

The CNGS beam and the Borexino events in October 2006

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1 Introduction

We present here a brief report on the CNGS beam in the period 26-27 october 2006. During this time Borexino, with 1122 t of water in the SSS (83% of its volume), took some data and 12 neutrino induced muon events have been detected (10 expected) one of which has also been detected by Opera.

2 The CNGS beam in October 2006

The CNGS beam was supposed to last from October 26th up to November 7th, with a long SPS supercycle including 3 CNGS cycles [see fig.1].

On October 26th the beam was regularly on but then, in the morning of the 27th, the beam was stopped because of a water leak in the cooling system of the CNGS beam reflector [see fig.2]. To check the situation, the top shielding of the reflector was remotely opened and the accessible manifolds, joints and fittings for cooling water on the top were inspected using a camera. No fault was observed on the upper part of the reflector, this pointing towards the fact that the fault was in the lower part of the reflector. To access this area, the shielding has to be removed: since the radiation levels at the reflector were very high and a cool-down of the area would have taken all this year remaining CNGS run time before allowing a clear diagnosis and safe repair work, it was decided to stop the CNGS run. So there was beam only from the 26th at around noon time till the next day, october 27th at around 11:11 (CEST time = UTC + 2 hours), for a total of ≈ 21 hours.

We are supposed to have two extractions in each of the 3 cycles in each supercycle, for a total of 6 extractions for each SPS supercycle; each extraction is $10.5\mu s$ long and the two are $50ms$ apart.

The beam intensity, for all extractions, is plotted in fig.3 top (intensity units are *pot*- proton on target- 10^{13}); the first and second extraction intensities are plotted separately in fig. 3 bottom : as can be seen the values ($\approx 0.4 \cdot 10^{13}$ pot/extraction for most of the extractions) were lower ($\approx 17\%$) than the nominal $2.4 \cdot 10^{13}$ pot/extractions.

The two extraction intensity values versus time are plotted in figure 4-1; in figure 4-2 is plotted the CNGS proton integrated intensity during the October Borexino data taking periods.

In figures 5-1,2,3 are plotted some cycle intensities (the intensities of the first and second extractions are superimposed) at different time of the days; we can see that whenever there are 6 extractions the two extractions in the central cycle have always a higher intensity: this behaviour explain the two bands in the fib.4-1.

The time difference between the second extractions is plotted in fig. 6-top: the nominal "6 seconds" (inter-cycles) and "22.8 seconds" (inter-supercycles) values are achieved only in stable "good" beam situation (as can be seen in fig.6-bottom, where these values are plotted versus time; there is a "12 seconds" difference whenever there in an empty central cycle, a "28.8 seconds" value when we have one first or last missing cycle and a "34.8 seconds" value when only one (out of

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three) cycle is full. As can be seen in fig.5-1 and 6-bottom the beam was quite poor during the first afternoon (only 2 extractions out of 6), becoming very stable and with all the expected 6 extractions per supercycle later on, especially during the night hours, from 21PM till 7 AM (UTC). At 7AM they started to try to have all three cycles at the same high intensity, but then the beam had to be stopped after 2 hours.

In fig.7 is plotted the extraction time spread around the expected extraction time (in seconds): as can be seen the time spread is at most tens of microseconds.

3 The Borexino expected muon events

During the CNGS october runs there were 1122 t of water in the SSS, corresponding to a height of ≈ 10 meters and a surface perpendicular to the beam of 117.10 m². For the Borexino running time ($\approx 31\%$ of the good beam time, as listed in table 1) we had a total beam intensity of $1.93 \cdot 10^{16} pot$ corresponding to 10 expected neutrino induced muons from the rocks and zero from CC current interaction in the detector^[1].

4 The Borexino Data Sample

After some initial setup and control runs, the analyzed runs are listed in table 1.

RUN	starting	ending	events
2902	oct 26-11:25	oct 26- 11:28	1184
2903	oct 26-11:30	oct 26- 12:24	6903
2909	oct 26-13:53	oct 26- 15:53	15216
2910	oct 26-15:53	oct 26- 16:45	7350
2912	oct 26-17:13	oct 26- 17:14	1037
2914	oct 26-17:21	oct 26- 17:39	2880
2916	oct 26-17:48	oct 26- 19:12	7224
2917	oct 26-19:21	oct 26- 21:21	13745
2918	oct 26-21:21	oct 26- 23:22	10484
2919	oct 27-09:01	oct 27- 11:02	12832

Table 1: Good runs taken during the CNGS beam period. Note: times are talian Daylight Saving Times.

The "good" beam period, as previously explained is during the runs 2917-18-19.

5 The Borexino detected CNGS muon events

Each extraction time (in UTC units) and intensity (in *pot* units) are written at CERN on the *LHCLOG_CNGS_OPERA* Data Base. These DB values are read and written on a file. The Borexino event GPS times are also read^[4] and written on a file. The time difference between the Borexino event GPS time and the closest previous extraction UTC time are then calculated and plotted (see fig.8). Clearly there is a peak around $2.4ms$, the approximate Time of Flight between CERN and LNGS (see below).

The events with the difference values in this peak are listed in table 2. They have been eye checked to be "beam event" using the Borexino event display program^[5]. The event number 11300, in run 2909, is also seen by the Opera experiment⁶ (see figure 10).

Plotting the time differencies on a finer scale, we see (fig.9-top) that they actually have a $\approx 10\mu s$ spread (being such the extraction time duration).

We expect that $BxGPS = CernUTC + beamToF - LNGSdelay + Offset$;

num.	RUN	ev. num.	extr.num.	extr. UTC	diff in microsec
1	2909	11300	122	1161868864342099968	2407
2	2916	6923	121	1161882341492111872	2404
3	2917	8566	121	1161887596292113152	2408
4	2917	10899	122	1161888871942108160	2409
5	2917	11008	121	1161888941492120832	2410
6	2917	12782	121	1161889747892112128	2406
7	2918	1421	121	1161890687492109824	2407
8	2919	2934	121	1161933700292116992	2408
9	2919	8083	121	1161936832292110592	2405
10	2919	11059	121	1161938607092103168	2413
11	2919	11191	121	1161938711492108032	2413
12	2919	12208	122	1161939239542110976	2410

Table 2: CNGS muon events detected by Borexino. The extraction UTC time is in nanosec since 1st january 1970.

knowing that the ToF from CERN to Opera is 2440079 nanoseconds and assuming an average distance Opera-Borexino of 53.28 m meters (178 ns), we can define a ToF for Borexino of 2439901 nanoseconds; knowing also that the time delay between the LNGS master (at the outside Lab) and the Borexino slave(in hallC) UTC values is equal to 41729.5 nanoseconds (as measured by us^[2]) we plot this offset in fig.9-bottom.

As can be seen, the Borexino offset (due to cables, electronics...) is ≈ 5 microseconds.

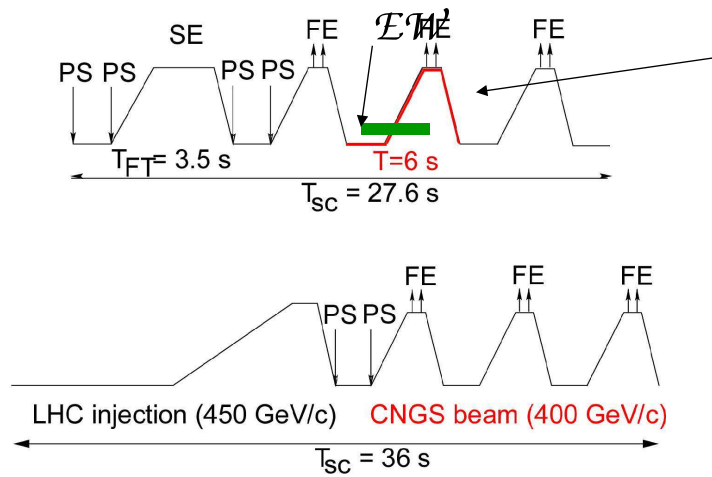
6 Conclusion

The very short october CNGS beam period has proved to be very useful for Borexino: not only we were able to detect the expected number of events but also to test, debug and develop the DAQ, the monitoring system and the event display.

These muon events have been found using only their GPS timing information, but they can be used to debug and optimize the muon identification algorithms and their hit-time distributions could also help us to better understand the SSS light reflection behaviour.

References

- [1] L.Perasso: *Borexino, CTF and the CNGS neutrino beam* Borexino General Meeting - 7 july 2006
- [2] P.Alvarez, D.Autiero, G. Di Carlo, C. Guerin, B.Ninet, L.Perasso, M. Selvi: *Measurements of the fibers delays for the GPS signal underground distribution* LNGS - July 20, 2006
- [3] D.Autiero et al.: cernrep 98-02
- [4] Using a script by Marco Pallavicini
- [5] By Alessandro Razeto
- [6] Dario Autiero, private communication.



Two fast extractions/cycle

*10.5 micro seconds
Separated by 50 ms*

Figure 1: CNGS beam structures. Note: in October 2006 the supercycle period was 34.8 seconds.

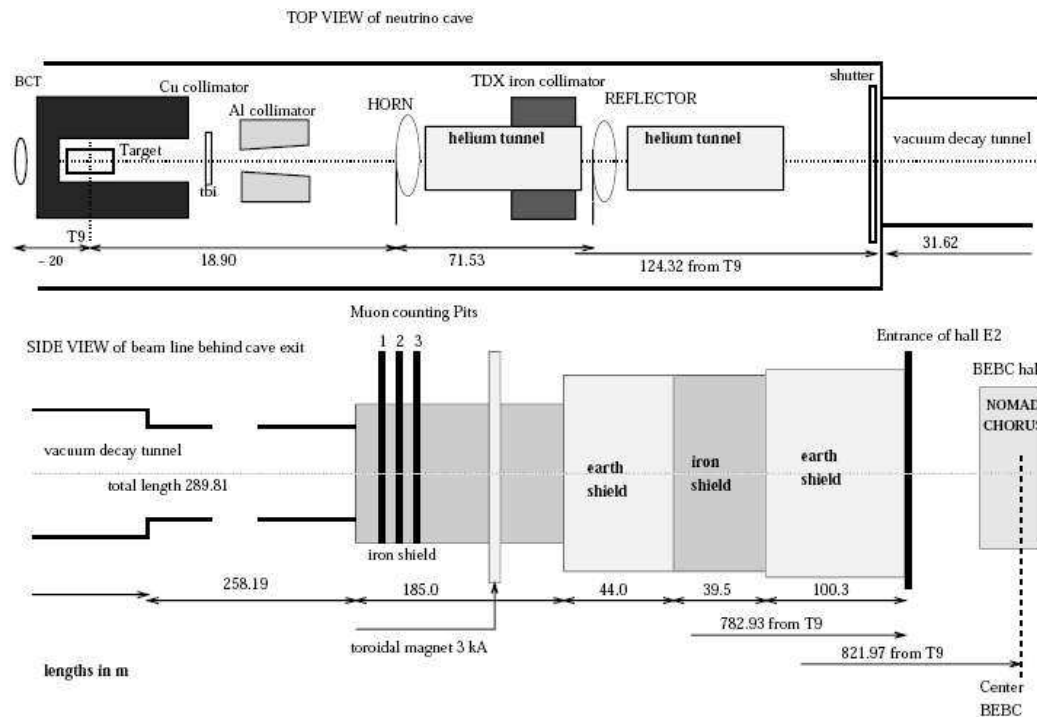


Figure 2: Schematic layout of the CERN-WANF beam line [units are in meters]^[3]

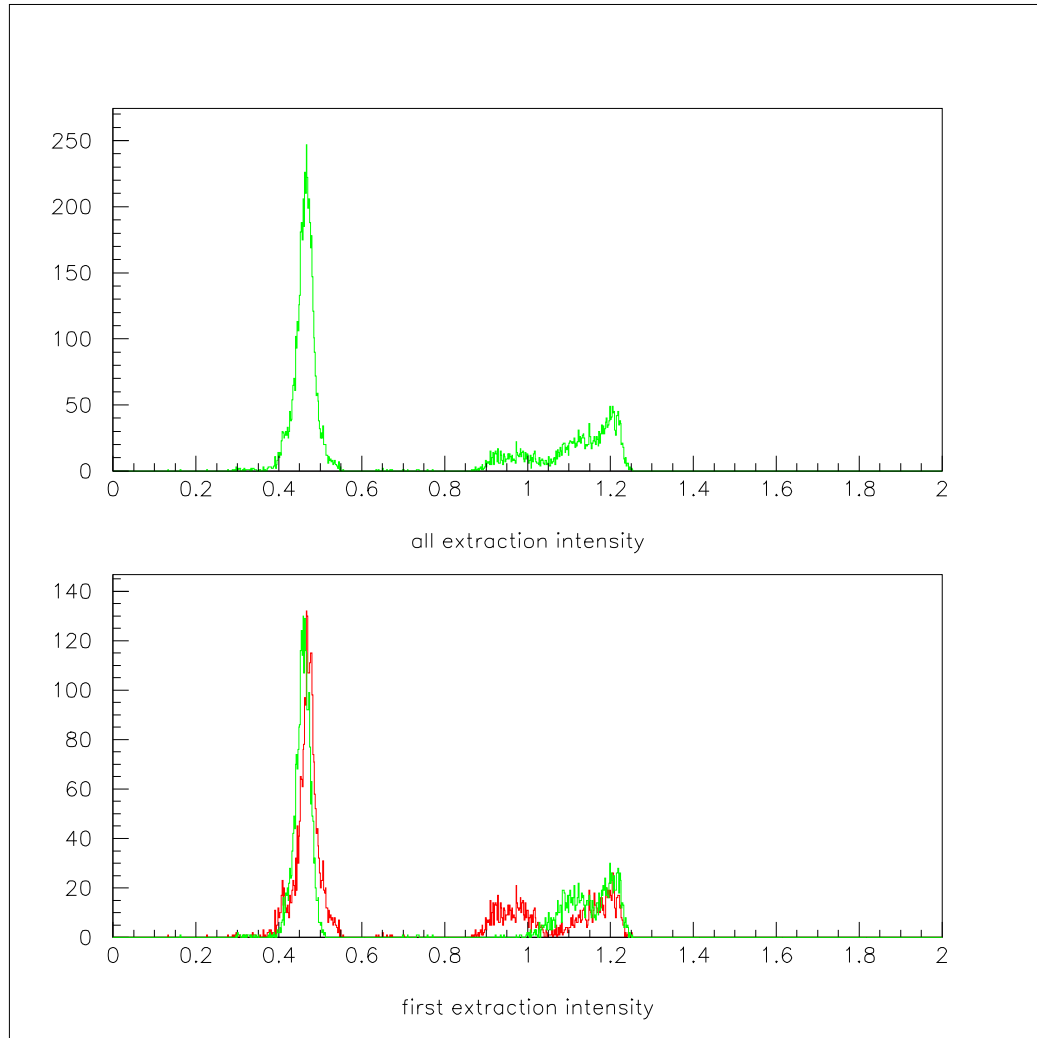


Figure 3: Top: all extraction intensities (units are $\text{pot } 10^{13}$). Bottom: the two extraction intensities are superimposed (red = first, green = second); at around $4.5 \cdot 10^{13}$ pot the second extraction is slightly lower, while for the intensity values at around $1 \cdot 10^{13}$ the second extraction has higher values.

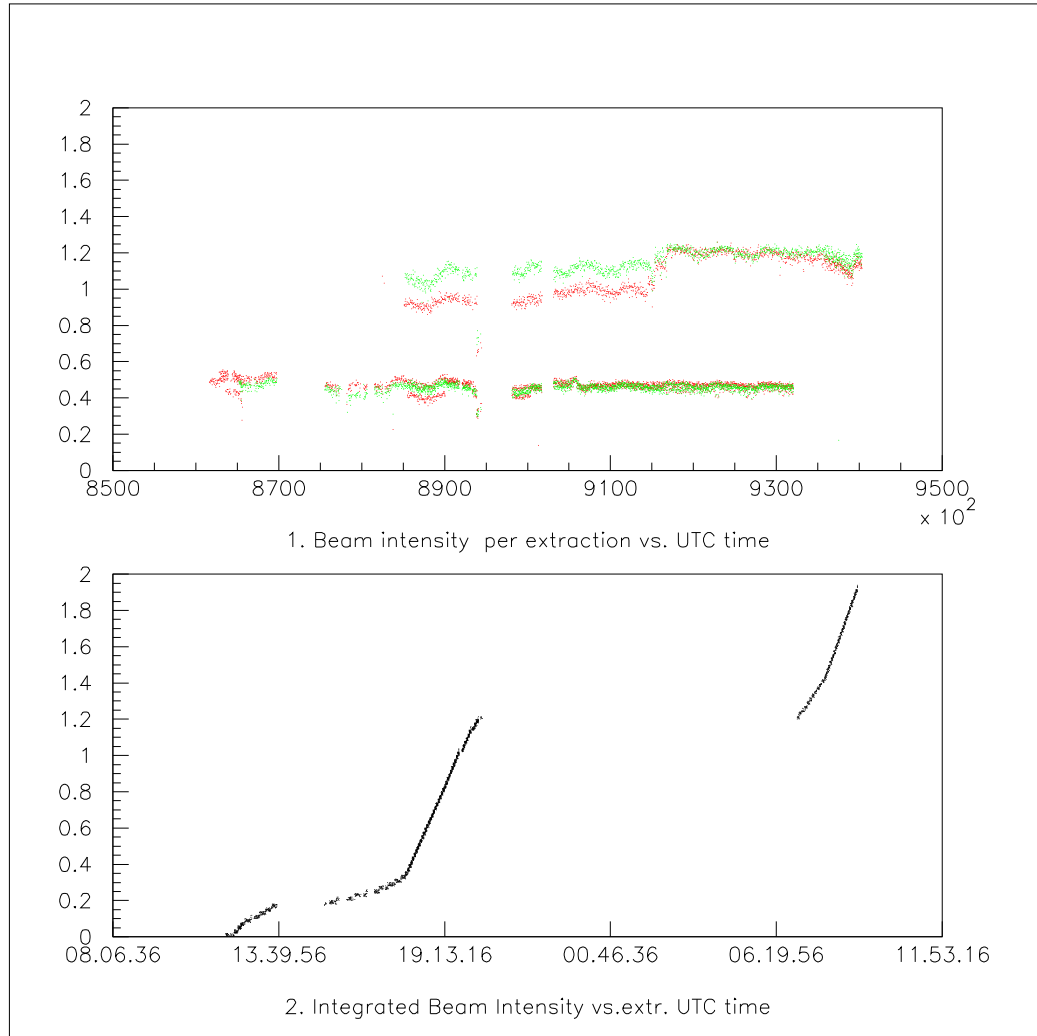


Figure 4: 1): Each extraction intensity versus UTC time [hours.min.sec] (red = first extraction, green = second one). 2) The CNGS proton integrated intensity during the Borexino data taking period in October 2006.

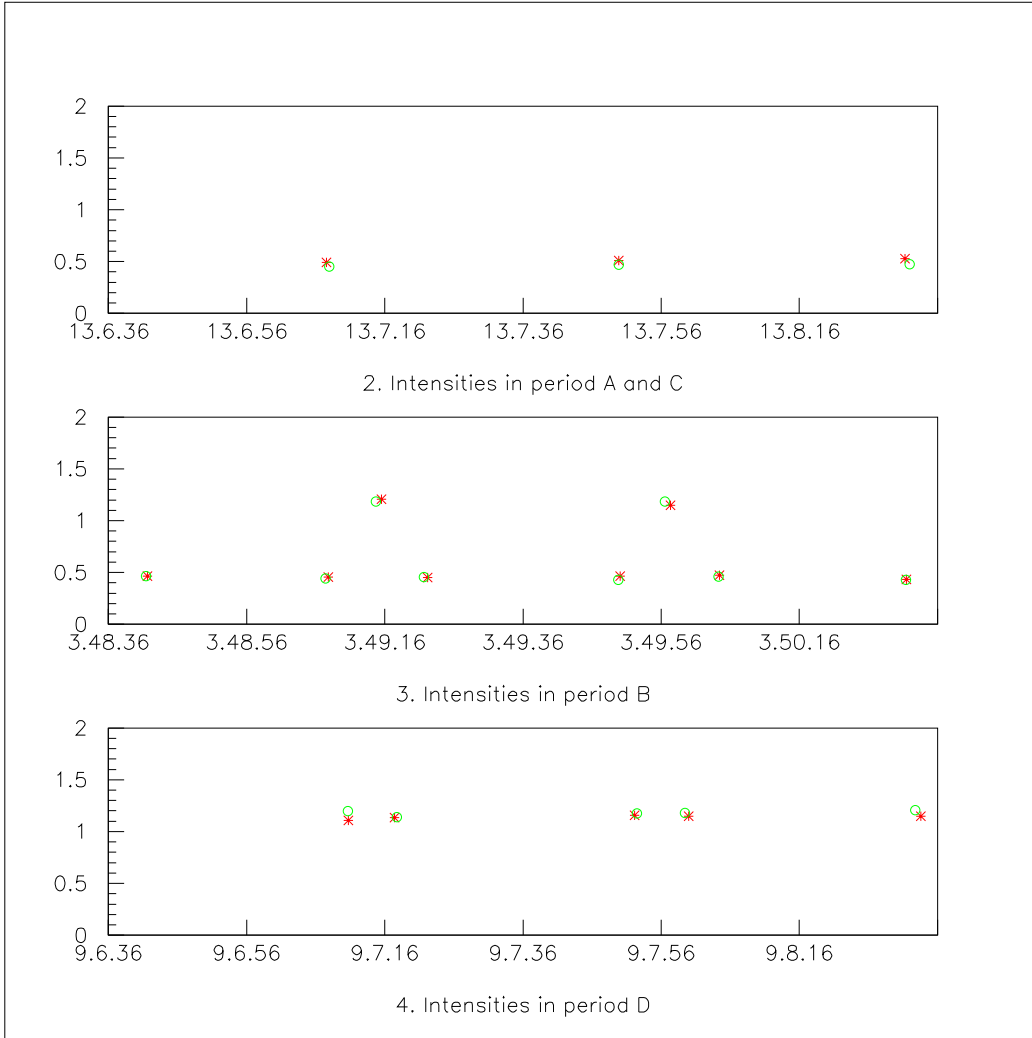


Figure 5: Few single extraction intensity versus time: 1) The signal is only in the two extractions in the first cycle (followed by two empty cycles); 2) The signal is in all the extractions in the supercycles (with 3 + 3 extractions each); here we can see that the two extractions in the central cycle have always a higher intensity: this behaviour explains the two bands in fig.4-1; 3) The signal is only in the two extractions in the first and second cycle (followed by one empty cycle).

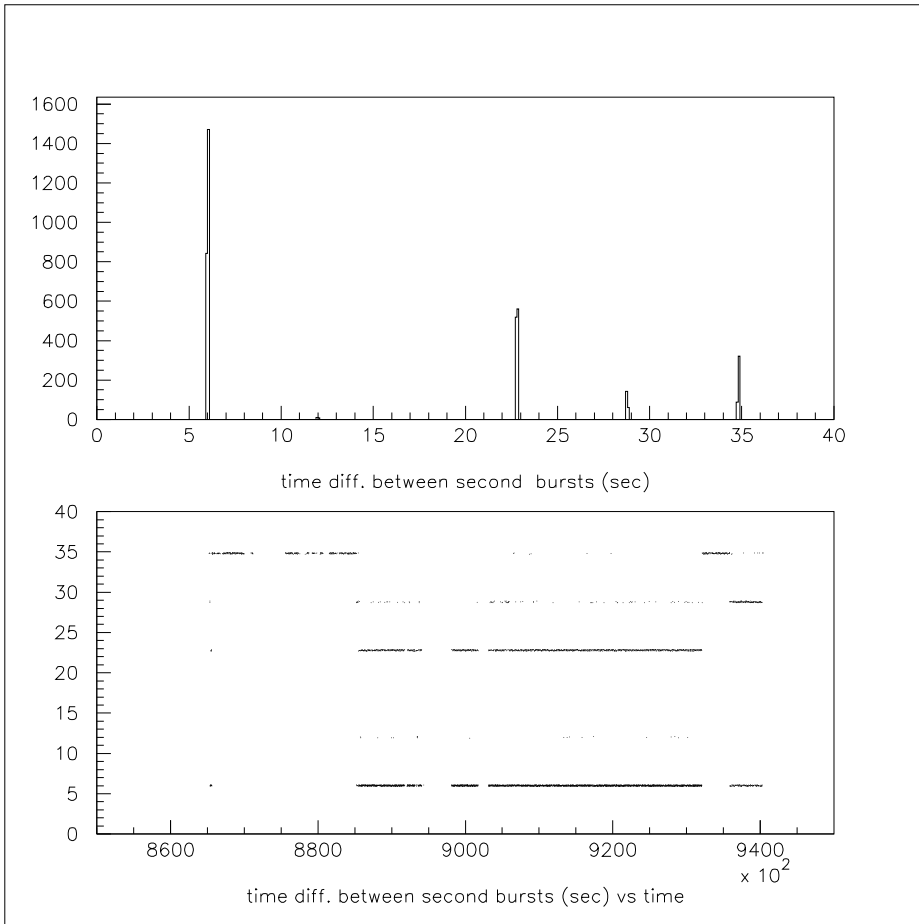


Figure 6: Top: Time difference (units are seconds) between the second extractions (top); Bottom: the same versus time (units = UTC minus 1161000000).

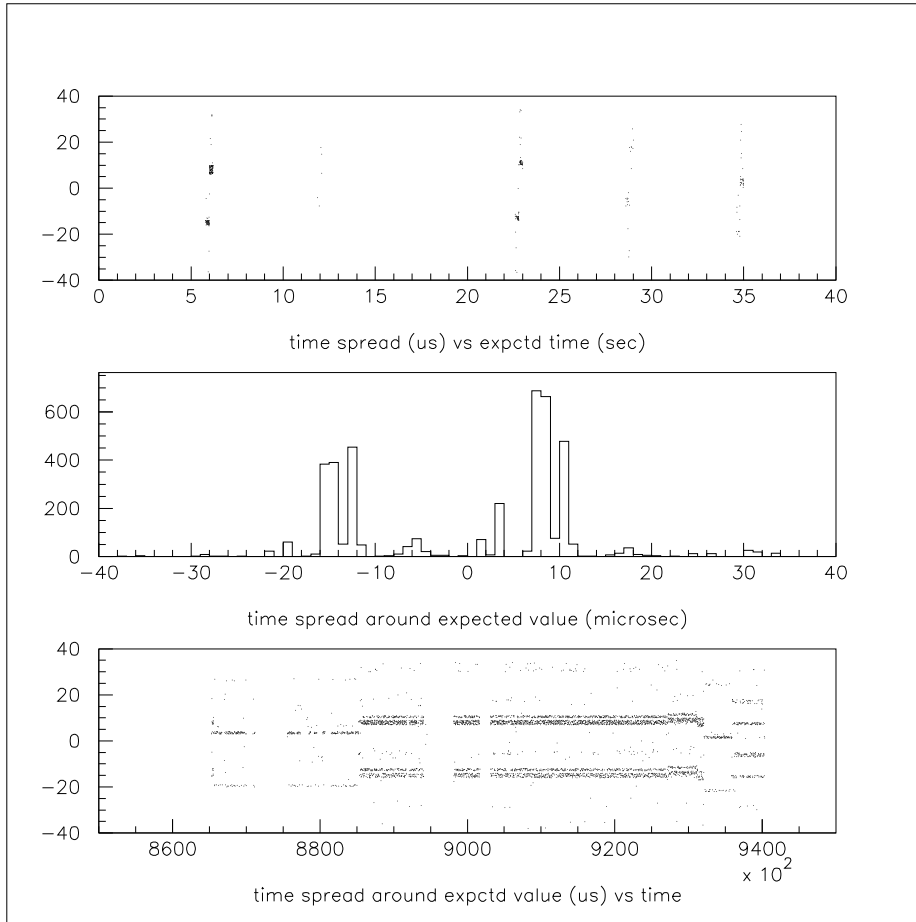


Figure 7: Top: Extraction time spread around the expected values versus the expected time (central); Central: Time spread projection; Bottom: Extraction time spread around the expected values versus time and versus time (units = UTC minus 1161000000).

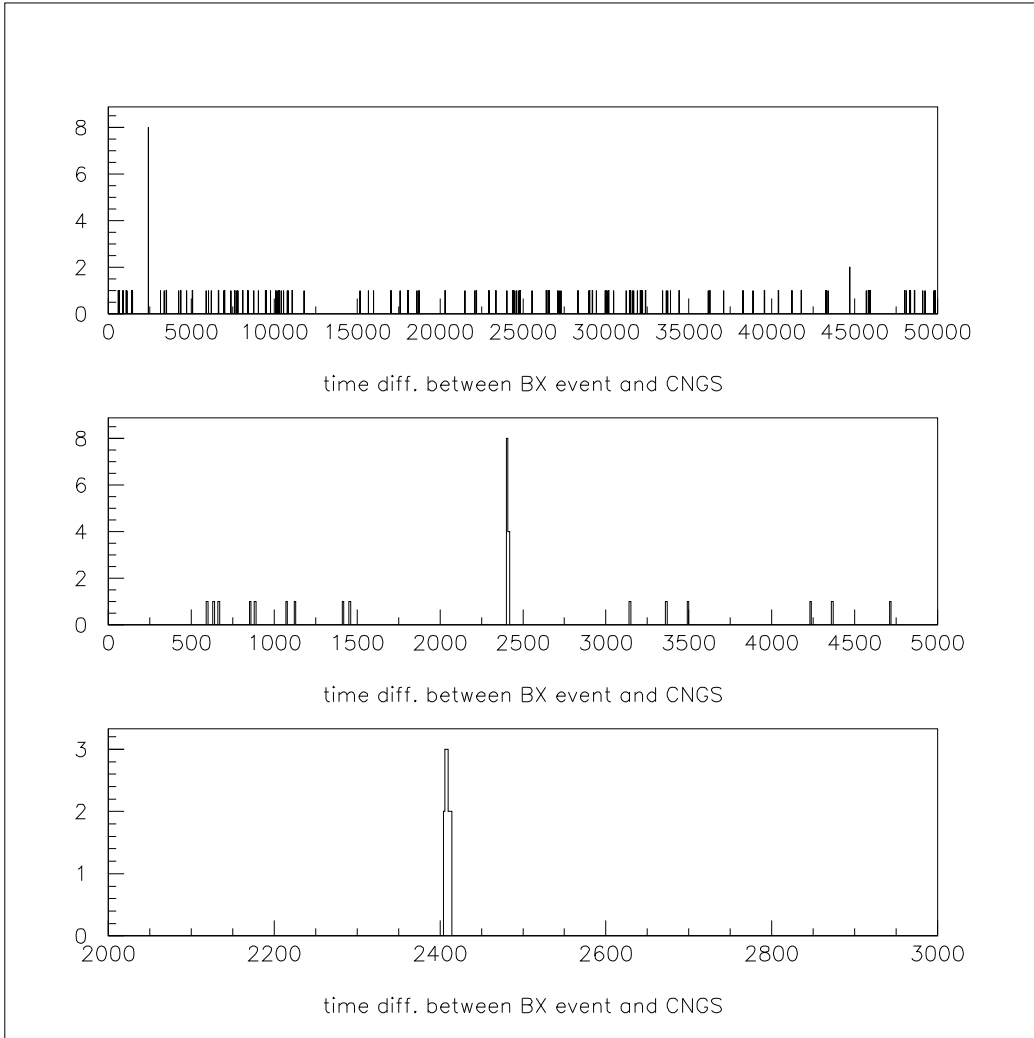


Figure 8: Borexino event time difference: (BxGPS - CernUTC) in microseconds

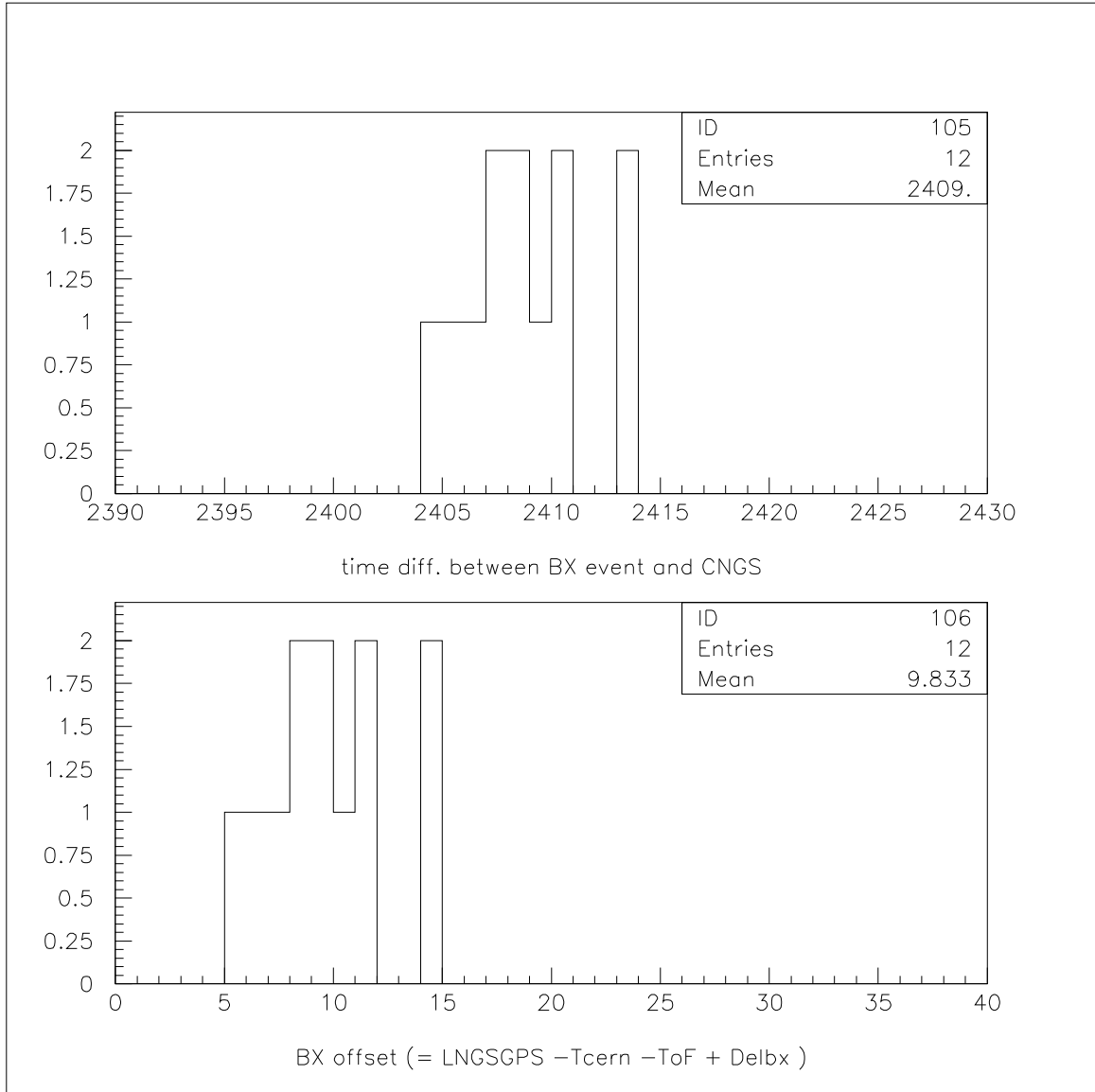


Figure 9: Top: Blow up of the Borexino event time difference: (BxGPS - CernUTC) in microseconds;
 Bottom: Borexino offset: BxGPS - CernUTC - ToF + LNGSdelay [microseconds]

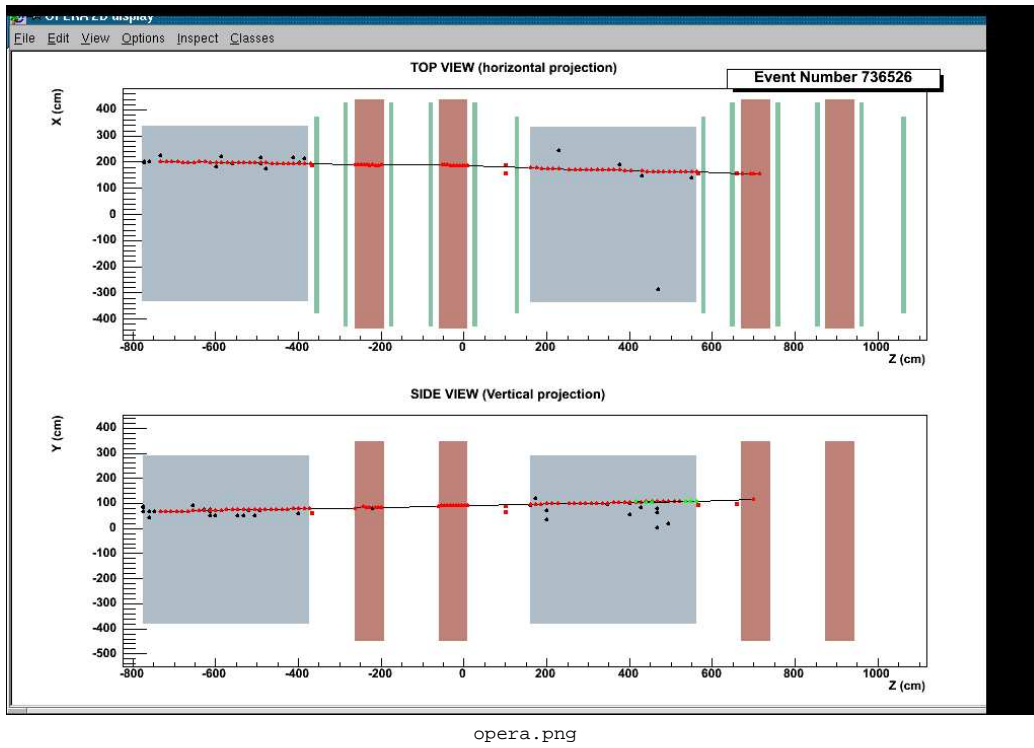


Figure 10: The event 11300 (in Run 2909) as seen also by the Opera experiment⁶.