Toward a high precision neutrino speed measurement with Borexino

LNGS - March 28th, 2012

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on behalf of the Borexino Collaboration

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Overview

- **Speed** measurement in Borexino
  - Signal with scintillator and water detectors
  - Old system limitations
  - Work in progress on 2011 data

- Toward a **high precision measurement**
  - **New hardware**
    - **Trigger**
    - GPS-based time measurement
  - Plans for a new **geodesy** measurement

- Conclusions
The Borexino detector

**Scintillator:**
270 t PC+PPO (1.5 g/l)
in a 150 μm thick
inner nylon vessel (R = 4.25 m)

**Buffer region:**
PC+DMP quencher (5 g/l)
4.25 m < R < 6.75 m

**Outer nylon vessel:**
R = 5.50 m
(²²²Rn barrier)

**Stainless Steel Sphere:**
R = 6.75 m
2212 PMTs
1350 m³

**Water Tank:**
γ and n shield
μ water Č detector
208 PMTs in water
2100 m³

**Carbon steel plates**

**20 steel legs**
CNGS events detection

- **CNGS** muons (neutrinos) are detected by Borexino in two ways:
  - **Scintillation** for muons crossing the SSS
  - **Cerenkov light** in water

- As for other experiments, most of the events are due to neutrinos interacting in the rock upstream
  - Internal events exist, but are very difficult to tag

- Simple kinematics tells that there is no crucial difference between the two classes of events

\[
\Delta t = \tau_\mu - \frac{L_\mu}{c} = \frac{L_\mu}{c} \left( \frac{1 - \beta}{\beta} \right) \approx \frac{L_\mu}{2\gamma^2c} \approx 0.1 \cdot 10^{-9}\text{s}
\]

- Actually, a Monte Carlo evaluation of the effects related to **multiple scattering** is foreseen. **Probably small.**
Muon detection capability

- CNGS events are well tagged by time coincidence only
- However, we have also a well developed muon identification capability
- Expected background close to zero
- Muon detection is efficient at all angles
Internal geometry

Units: mm

North

$R_w = 9006.$
$A = (R_w, 0, 0)$
$A = (9006., 0, 0)$

$B = (R_s, 0, 0)$
$B = (6860., 0, 0)$

$P = (R_w, 0, -H_s)$
$P = (9006., 0, -7860.)$

$Q = (R_s \cos \psi, 0, -R_s \sin \psi)$
$Q = (6849., 0, -383.)$

$\vec{x}$ axis

$\vec{y}$ axis, toward reader

$\vec{z}$ axis

Beam direction angle:
$\psi = 3.2^\circ$ (55.8 mrad)
$\sin \psi = 0.5582$
$\cos \psi = 0.9984$

$\vec{w} = (-\cos \psi, 0, \sin \psi)$
$\vec{w} = (-0.9984, 0, 0.5582)$

Time of flight corrections to be evaluated with Monte Carlo
2009-2011 data: statistics

- **Standard beam (2007-2011)**
  - ~140 events / 10^{17} p.o.t. in total
  - ~50% through inner detector,
  - ~50% through water detector only
  - Water Detector events are less precise, probably

- **Short bunch beam 2011**
  - 74 events in total
  - 38 detected events with inner detector

<table>
<thead>
<tr>
<th>Year</th>
<th>Run</th>
<th>p.o.t (10^{19})</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>5972-6132</td>
<td>0.06</td>
<td>883</td>
</tr>
<tr>
<td>2008</td>
<td>8013-9052</td>
<td>1.31</td>
<td>19079</td>
</tr>
<tr>
<td>2009</td>
<td>10201-11685</td>
<td>2.34</td>
<td>33730</td>
</tr>
<tr>
<td>2010</td>
<td>12833-14620</td>
<td>3.25</td>
<td>47221</td>
</tr>
<tr>
<td>2011 OB</td>
<td>15509-16938</td>
<td>4.37</td>
<td>61138</td>
</tr>
</tbody>
</table>

Total: 162051 events
2009-2011 data: different trigger periods

- 3 periods
  - change in trigger make delays different
- consistent results
  - shifts are understood
- very high statistics
• same plot after Borexino trigger correction

• small shift still present in CERN waveforms as well

• known problem, already noticed and corrected for by Opera
Fitting 2009–2011 data

Digital filter developed and applied to waveforms to remove high frequency noise

Leading Edge

Trailing Edge
Nov. 2011 data

4 neat peaks from Nov. 2011 “bunched beam”
Un-even intensity
38 events

Inner detector only

arbitrary offset
Nov. 2011 data: folding

Inner detector only

38 events
r.m.s. = 38 ns
error ~ 7 ns
Comments on 2011 data

- The policy of the Borexino Collaboration has been since the very beginning to release results only when:
  - Data analysis has been completed by at least two independent groups
  - The work is complete and thoroughly checked by the Data Validation Committee
  - This process is still in progress
    - We make no exception for the neutrino speed measurement
  - Our goal is a paper soon after the “short bunch beam” in May

- 38 events
  - r.m.s. = 38 ns
  - error ~ 7 ns
New trigger: no digital clocks

Analogue Trigger Threshold: 
~ 2 MeV

Internal delays measured with 
0.1 ns accuracy
Main features:

- Trigger delivered outside with optical fiber
- No digital parts (low jitter)
- Real time monitoring of fiber lengths and internal delays
New design: High Precision Timing Facility
Online monitoring of detector delays

- The connection between the detector in Hall C and the GPS receiver outside is monitored real time
  - Physics triggers are split in two signal that travel along both fibers
  - Calibration pulses go back and forth along the calibration fiber
- We measure every 10 s the length of both paths (up to small constant delays)
GPS

Rb

GPS

Fan Outs

Optical

TICs
Online monitoring of detector delays

Fibre Loop
Stable within ± 1 ns
Day-night modulation

calendar date
09/03
11/03
13/03
15/03
18/03
20/03

total loop time (s)
86.691
86.690
86.690
86.689
86.689
86.688
86.688
86.687
86.687
86.686
86.686
86.685
86.685
86.684
86.684
86.683
86.683

-6
10×
Online monitoring of detector delays

Fibre Difference
Stable within ± 0.1 ns
Day-night modulation still visible

Fibre Difference
Stable within ± 0.1 ns
Day-night modulation still visible
Borexino is equipped with a calibration system designed for high precision timing

- A laser pulse, 394 nm, a few tens of ps long, is distributed to all PMTs through a set of optical splitters (passive) and optical fibers
- By means of OTDRs we have measured the length of the fibers with 100 ps accuracy (@ 394 nm)
  - We can also pulse the Outer Detector, but with less precision
- Accurate and safe internal delays measurements possible through laser pulses
- The delay from the PMTs photocathode up to the main TIC input is possible by summing just 2 contributions, both known with ~ 0.2 ns precision
Calibration of the calibration system

- In order to use the Timing Laser to measure the detector delays accurately, we must know the exact length of the fibers.

- We have used an OTDR (Optical Time Domain Reflectometer) to measure the length of all fibers at 850 nm.

- We have inserted a known fiber in the path made by the very same batch and used Borexino data to rescale the delay at 394 nm.

- Final precision: < 100 ps
  - Dominated by measurement of fiber physical length (~ few cm)
Collaboration with INRIM, ROA and CERN

- The preparation of a high precision GPS system requires knowledge and skills that do not belong to INFN

- We have activated a cooperation and a “convenzione” with INRIM - Istituto Nazionale di Ricerca Metrologica, the italian institute of metrology
  - We have also an indirect collaboration with ROA, Real Observatorio de l’Armada, the spanish equivalent

- The HPTF have been throughly tested and calibrated in Torino at INRIM

- INRIM personnel is working with CERN Timing and CNGS groups in order to perform the complete calibration of the time link between CERN and HPTF

- THANKS TO ALL
Expected error budget (estimate)

- Errors on a single event
  - Statistical
    - Uncertainty in the muon entrance point: ~ 0.7 m -> ~ 3 ns
    - Uncertainty in the light propagation and trigger formation jitter -> ~ 5 ns
    - GPS measurement -> ~ 2 ns
  - Systematic
    - Internal delays -> ~ 0.5 ns
    - Geodesy - 15 cm -> ~ 0.5 ns
    - GPS systematic -> ~ 1.5 ns
    - Muon entrance point -> ~ 0.5 ns
  - Total r.m.s. ~ 6 ns

- With ~200 events, we expect:
  - Statistical ~ 0.5 ns
  - Systematic ~ 2 ns

  NOTE: Estimates! Only data will tell which will be the final precision.
We are in contact with Prof. R. Barzaghi and his group of Politecnico di Milano

- Experts in geodesy measurement

In agreement with LVD and Icarus collaborations, and in strict coordination with the Laboratory, we will re-do the geodesic measurement of the position of the Underground Laboratory and of the three detectors

- First inspections already done

- The activity is foreseen for May, when, luckily enough, the highway is already scheduled to close at night for other works
Geodesic measurements

INFN GS: 2 semi-permanent GPS Networks

a) Tunnel entrance (L’Aquila)
b) Tunnel entrance (Teramo)

The two entry point coordinates ▲ and the two orientation points △ are needed in order to estimate the coordinates inside the GS Lab.

Tunnel 10176 m

credit: Prof. R. Barzaghi
Monumentation of the GPS points

Semi permanent GPS networks

Four day static measurements
h24, L1/L2 receivers (solar powered).
- 4 Trimble 4700 receivers
- 2 Trimble 5700 receivers

Marker
On rock
(if possible)

credit: Prof. R. Barzaghi
Geodesic measurement

Tunnel measurements

Theodolite TS 30 Leica
Angular rms = 0.5”
Distance rms = 0.5 mm + 0.5 ppm

DATUM WGS84
3D Coordinates

Traverse survey
Trellis pattern: 250/500 m distance between points.

credit: Prof. R. Barzaghi
Tunnel measurements

Azimuth measurements
Three Azimuths will be measured inside the tunnel with Gyro theodolite (DMT Gyromat), to constrain the traverse pattern.

credit: Prof. R. Barzaghi
Accuracy
GPS baseline Cern-INFN = 5 cm
Traverse survey = 2-5 cm (?)
(depending on lateral refraction).
Point inside the lab = 2-3 cm

TOTAL = less than 8 cm (1 sigma)

credit: Prof. R. Barzaghi
Conclusions

• None, a lot of work in progress
  
  • We have a good understanding of 2007-2011 data
  
  • We have a brand new trigger and GPS facility up and running
    ▶ Turned on 1 week ago. Debugging and testing still in progress.
  
  • We have strong support from INRIM on timing, and from Politecnico di Milano on Geodesy (in agreement with Icarus and LVD)
  
  • We are ready for May run
    ▶ We aim at 2 periods: 1 week with 532 ns period (4 bunches), and 1 week with 100 ns period (16 bunches)
  
  • We plan to release results soon after the run in May 2012

Borexino Investment

<table>
<thead>
<tr>
<th>Country</th>
<th>Investment (k€)</th>
</tr>
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<tbody>
<tr>
<td>INFN-2</td>
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</tr>
<tr>
<td>USA</td>
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<tr>
<td>France</td>
<td>10</td>
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<tr>
<td>Poland</td>
<td>5</td>
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<td>Total</td>
<td>60</td>
</tr>
</tbody>
</table>

LVD: 8 k€
Geodesy: ~40 k€ Icarus + LVD