Borexino, CTF and the CNGS neutrino beam

Laura Perasso - INFN Milano

Content:

I. The CNGS beam: its latest schedule

II. Preliminary rate values for the detected CNGS beam induced muons

III. Conclusions
Thanks to:

George Korga
Igor Machulin
Emanuela Meroni
Alessandro Razeto
The last meeting:

**CNGS START-UP**

LNGS, 6th April 2006
14:00 'E. Majorana' lecture hall

CNGS Project: Primary Beam (35') M. Meddahi (CERN/AB)
CNGS Project: Secondary Beam (35') E. Gschwendtnner (CERN/AB)
CNGS Simulated Beam Fluxes (5') P. Sala (INFN/Milano)
Timing and Data Exchange btw. CERN and LNGS (30') D. Autiero (IN2P3/Lyon)

(from D. Autiero)
“Waiting for the beam”:

Continuation more focused on the event signatures of the CNGS beam in the LNGS experiments.

Presentations by:

1. Dario Autiero: “Update on the CNGS beam”
2. Stefano Dusini: “CNGS beam monitoring with OPERA detector”
3. Gabriella Sartorelli: “CNGS beam monitor with LVD”
4. Laura Perasso: “Borexino, CTF and the CNGS neutrino beam”

(all on the LNGS web pages)
\[ <E_{\nu\mu}> \sim 18 \text{ GeV} \]

Fluxes @ \( E_\nu \sim 18 \text{ GeV} \) [\( \nu/\text{cm}^2/10^{19}\text{pot} \)]:

\[ \nu_\mu \sim 3.2 \times 10^5 \]
\[ \overline{\nu}_\mu \sim 6.4 \times 10^3 \]
\[ \nu_e \sim 1.4 \times 10^3 \]
\[ \overline{\nu}_e \sim 1.8 \times 10^2 \]

\( (\nu_\mu + \overline{\nu}_\mu) \sim 99.5\% \) (2\% \( \overline{\nu}_\mu/\nu_\mu \))

\( (\nu_e + \overline{\nu}_e) \sim 0.48\% \)

For comparison, MINOS, \( <E_{\nu\mu}> \sim 3\text{GeV} \)

\( (\nu_\mu + \overline{\nu}_\mu) \sim 98.5\% \) (6.5 \% \( \overline{\nu}_\mu \))

\( (\nu_e + \overline{\nu}_e) \sim 1.5\% \)

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BX - GM LNGS 7/july 2006
CNGS Geodesy:

Radial beam distribution at LNGS:

Full width at half maximum: 2.8 Km
Flat region at +- 500 m  
**effect on** cc events

- horn off axis by 6mm  < 3%
- reflector off axis by 30mm  < 3%
- proton beam on target  < 3%
- off axis by 1mm
- CNGS facility misaligned  < 3%
- by 0.5mrad (beam 360m off)

Angular accuracy of CNGS direction: 0.05 mrad -> 37 m over 730 Km
This uncertainty has practically no effect on the observed rates

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G. Sartorelli, *Waiting for the neutrino beam, LNGS*, June 22nd 2006
Modified due to a PS power supply (installed in 1968!!) fault on 18/5/2006. It has been replaced....
**New SPS schedule**
(approved by the RB on 7/6/2006)

- **18-30 Aug 2006**
  - Low intensity (Scycle= 18 s)

- **20 Oct-8 Nov**
The CNGS beam monitoring at LNGS

The CNGS $\nu_\mu$ beam can be monitored detecting the muons produced by the neutrino interactions with muon identification systems.

in the detectors

in the rocks in front of the detectors
Event Generation

The interaction vertex is sampled uniformly in this rock volume.

- Interaction kinematics with LIPARI code
- Muon transport in rock with MUSIC
- LVD detector simulation with GEANT

G. Sartorelli, Waiting for the neutrino beam, LNGS, June 22nd 2006
μ energy spectrum

μ energy spectrum at interaction vertex

\begin{tabular}{|c|c|}
\hline
Mean & 13.64 \\
RMS & 13.98 \\
\hline
\end{tabular}

μ energy spectrum after path in rock

\begin{tabular}{|c|c|}
\hline
Mean & 14.94 \\
RMS & 18.02 \\
\hline
\end{tabular}

G. Sartorelli, Waiting for the neutrino beam, LNGS, June 22nd 2006
## Number of $\mu$ from the rock

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock Mass</td>
<td>1969 ktons</td>
</tr>
<tr>
<td>Nominal CNGS intensity</td>
<td>$4.5 \times 10^{19}$ pot/year</td>
</tr>
<tr>
<td>$CC$ interaction rate</td>
<td>$5.85 \times 10^{-17}$ $CC$/pot/year</td>
</tr>
<tr>
<td>$\nu_\mu$ in rock</td>
<td>$5.18 \times 10^6$ / year</td>
</tr>
<tr>
<td>Number of $\mu$ in LVD “mother volume”</td>
<td>33600 / year</td>
</tr>
<tr>
<td>LVD geometric efficiency</td>
<td>79%</td>
</tr>
<tr>
<td>LVD global efficiency</td>
<td>72%</td>
</tr>
<tr>
<td>Detected $\mu$ in LVD</td>
<td>~ 120 / day</td>
</tr>
</tbody>
</table>

*G. Sartorelli, Waiting for the neutrino beam, LNGS, June 22nd 2006*
Number of internal $\nu$ events

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Scintillator Mass</td>
<td>1000 tons</td>
</tr>
<tr>
<td>Steel Mass (tank and portatank)</td>
<td>850 tons</td>
</tr>
<tr>
<td>$\nu_\mu$ CC in LVD</td>
<td>4770 / year</td>
</tr>
<tr>
<td>$\nu_\mu$ NC in LVD</td>
<td>1460 / year</td>
</tr>
<tr>
<td>selection efficiency</td>
<td>97% (CC) 91% (NC)</td>
</tr>
<tr>
<td>Detected internal events in LVD</td>
<td>~ 30 / day</td>
</tr>
</tbody>
</table>
Preliminary rate values for the CNGS induced muons in Bx and CTF

With the help of Igor Machulin and Emanuela Meroni

!! Warning !!

!! all these numbers are from very simplified calculations !!

!! no MC done so far !!!
How many $\nu_\mu$ induced muon from the rocks do we have??

Procedure:

Scaling the LVD results [M.Aglietta et al., hep-ex/0304018 v1 18 april 2003], with the usual assumptions:

33600 $\mu$ hitting the LVD “mother volume”/year

$\Rightarrow$33600 / (LVD sup) X (Bx sup) = 33600 / (13.75m X 12m) X 266 m$^2$ = 54167 $\mu$/year

$\Rightarrow$271 $\mu$/day in Borexino

$\Rightarrow$33600 / (LVD sup) X (CTF sup) = 33600 / (13.75m X 12m) X 110m$^2$ = 22400 $\mu$/year

$\Rightarrow$112 $\mu$/day in CTF
How many CC + NC events do we have in the detectors??

Assumptions:
these CNGS event rates in Borexino and CTF have been calculated assuming:

• Nominal CNGS beam intensity = $4.5 \times 10^{19}$ pot/year
• CC interaction probability = $4.96 \times 10^{-17}$ CC/pot/kton mass for $E_{\nu} < 30$ GeV
  [P. Sala]
• One year = 200 days

For:
mass(Borexino) = 3.327 ktons   mass(CTF) = 0.950 ktons

$\Rightarrow N_{CC_{int}}(\text{Borexino}) \Rightarrow 37 \text{ CC } \mu/day \ (+ 11 \text{ NC ev/day})$

$\Rightarrow N_{CC_{int}}(\text{CTF}) \Rightarrow 11 \text{ CC } \mu/day \ (+ 3 \text{ NC ev/day})$

$\sim 48 \text{ ev/day in Borexino}$

$\sim 14 \text{ ev/day in CTF}$
The total CNGS $\nu_\mu$ induced muons (from CC in the detector itself or in the upstream rocks) or hadrons (form NC in the detector) calculated rates are:

$$48(\text{CC+NC}) + 271 \text{ (from rocks)} = 319 \text{ ev/day in Borexino}$$

$$14(\text{CC+NC}) + 112 \text{ (rocks)} = 126 \text{ ev/day in CTF}$$

How do they compare to our cosmic muon bkgnd ??

How many are detected, taking into account the detector efficiencies ??
**CNGS muons vs. cosmic muons**

Cosmic $\mu$ flux [$\mu$/day] in Borexino (expected):

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>IV</td>
<td>2025</td>
</tr>
<tr>
<td>Buffer</td>
<td>3125</td>
</tr>
<tr>
<td>SS Sphere</td>
<td>5150</td>
</tr>
<tr>
<td>Water tank</td>
<td>9900</td>
</tr>
</tbody>
</table>

and in CTF (measured):

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>IV</td>
<td>130</td>
</tr>
<tr>
<td>Water tank</td>
<td>2900</td>
</tr>
</tbody>
</table>

Considering the 10.5 $\mu$s spill length (with a 50ms interspill gap) in a 18 s cycle, we have a reduction factor $\sim 10^{-6}$ corresponding to a cosmic $\mu$ flux in coincidence with the CERN spill:

$\sim 3 \times 10^{-2}$ ev/day in Borexino

$\sim 1 \times 10^{-2}$ ev/day in CTF

Total CNGS $\nu_\mu$ induced events:

- $319 \text{ ev/day cross Borexino} = 3\% \text{ of the cosmics}$
- $126 \text{ ev/day cross CTF} = 4\% \text{ of the cosmics}$

BX and CTF must use the beam spill window (10.5 microseconds) info to identify the CERN $\mu$. 

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Waiting for the beam - LNGS

22/06/2006
Expected CNGS performance: $4.5 \times 10^{19}$ pot/year

"standard" SPS cycle: $t = 16.8 \text{s} = 12 \text{s FT} + 4.8 \text{s MD}$

=> CNGS commissioning: $t = 18.0 \text{s} = 12 \text{s FT} + 6 \text{s CNGS}$

=> CNGS low intensity: $t = 18 \text{s} = 12 \text{s FT} + 6 \text{s CNGS} \ (0.3 \times 10^{19} \text{ pot})$

=> CNGS high intensity: $t = 34.8 \text{s} = 12 \text{s FT} + 3 \times 6 \text{s CNGS} + 4.8 \text{s MD} \ (1 \times 10^{19} \text{ pot})$

<table>
<thead>
<tr>
<th>Beam parameters</th>
<th>Nominal CNGS beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal energy [GeV]</td>
<td>400</td>
</tr>
<tr>
<td>Normalized emittance [$\mu$m]</td>
<td>H=12 V=7</td>
</tr>
<tr>
<td>Emittance [$\mu$m]</td>
<td>H=0.028 V=0.016</td>
</tr>
<tr>
<td>Momentum spread $\Delta p/p$</td>
<td>0.07% +/- 20%</td>
</tr>
<tr>
<td># extractions per cycle</td>
<td>2 separated by 50 ms</td>
</tr>
<tr>
<td>Batch length [$\mu$s]</td>
<td>10.5</td>
</tr>
<tr>
<td># of bunches per pulse</td>
<td>2100</td>
</tr>
<tr>
<td>Intensity per extraction [$10^{13}$ p]</td>
<td>2.4</td>
</tr>
<tr>
<td>Bunch length [ns] (4 $\sigma$)</td>
<td>2</td>
</tr>
<tr>
<td>Bunch spacing [ns]</td>
<td>5</td>
</tr>
</tbody>
</table>

(from D. Autiero)
To correlate the events recorded by the experiments with the beam spill windows (10.5 microseconds):

\[ T(\text{LNGS}) = T (\text{kicker at CERN}) + \text{TOF} \]

Using UTC times recorded at CERN and LNGS

UTC clocks synchronizations and calibrations needed
From Autiero’s presentation:

- the **early warning signal**: the next neutrino spill can be predicted in advance of several seconds and this info can be transmitted through their network ⇒ *implemented and tested since March*
  already used by OPERA;
  *to be decided*: the list of machines which should receive the signal

- the **complete calibration of the time distribution chain of OPERA**
  ⇒ *in progress*
  - Alessandro Razeto had contacts with LNGS Computer Center and Opera
  *for eventual use of this information by BX and CTF*

- the **CERN-LNGS UTC clocks intercalibration** for the neutrino spill synchronization
  ⇒ *finished:*
    - understood and taken account of the 356 ns offset
    - Δt < 100 ns
• the **CNGS-LNGS database** (ORACLE based, 1TB/day info):
  - to correlate the events recorded by the experiments with the beam spill windows (10.5 microseconds): \( \Delta t < 100 \text{ ns} \)
  - the LNGS exp. will be able to write the events observed in correlation to the spills

  => *in progress*: access being tested by OPERA, docs available
### Final rates taking into account the detector geom efficiencies

**In Borexino:**

<table>
<thead>
<tr>
<th>muons generated</th>
<th>Det eff.</th>
<th>Final rate [ev/day]</th>
</tr>
</thead>
<tbody>
<tr>
<td>inside the det.</td>
<td>48</td>
<td>~98%*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>47</td>
</tr>
<tr>
<td>in the rocks</td>
<td>271</td>
<td>~99%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>268</td>
</tr>
<tr>
<td>Total rate</td>
<td>319</td>
<td>315 [ev/day]</td>
</tr>
<tr>
<td>Cosmic muon rate bk</td>
<td></td>
<td>3 (10^{-2}) ev/day</td>
</tr>
</tbody>
</table>

**In CTF:**

<table>
<thead>
<tr>
<th>muons generated</th>
<th>Det eff.</th>
<th>Final rate [ev/day]</th>
</tr>
</thead>
<tbody>
<tr>
<td>inside the det.</td>
<td>14</td>
<td>~50%*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>in the rocks</td>
<td>112</td>
<td>~98%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>110</td>
</tr>
<tr>
<td>Total rate</td>
<td>126</td>
<td>117 [ev/day]</td>
</tr>
<tr>
<td>Cosmic muon rate bk</td>
<td></td>
<td>1 (10^{-2}) ev/day</td>
</tr>
</tbody>
</table>

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Waiting for the beam - LNGS

22/06/2006

*dep. on the trigger thresh*
**Final detected event rates in the first runs:**

<table>
<thead>
<tr>
<th>Run #</th>
<th>LVD</th>
<th>BX</th>
<th>CTF</th>
</tr>
</thead>
<tbody>
<tr>
<td>nominal</td>
<td>4.5 (10^{19}) pot/year</td>
<td>(\sim 150) /day</td>
<td>315/day</td>
</tr>
<tr>
<td>1</td>
<td>(2 \times 10^{16}) pot/week</td>
<td>(\sim 13) /week</td>
<td>28/week</td>
</tr>
<tr>
<td>2</td>
<td>(3 \times 10^{16}) pot/week</td>
<td>(\sim 20) /week</td>
<td>42/week</td>
</tr>
<tr>
<td>3</td>
<td>(5 \times 10^{16}) pot/week</td>
<td>(\sim 33) /week</td>
<td>70/week</td>
</tr>
</tbody>
</table>
We can have BX-CTF-Opera coincidences
How many $\nu_{\mu}$ induced muon from the rocks do we detect both in Opera and in Borexino and CTF ?

Scaling the LVD results [M. Aglietta et al., hep-ex/0304018 v1 18 april 2003], with the usual assumptions:

33600 $\mu$ hitting the LVD “mother volume”/year

$\Rightarrow 33600 / ( \text{LVD sup}) \times (\text{Bx sup}) = 33600 / (13.75m \times 12m) \times (6.7 \times 6.7) m^2 = 9141 \mu/\text{year}$

$45 \mu/\text{day}$
• Can Borexino/CTF monitor the CNGS \( \nu \) beam ?? Yes !

In LNGS - HallC we will have :

• \(~ 315 \ \text{ev/day in Borexino} \) \((\sim 150 \ \text{detected ev/day in LVD})\)
  \(~ 60 \ \mu\text{/day hit OPERA}\)

• \(~ 117 \ \text{ev/day in CTF}\)

  Corresponding to a 3\% stat. error in:

  \(\text{3.5 days for Borexino (7 for LVD)}\)
  \(\text{9.5 days for CTF}\)

What we have to do ??

These are very preliminary results

\(\RightarrowMC\)- calculate all the acceptances of the detectors for these \emph{horizontal} muons

• What is needed for monitoring ??

  Spill timing information

• Can Bx do something else ??

  Yes !! Beam burst structure, Calibrations, Track algorithm checks, ….

  ?? Some physics?? \(\sigma_{cc}??\)
What we have to do ??

**Decide if/how we want:**
- to study this new bkgnd
- to monitor the CNGS beam
  => decide which actions to do, who does what, by when
- to take advantage of it
  => decide which actions to do, who does what, by when

**Needed:**

Software:
- MC simulations
- Interface with the CNGS database (read and write)

Hardware:
- spill info read-out (BX clock calibrations)

*Can Bx do something else ??*
- Think about it !!