Artificial Neutrino Source Experiment in Borexino

A. Ianni on behalf of the Borexino coll.

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Motivations for a $\nu$ source experiment

• LSND: $3.8 \sigma$ excess of $\overline{\nu}_e$ in a $\overline{\nu}_\mu$ beam
  – $L/E \sim 0.5 - 2$
• MiniBooNE: 99.4% CL evidence of $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ oscillations with $L/E \sim 1$
• Reactor antineutrino anomaly: 98.6% CL deficit which could be explained in the framework of a forth sterile $\nu$
• Hints from CMB and BBN for $N_{\text{eff}} > 3$

A source experiment coupled with a large low background Liquid Scintillator underground detector could
  – Search for new physics with $L/E \sim 1$
  – Probe neutrino-electron scattering interaction at 1 MeV scale
  – Probe neutrino magnetic moment

• A source experiment in Borexino was one of the research goals in the early proposal back in 1991
A ν source experiment in BX

Work in progress:

– Study the sensitivity and discovery power for a SBL experiment in BX
– Study the feasibility of making a 50-300 PBq scale source using:
  • $^{51}$Cr, $^{90}$Sr-$^{90}$Y and $^{144}$Ce-$^{144}$Pr
– Address logistic and technical issues
## Source features

<table>
<thead>
<tr>
<th>Source</th>
<th>decay</th>
<th>$\tau$ [days]</th>
<th>Energy [MeV]</th>
<th>Kg/MCi</th>
<th>W/kCi</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{51}\text{Cr}$</td>
<td>e-capture ($E_\gamma$=0.32 MeV 10%)</td>
<td>40</td>
<td>0.746 81%</td>
<td>0.011</td>
<td>0.19</td>
</tr>
<tr>
<td>$^{90}\text{Sr-90Y}$</td>
<td>Fission product $\beta^-$</td>
<td>15160</td>
<td>&lt;2.28 MeV 100%</td>
<td>7.25</td>
<td>6.7</td>
</tr>
<tr>
<td>$^{144}\text{Ce-144Pr}$</td>
<td>Fission product $\beta^-$</td>
<td>411</td>
<td>&lt;2.9975 MeV 97.9%</td>
<td>0.314</td>
<td>7.6</td>
</tr>
</tbody>
</table>
Source locations in Borexino

- **A**: underneath WT
  - $D = 825 \text{ cm}$
  - No change to present configuration
- **B**: inside WT
  - $D = 700 \text{ cm}$
  - Need to remove shielding water
- **C**: center
  - Major change
  - Can be done at the end of solar neutrino physics
$\nu_e$ experiment with $^{51}$Cr

Detection channel: Elastic Scattering
Cr51 Gallex source
Borexino neutrino and background signal

Borexino electron recoil spectrum

- $^7$Be solar neutrinos
- CNO solar neutrinos
- $^{210}$Bi (used 10 cpd/100 tons)
- $^{11}$C 28 cpd/100 tons

$dN/dT$ [events/400 days/100 tons]

Visible energy [MeV]
370 PBq $^{51}$Cr source outside BX
Oscillation pattern with external source

\[ \Delta m_{SBL}^2 = 2 \text{ eV}^2 \quad \sin^2 2\theta_{SBL} = 0.1 \]
Sensitivity of the $^{51}$Cr source

FM = 132 tons; transportation time = 3 days; data taking = 400 days

Baseline: < 6.6 m

$E/L \sim 0.1 - 1$

Predicted w/o oscillations = 14498 events

Predicted w/ oscillations = 13781

Background = 14588
Discovery power with $^{51}\text{Cr}$ source outside BX

![Diagram showing the discovery power with $^{51}\text{Cr}$ source outside BX](image)

A. Palazzo @ TAUP 2011
$\bar{\nu}_e$ experiment

Detection channel: Inverse-beta decay

Probe oscillation pattern in energy and space domain
Sensitivity of $^{90}\text{Sr}$ source outside BX

FM = 283 tons; transportation time = 10 days; data taking = 365 days

Baseline: < 8.5 m
E/L $\sim$ 0.2 – 2

Predicted w/o oscillations = 17596 events
Background from accidentals, reactor antineutrinos and geoneutrinos is negligible
Discovery power with $^{90}\text{Sr}$ source outside BX

![Graph showing discovery power with $^{90}\text{Sr}$ source outside BX. The graph illustrates the relationship between $\Delta m_{\text{new}}^2$ and $\sin^22\theta_{\text{new}}$. The figure includes curves for reactive anomalous 90% CL and BX 3$\sigma$ discovery, with a region marked as 90% CL excluded.]
Source @ center

• Use: $^{144}\text{Ce-}^{144}\text{Pr}$
  (effective $\tau=411$ days, $Q_\beta=2997.5$ keV with 97.6% BR)
• Source configuration and background as from: M. Cribier et al. 2011, arXiv:1107.2335
• Use Borexino IB and a volume with $R_{\text{in}}=2\text{m}$ and $R_{\text{out}}=5.5\text{m}$ to remove background from source shielding
• $E/L \sim 1$
Borexino with source @ center

Borexino Experiment

Source+shielding

Volume to reject background from source shielding

Target volume

- External water tank 18m φ
- Stainless steel sphere 13.7m φ
- (1320 m 3 P C)
- Nylon outer vessel 11.0 m φ
- Nylon inner vessel 8.5 m φ
- Fiducial volume 6.0 m φ

2200 Thorn EMI 8" PMTs (1800 with light collectors, 400 without light collectors)

208 PMTs in water for External Muon Detector

Steel plates in concrete for extra shielding: 10m x 10m x 10cm, 4m x 4m x 4cm
Oscillation pattern with an internal source

\[
\Delta m_{SBL}^2 = 2 \text{ eV}^2 \quad \sin^2 2\theta_{SBL} = 0.05
\]
$^{144}\text{Ce-}^{144}\text{Pr source @ center}$

Remove 29tons of LS around the source to reject background due to source shielding.

Choose $R_{in} = 2\text{m}$ and $R_{out} = 5.5\text{m}$ including Inner Buffer region filled with LS.

$\Delta m_{SBL}^2 = 1 \text{ eV}^2, \sin^22\theta_{SBL} = 0.1$, $N_{\text{predicted}}(\Delta m_{SBL}^2, \sin^22\theta_{SBL}) = 59294$ with an exposure = 0.584 kton-$\text{y}$.
$Δm_{SBL}^2 = 2 \text{ eV}^2$, $\sin^2 2\theta_{SBL} = 0.15$, $N_{\text{predicted}} (Δm_{SBL}^2, \sin^2 2\theta_{SBL}) = 140208$ with an exposure = 0.613 kton-$\lambda$osc $= 2.8 \text{ m}$
Discovery with $^{144}\text{Ce} \ @ \ @ \ @ \ @ \ center$
Conclusions

- Borexino is a running low background detector with an available location for an external neutrino source

- Work is in progress to understand the feasibility of a $^{51}$Cr and $^{90}$Sr experiment to be located outside BX
  - $^{51}$Cr source using $^{50}$Cr from Gallex looks feasible in a few years
  - Work in progress for activation, safety issues and transportation
  - Make use of previous experience from Gallex/SAGE and Bellotti/Kirsten 2001 proposal
  - Feasibility of 1MCi $^{90}$Sr source from experience based on thermoelectric generator technology

- The external source experiment can search for new physics with $L/E \sim 1$ and more (neutrino magnetic moment etc)

- If indication confirmed, in the long term the possibility to use an internal source is not excluded
Spares
The case of reactor anti-neutrinos with a forth sterile $\nu$

$\theta_{14}, \Delta m_{14} \sim 0.1 - 1 \text{ eV}^2$

$\theta_{13}, \Delta m_{13} \sim 3 \times 10^{-3} \text{ eV}^2$

$\theta_{12}, \Delta m_{12} \sim 10^{-4} \text{ eV}^2$

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$N_{\text{osc}} / N_{\text{std}}$

Reactor–Detector distance [km]

$v$ source

SBL

LBL
**The Borexino experiment**

Goals:
1) 7Be solar neutrinos
2) 8B solar neutrinos
3) Geo-neutrinos
4) SN neutrinos
5) Rare processes

Method:
1) 300 tons of high purity organic LS
2) High energy resolution 5%/1MeV
3) Good PSD
3) Good event vertex
   Reconstruction: ~12cm/1MeV