue the surface contamination). Vessel radius is found with less than 1 cm error. The radial cut at 3 m, which defines the fiducial volume, guarantees about 4 σ from the surface contamination.

Vessel radius and origin calibrated exploiting **fast coincidences** of ^{222}Rn and ^{220}Rn chain segments emanated from vessel nylon

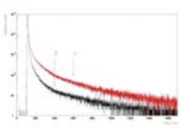




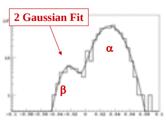
The two plots confirms the CCD camera calibration results: **vessel origin is shifted** along positive z-axis by about 5 cm.

Pulse Shape

α/β analysis with the optimum Gatti method based on the different time response of the scintillator to α and β particles

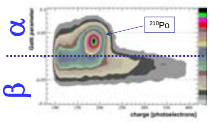


α and β pulses

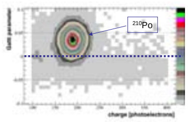


Gatti parameter

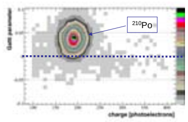
^{7}Be ν energy range



Without radial cut



R < 3.8 m

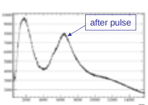


R < 3. m (FV)

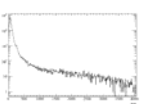
Muon identification with the pulse shape analysis.

Muons are track-like events and their pulse shape differ from neutrino candidates (point-like events) because is "slower". Its mean time and the time of the first peak are shifted to longer times. The inner detector is, hence able, to recognize efficiently muons. The cuts have been calibrated on events tagged by the muon veto (OD).

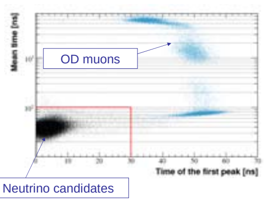
Energy range	ε
< 0.2 MeV	5%
0.2 - 2.5 MeV	85.2%
> 2.5 MeV	> 99.9%



Pulse of muons crossing the scintillator



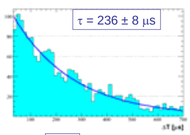
Pulse of muons crossing the buffer

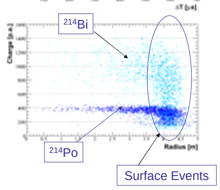


Fast Coincidences

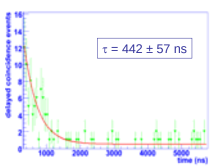
Fast coincidence identification have a determinant role in the Borexino analyzes: beyond the **event by event identification** of single nuclides, they allow **statistical subtractions** of segments of radioactive chain in equilibrium (^{214}Bi-Po, ^{212}Bi-Po) or secondary decaying channels with known branching ratio (^{85}Kr-Rb). Moreover, they represent **optimal calibration candles** for studying the detector response in energy and time.

^{214}Bi $\xrightarrow{\beta}$ ^{214}Po $\xrightarrow{\alpha}$ ^{210}Pb (τ = 236 μs; 3.2 MeV; ~700 keV eq.)

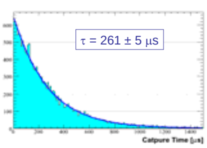




^{212}Bi $\xrightarrow{\beta}$ ^{212}Po $\xrightarrow{\alpha}$ ^{208}Pb (τ = 432.8 ns; 2.25 MeV; ~1000 keV eq.)



n + p $\xrightarrow{\tau \sim 250\ \mu s}$ d + γ



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