The SABRE Proof of Principle
Simone Copello
on behalf of the SABRE collaboration
Dark Matter detection through annual modulation

- Direct Dark Matter detection is based on elastic scattering off nuclei:
  - Single site event
  - For WIMP masses in the range 10 GeV – 1 TeV the typical recoil energy is 1 – 50 keV
- Expected rates are very low: $10^{-1}$ to $10^{-6}$ events/day/kg
  - Very low background
  - Underground laboratory
- Annual modulation is a powerful signature in the event rate. It is caused by the combination of Earth and Sun velocities.
Dark Matter detection through annual modulation

**Ingredients** for the annual modulation signal:

- **Standard halo model:** spherical halo surrounding the galaxy, with a local mass density of
  \[ \sim 0.3 \text{ GeV/c}^2/\text{cm}^3 \]

- **WIMP velocity (with respect to Earth):**
  \[ [220 + 15 \cos \omega(t-t0)] \text{ km/s} \]

A signal has been observed by the DAMA/LIBRA experiment at LNGS, Italy.

**DAMA/LIBRA–phase2**
- **Exposure:** 1.13 ton × year (6 years)
- **Sensitive mass:** about 250 kg of radio-pure NaI(Tl) crystals
- **Statistical significance:** 9.5 \( \sigma \) in (1 - 6) keV, 12.9 \( \sigma \) in (2 - 6) keV

* Including DAMA/Nal and DAMA/LIBRA–phase1 data

**WIMP interpretation is in tension with other experiments: an independent confirmation, using NaI, is needed.**

Simone Copello - WIN2019
Sodium iodide with Active Background REjection

SABRE aims to detect the annual modulation signal by using NaI(Tl) crystals, in order to have a direct (model independent) confirmation/confutation of DAMA results.

4 key features:
1. High purity crystals: High purity powder and clean crystal growth method
2. Active background rejection: active veto of liquid scintillator
3. Low energy threshold: High QE Hamamatsu PMTs, directly coupled to the crystals
4. Double location: both in Northern and Southern hemispheres

More detail about the SABRE project can be found in arXiv:1806.09340
The collaboration

~50 physicists from three countries

**U.S.A**
- Princeton University
- Lawrence Livermore National Laboratory (LLNL)
- Pacific Northwest National Laboratory (PNNL)

**Italy**
- Laboratori Nazionali del Gran Sasso (LNGS)
  - University of Milano and INFN
  - University of Roma "Sapienza" and INFN
  - Gran Sasso Science Institute

**Australia**
- Australian Nuclear Science and Technology Organization
- Australian National University
- Swinburne University of Technology
- University of Adelaide
- University of Melbourne
Active veto

Achieved by means of:

- **Liquid scintillator detector** used as active veto for both external and intrinsic background (energy threshold ~100 keV)

In addition to:

- **Passive shielding** (water, lead and PE) against external backgrounds

- **Underground laboratories** against cosmic rays

Mainly designed to tag $^{40}$K events

$^{40}$K has a 10% probability to produce an electron capture followed by an Auger electron (3 keV) and a gamma of 1460 keV.

Other intrinsic background sources are $^{87}$Rb, $^{232}$Th (chain), $^{238}$U (chain) and $^3$H.
High purity crystal

Ultra pure NaI crystal:

• Low contamination Astro Grade NaI powder (by Sigma Aldrich)

• Crystal growth procedure developed by Princeton University and Radiation Monitoring Devices in Boston

  **Target crystals are 4” in diameter and 8” in length (mass ~5 kg)**

Low background detector module:

• Low radioactivity PMTs

• Material screening with HPGe
High purity crystal

- An ingot of 6 kg has been recently produced (96 mm diameter)
- Cut in octagonal shape, final length 151 mm (3.6 kg)
- Currently in travel by boat to LNGS

- Preliminary measurements of K contamination (ICP-MS of tip and tail samples) suggest a value below 5 ppb

<table>
<thead>
<tr>
<th>Element</th>
<th>DAMA powder [ppb]</th>
<th>DAMA crystals [ppb]</th>
<th>Astro-Grade [ppb]</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>100</td>
<td>~13</td>
<td>9</td>
</tr>
<tr>
<td>Rb</td>
<td>n.a.</td>
<td>&lt;0.35</td>
<td>&lt;0.2</td>
</tr>
<tr>
<td>U</td>
<td>~0.02</td>
<td>0.5-7.5×10⁻³</td>
<td>&lt;10⁻³</td>
</tr>
<tr>
<td>Th</td>
<td>~0.02</td>
<td>0.7-10×10⁻³</td>
<td>&lt;10⁻³</td>
</tr>
</tbody>
</table>

- And a light yield of ~10 photo-electrons/keV
Low energy threshold

When looking for annual modulation signature, the lowest is the energy threshold the better it is

Expected amplitude for $\sigma_{xN} = 10^{-5}$ pb

• 2 Hamatsu R11065 3” PMTs per crystal (coincidence)
• High quantum efficiency (~35%)
• PMTs directly coupled to the crystal: no light guides to optimize light collection
• High crystal light yield
Double location

Seasonal effects have opposite phases

Both at ~3000 m.w.e. -> $10^6$ muon flux reduction factor

Laboratori Nazionali del Gran Sasso (LNGS), Italy.

Stawell Underground Physics Laboratory (SUPL), Australia.
SABRE *Proof of Principle* at LNGS

Main goal: validate the crystal growth procedure and the rejection power of the active veto

A single detector module will be used. It is composed by Teflon (also for crystal wrapping) and OFHC copper
The detector module, placed into the veto detector, will be isolated by the liquid scintillator by means of a copper tube.

The veto is composed by a vessel, filled with ~2 ton of liquid scintillator, internally covered with Lumirror reflector and equipped with ten 4” Hamamatsu R5912-100 PMTs.
The veto vessel is surrounded by a shielding of polyethylene (≥40 cm) and water (≥80 cm) placed on a layer of 15 cm of lead.

- Cristal Insertion System
- Top water tanks
- Side water tanks
- Veto vessel
- Side PE
- Bottom PE

Completed and ready for scintillator filling
Expected sensitivity

- Inputs:
  - Standard halo model
  - 2 keV threshold (ROI is [2;6] keV)
  - 50 kg of NaI detectors (~10 crystals)
  - 3 years exposure
  - Background 0.36 cpd/kg/keV_{ee} (from MC)
  - Quenching: [0.13; 0.21] for Na and 0.09 for I

- The WIMP interpretation of DAMA result can be tested with three years of data
  - Minimum of exclusion plot close to $10^{-42}$ cm$^2$

Monte Carlo simulations and sensitivity study are described in arXiv:1806.09340
Conclusions

• The SABRE project aims to provide a direct confirmation/confutation of DAMA observations, through annual modulation signature.

• The two SABRE detectors, in the two hemispheres, will use ultrapure NaI crystals and active vetos, with liquid scintillator, for background reduction.

• The current stage, Proof of Principle, has the purpose to verify the background expectations and the crystal purity in few months.

• The SABRE PoP facility (fluid handling, shieldings, data acquisition SW and HW) are ready.

• A promising NaI(Tl) crystal is on its way to LNGS: SABRE PoP will start data taking very soon.

Thank you for your attention!

Simone Copello - WIN2019