Prospects for DAMA/LIBRA and beyond

A. Incicchitti
INFN Roma
TAUP2003

Roma2, Roma, IHEP/Beijing
http://www.lngs.infn.it/lngs/htexts/dama/
DAMA/NaI milestones

Proposal by R. Bernabei, P. Belli, C. Bacci, A. Incicchitti, R. Marcovaldi and D. Prosperi on large mass NaI(Tl) and liquid Xenon experiments for Dark Matter search and first funding on 1990

Several results since the beginning and various test/preliminary set-ups

The ~ 100 kg NaI(Tl) set-up:

- First result on WIMP annual modulation signature presented at TAUP97
- Data from 4 annual cycles released and published.
- Several other rare processes investigated.
- New electronics and DAQ in summer 2000.
- Out of operation in July 2002

JULY 2003: RELEASE OF THE CUMULATIVE 7 ANNUAL CYCLES EXPOSURE

The Chinese colleagues joined the project in 1992

DAMA/R&D and DAMA/LXe operative set-ups
LIBRA in DAMA: milestones

• In 1996 1 ton set-up proposed and an intermediate step of ~250 kg obtained with founding for a new R&D
• 1999 successful completion of the second generation R&D with chemical/physical radiopurification of the NaI and TlI selected powders + new selection of corollary materials and protocols
• 2002 end production of detectors and of new parts in the installation
• Jul 2002 - Jan 2003 dismounting of the ~ 100 kg set-up and installation of LIBRA
• Jan - Mar 2003 test runs
• March 2003 start measurements
~100 kg NaI(Tl) DAMA set-up: data taking completed on July 2002

Performances:


Results on WI MPS:

• PSD: PLB389(1996)757
• Annual Modulation Signature:

Results on rare processes:

• Possible Pauli exclusion principle violation PLB408(1997)439
• Nuclear level excitation of $^{127}$I and $^{23}$Na during CNC processes PRC60(1999)065501
• Electron stability and non-paulian transitions in Iodine atoms (by L-shell) PLB460(1999)235
• Exotic Dark Matter search PRL83(1999)4918
• Search for solar axions by Primakoff effect in NaI(Tl) crystals PLB515(2001)6
• Exotic Matter search EPJdirect C14(2002)1

Model independent evidence for WIMPs in galactic halo by annual modulation signature at 6.3 $\sigma$ C.L.:

(107731 kg⋅d)

The several peculiar features of the signature satisfied. No systematics or side reactions able to mimic it. Some of the many possible model frameworks investigated in the corollary quests for a candidate

DAMA/NaI out of operation

The switching off of the ~100kg NaI(Tl) set-up at end of July 2002

Opening the shield

Dismounting the ~100kg NaI(Tl) set-up in August 2002 in HP N₂ atmosphere
New radiopure detectors by chemical/physical purification of the NaI and TlI powders: result of a dedicated second generation R&D

<table>
<thead>
<tr>
<th></th>
<th>natK (ppm)</th>
<th>238U (ppb)</th>
<th>232Th (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old NaI powder</td>
<td>&lt;0.8</td>
<td>0.56±0.04</td>
<td>0.21±0.01</td>
</tr>
<tr>
<td>New NaI purified powder</td>
<td>&lt;0.1</td>
<td>0.02</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Intermediate test prototype

<table>
<thead>
<tr>
<th></th>
<th>natK&lt; 5 ppb</th>
<th>U/Th ~1 ppt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kyropoulos crystallization process (in platinum crucible when growing for final detectors) acts as an additional considerable purification step</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In the final detectors’ realization improved owen, crucible and protocol: features will be published in a devoted paper

Kyropoulos crystallization process (in platinum crucible when growing for final detectors) acts as an additional considerable purification step

LIBRA


detectors | natK < 50 ppb | U/Th several ppt

Crystallization process (in platinum crucible when growing for final detectors) acts as an additional considerable purification step

Kyropoulos crystallization process (in platinum crucible when growing for final detectors) acts as an additional considerable purification step
PMTs

• 3” window PMTs

• Low radioactive glass (special development)

• Flying leads directly connected to voltage dividers made of miniaturized SMD components mounted on thin teflon sockets (all selected for low bckg)

• The solders were performed by low radioactive Boliden lead and low radioactive resin

• The residual contaminants in the PMTs mounted on the DAMA/NaI detectors were already published in: Il Nuovo Cim. 112 A (1999) 545

  measurements with and without bent light guide (i.e. shielding and not shielding the PMT contribution) and a low background NaI(Tl) gave:

  $$^{nat}K: (60\pm15) \text{ ppm;} \quad 2^{32}\text{Th: } (30\pm10) \text{ ppb;} \quad 2^{38}\text{U: } (30\pm20) \text{ ppb.}$$

• The residual contaminants in the PMTs of the other NaI(Tl) detectors of DAMA/LIBRA will be released in a devoted paper

• 3” diameter and 10 cm long UV Tetrasil-B light guides used, acting also as optical windows.

• PMT shielding: in DAMA/NaI low radioactivity Cu (housing + bricks); in DAMA/LIBRA low radioactivity Cu (new shaped shield +housing) for the whole PMT body
<table>
<thead>
<tr>
<th>Component</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystals</td>
<td>New detectors stored underground from June 2001 to beginning October 2002. Quality improved</td>
</tr>
<tr>
<td>PMTs</td>
<td>Stored underground since 2001</td>
</tr>
<tr>
<td>Voltage dividers</td>
<td>Low bckg materials stored and assembled underground</td>
</tr>
<tr>
<td>Wiring</td>
<td>New and conceptually modified</td>
</tr>
<tr>
<td>New low bckg Cu shield for PMTs</td>
<td>Improved etching and handling protocol</td>
</tr>
<tr>
<td>N₂ flux systems</td>
<td>Implemented</td>
</tr>
<tr>
<td>Environment</td>
<td>Implemented</td>
</tr>
<tr>
<td>Dismounting/Installing protocol</td>
<td>For the dismounting of the ~ 100 kg detectors and the installation of LIBRA detectors we used a “Scuba” system (a self-contained underwater breathing apparatus) modified in order to avoid that the entire breath is expelled into the surrounding air when the operator exhales. The cylinders were kept five meters away. Output two meters away.</td>
</tr>
<tr>
<td>Cooling water of air conditioner</td>
<td>Devoted line equipped with new chiller and UPS system for DAMA set-ups</td>
</tr>
<tr>
<td>Electronics</td>
<td>New implementation</td>
</tr>
<tr>
<td>DAQ</td>
<td>New implementation</td>
</tr>
</tbody>
</table>
The new **LIBRA** set-up ~250 kg NaI(Tl) (Large sodium Iodide Bulk for RAre processes) in the DAMA experiment

As a result of a new R&D for further purification of NaI(Tl) by exploiting new chemical/physical radiopurification techniques

- **PMT** +HV divider
- Cu etching with super- and ultra-pure HCl solutions, dried and sealed in HP N₂
- storing new crystals
- improving installation and environment
- etching staff at work in clean room
Detectors during installation; in the central and right up detectors the new shaped Cu shield surrounding light guides (acting also as optical windows) and PMTs was not yet applied. Closing the Cu box housing the detectors.

(a all operations involving crystals and PMTs -including photos- in HP N\textsubscript{2} atmosphere)

Installing LIBRA detectors.

Filling the inner Cu box with further shield.

Assembling a DAMA/ LIBRA detector.

Closing the Cu box housing the detectors.

View at end of detectors’ installation in the Cu box.
Further on LIBRA installation

working under the passive shield before installing the paraffin

installing LIBRA electronics

view with shielding completed

verifying Cd foils

upper glove box for calibration; the same as for ~100kg set-up (old photo)

Particular thanks to the Fire Department staff, inside LNGS, for having never left us alone during all the works on the installation performed in HP N\textsubscript{2} atmosphere.
LIBRA Data Acquisition System:

- **Computer**: Compaq Workstation with Intel processor (1 GHz) with SUSE Linux operating system
- **Bus**: MXI-2 and GPIB
- **Mainframe**: VXI and CAMAC

**Waveform Analyzer**: Tektronix TVS641A for bus VXI, 4 channels, Sample rate = 1 Gsample/s, 8 bit, bandwidth 250 MHz, 2 channels for each crystal

+ **ON-LINE monitoring system**
  (Temperatures, pressure, HV, N₂ flows, external radon etc.)
LIBRA electronic chain

Diagram showing the flow of signals through various components such as PMTs, crystals, Preamp Gain 10, Cable line, Light guide, Gate, Discrim, ADC, OR enable, and Single Trigger crystal recognition. The diagram includes various gates, triggers, and connectors for signal processing and data acquisition.
Some LIBRA performances

Example of energy resolution

$^{241}\text{Am}$

$\sigma/E = 6.3\%$

Typical baseline fluctuations

$\sigma = 1.07 \text{ mV (mV)}$

Time decay of $^{241}\text{Am}$ pulses

Typical time jitter due to the required coincidence

$\sigma = 5 \text{ ns}$

Frac3 vs Frac1 for $^{241}\text{Am}$ pulses

$\text{frac3} = [100-600]/[0-600]$

$\text{frac1} = [0-50]/[0-600]$
Example on sensitivity

Model Dependent approaches
An example: role of the increase of statistics and of the improvement in the bckg rate to identify a SI/SD coupled WIMP candidate in a particular given model framework

Nominal Sensitivity (note that it is always calculated by assuming arbitrarily absence of signal):
SI model framework, 2 keV thr. and ideal condition of zero bckg., in 5 years can be explored $M_w$ in the range 40-100 GeV down to $\xi \sigma \approx 10^{-10}$ pb and down to $\xi \sigma \approx 10^{-9}$ pb for few TeV masses

More complete scenarios can be investigated see (Riv. N. Cim. 26 n. 1 (2003) 1-73)

Reacheable C.L. as function of running time and of the low energy bckg rate. The shaded regions account for several model frameworks.

• Allowed regions evaluated by simulating the response of the ~250 kg NaI(Tl) set-up to a WIMP having $m_W=60$ GeV, $\sigma_{SI}=10^{-6}$ pb, $\sigma_{SD}=0.8$ pb and $\theta=2.435$ rad.
• Various exposure times are considered (from 1 to 5 y).
• In each panel different bckg rate.

Assumptions:
• $1\sigma$ C.L.
• $v_0=220$ km/s, fixed params
• isothermal spherical halo
Competitiveness of LIBRA

- Standard and well defined operating procedures, well known technology
- Proved possibility of an effective control of the experimental conditions during several years of running
- Possibility to deeply investigate model independent signature
- Sensitivity to both SI and SD couplings, favoured sensitivity in some of the possible particle and astrophysical models
- High benefits/cost
- When applicable, it offers also PSD capability
- Possibility to achieve competitive results also on other rare processes as $\beta\beta$ decays with passive and active sources etc.
- Potential interest in low energy neutrino physics
What can LIBRA do beyond WIMP search by elastic scattering in 5 years of running?

Possible PEP violating processes
maximal reachable sensitivity: \( \sim 3 \times 10^{27} \) y

Possible CNC processes in \(^{23}\text{Na}, \ ^{127}\text{I}\)
in case of a rate \( \sim 0.1 \) cpd/kg/keV in the region of interest and of the same duty cycle as at present:
a) reachable sensitivity for CNC EC \( 10^{24} \) y 90\%C.L. (or higher depending on \( r \))
b) reachable sensitivity for \( e^- \) disappearance \( 10^{25} \) y at 90\%C.L. (or higher depending on \( r \))

Nucleon and di-nucleon decay
maximal reachable sensitivity: \( \tau_n \rightarrow 10^{27} \) y

SIMP search
maximal explorable mass: above \( 10^{17} \) GeV

Neutral nuclearities
maximal explorable flux: \( \sim 5 \times 10^{-12} \text{s}^{-1} \text{cm}^{-2} \text{ster}^{-1} \)

WIMP search by inelastic scattering
reachable sensitivity for \( r \sim 0.1 \) cpd/kg/keV in the region of interest and the same duty cycle as at present 5 GeV/cm\(^3\); lower rate can allow to explore physical regions

Solar axion search
maximal reachable sensitivity: \( g_{a\gamma} \sim 10^{-10} \) GeV\(^{-1}\)

etc. ... and beyond (e.g. \( \beta\beta \) decays with passive and active sources, tests for \( \nu \) physics with artificial \( \bar{\nu} \) source etc. etc.)
... and beyond?

Competitiveness of 1 ton set-up for Dark matter pointed out firstly by R. Bernabei at IDM96 and proposed to INFN, which funded preliminarily an R&D for LIBRA as intermediate step.

**NaI(Tl)?**

- Well known technology
- High light output \( \sim 7.5 \text{ ph/keV} \) --> reliable low energy threshold
- Very good noise identification \( (\tau \text{ of order of tens ns vs } \tau \text{ of order of hundreds ns}) \)
- Well controlled operational condition feasible
- Routine calibrations feasible down to keV range
- Quenching factors for each growth easily and precisely measurable
- Cheaper than every other detector in the same field
- Do not need repurification procedures (reproducibility)
- Large mass feasible
- No safety problems
- Space for further radiopurification techniques
- etc....

A new R&D for ultra-low background NaI(Tl): for Dark matter, for other rare processes, as part of low background multidetector set-ups + e.g.

toward test for new physics with low energy anti-neutrino? NPA546(1999)19


etc....
Schema of the new R&D on ultra-low NaI(Tl)

1. NaI:
   new NaI purification process starting from standard materials and measurements on powder
2. Thallium:
   new source of raw material
   research on new purification method and measurements on powder
3. Housing:
   to investigate new housing materials and the low-background welding technique + measurements
4. Production procedures
   Investigation of new protocols for production and materials handling and measurements
5. Production of 1 NaI(Tl) - 3" x 3" - prototype
   using the output of items 1, 2 and selected materials and procedure from 3 and 4
   fixing a devoted protocol + measurements
6. Production of 1 NaI(Tl) - 3" x 3" - prototype
   using the best identified procedures and materials from points 2,3,4 and/or previous experience. The used NaI powder to be purified according to point 1 will be of the same quality as the latest WIMP crystals production. A devoted protocol will be fixed + measurements

first new purified powders already produced
Summary
Successfully running ~100kg NaI(Tl), 6.5 kg LXe and R&D set-ups over many years, many rare processes significantly investigated

First model independent evidence for a WIMP component in the galactic halo (6.3 $\sigma$ C.L.)

LIBRA (~250kg NaI(Tl)) is working ...wait for results

...and beyond?
- Further improvements in radiopurity, new R&D approved by INFN
  → multi-purpose NaI(Tl) ton set-up (R. Bernabei, IDM96)
- New ideas to fully exploit WIMP signal peculiarities and halo features