
INFN
LNGS
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso
GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES
Scuola Universitaria Superiore
SABRE
The SABRE Proof of Principle
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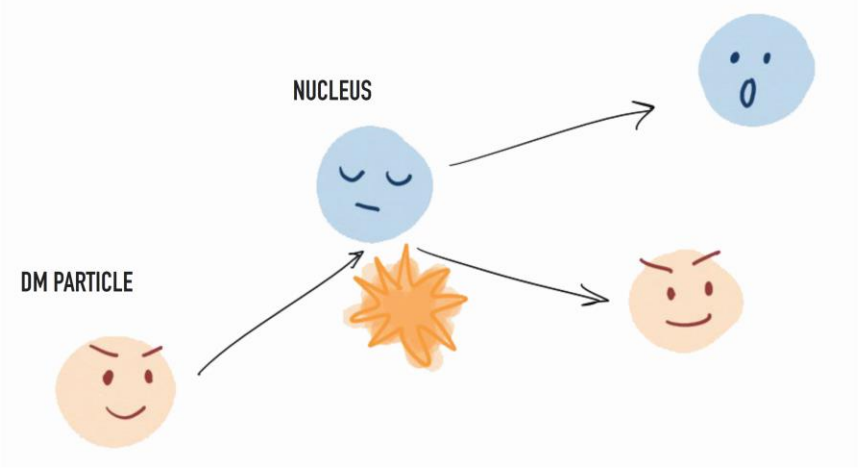
on behalf of the SABRE collaboration
WEAK INTERACTIONS AND NEUTRINOS
W±V
2019
BARI ITALY
WIN2019 – Bari, Italy - June 5th 2019

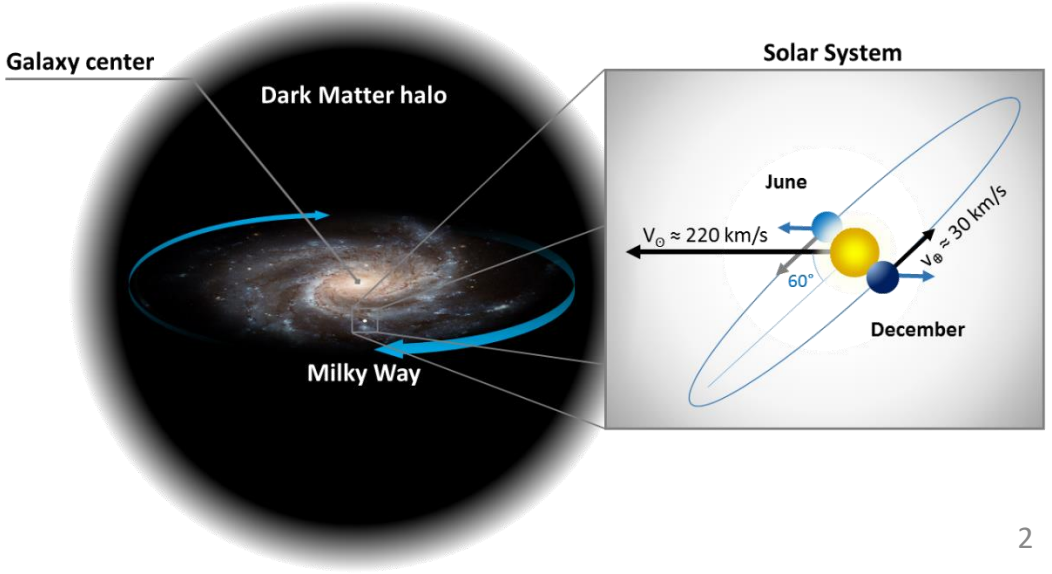
Dark Matter detection through annual modulation

- Direct Dark Matter detection is based on elastic scattering off nuclei:
  - Single site event
  - For WIMP masses in the rage 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:

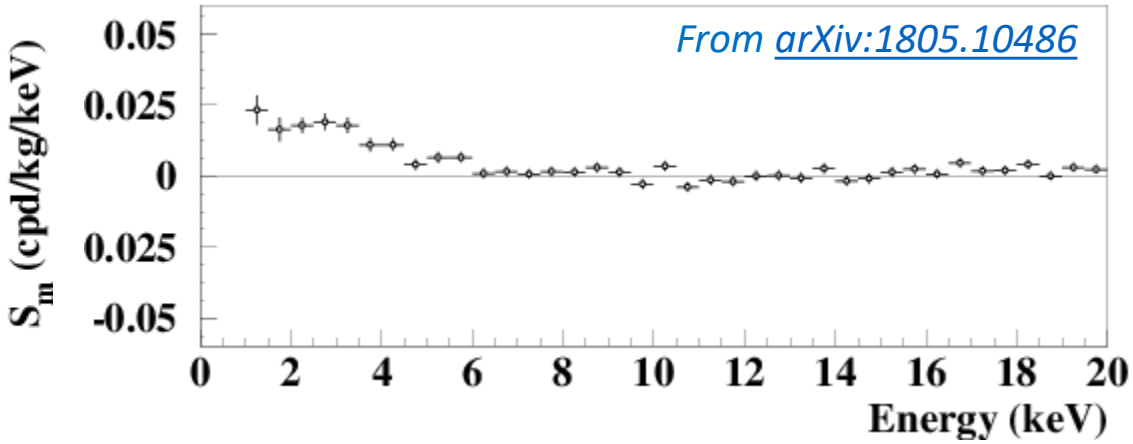
- Standard halo model: spherical halo surrounding the galaxy, with a local mass density of

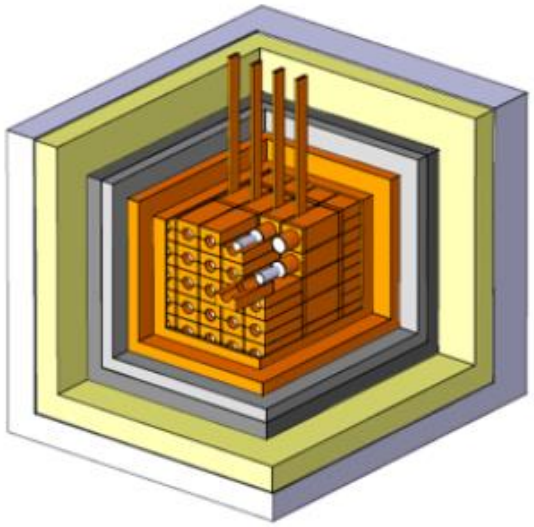
  ~0.3 GeV/c²/cm³

- WIMP velocity (with respect to Earth):

  [220 + 15 cos ω(t-t0)] 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 σ in (1 - 6) keV, 12.9 σ in (2 - 6) keV*

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

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

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)

Australia

- Australian Nuclear Science and Technology Organization
- Australian National University
- Swinburne University of Technology
- University of Adelaide
- University of Melbourne

Italy

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

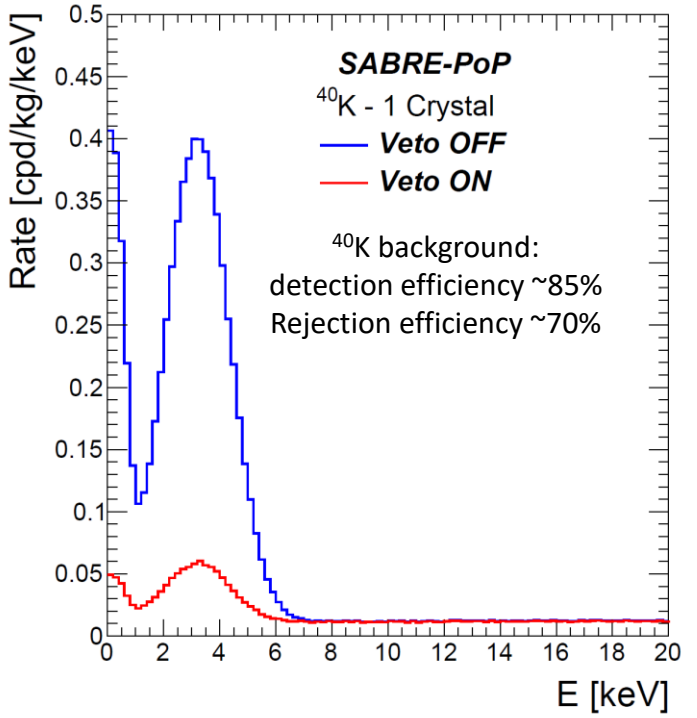
Active veto

Achieved by means of:

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

In addition to:

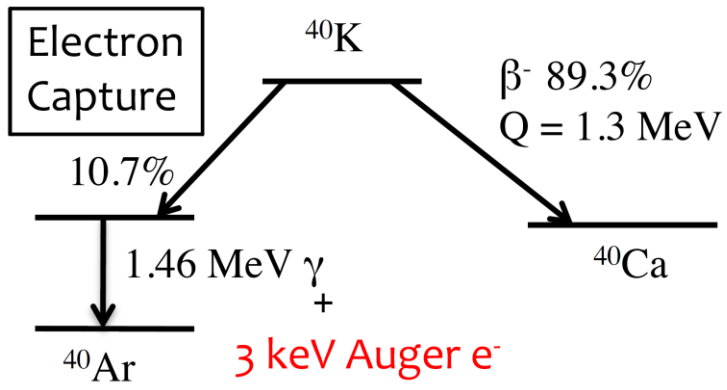
- **Passive shielding** (water, lead and PE) against external backgrounds
- **Underground laboratories** against cosmic rays

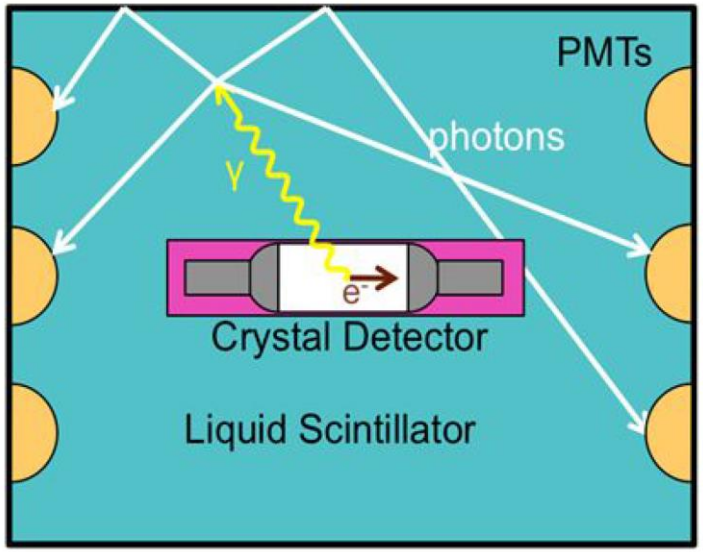


Mainly designed to tag ^{40}K events

^{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

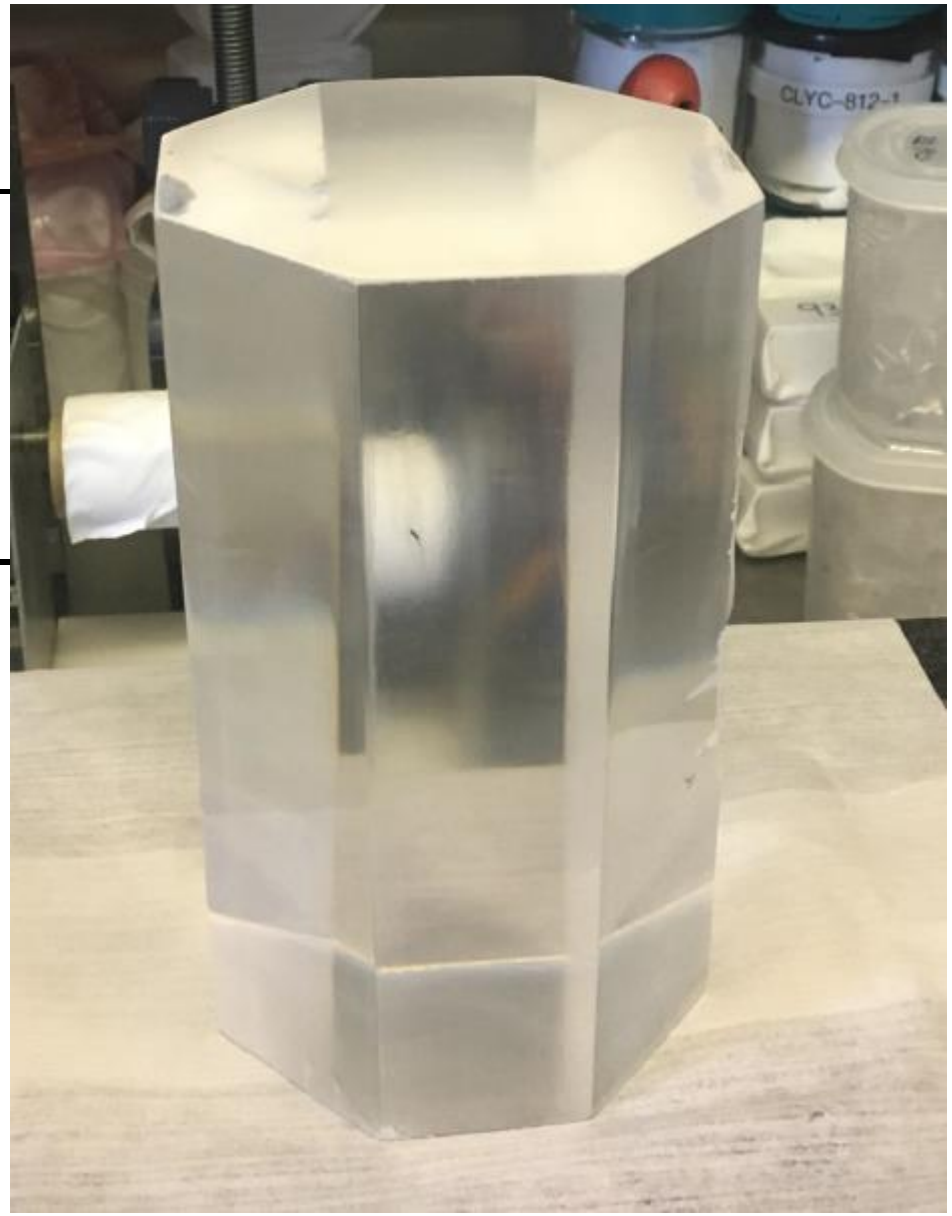
Target crystals are 4” in diameter and 8” in length (mass ~5 kg)

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



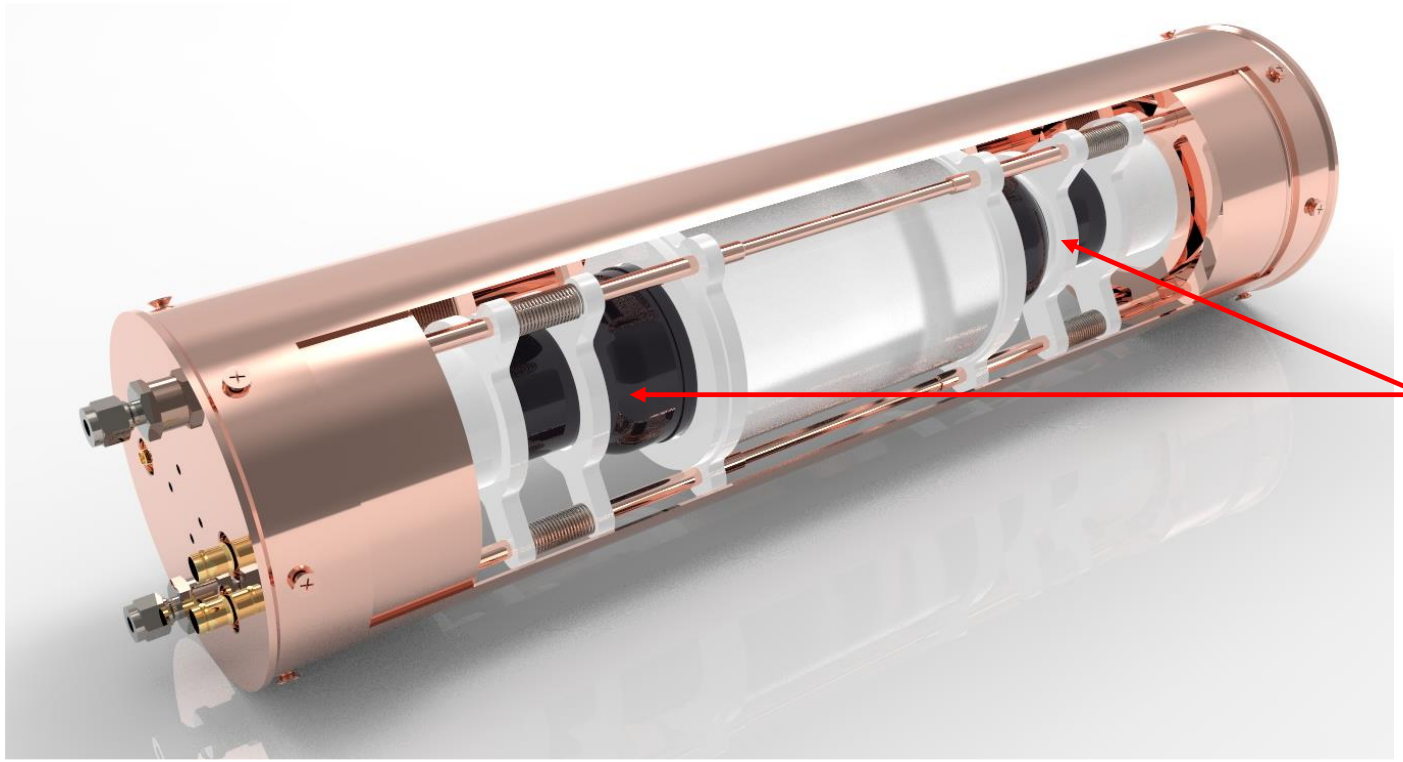
- Preliminary measurements of K contamination (ICP-MS of tip and tail samples) suggest a value below 5 ppb

Element	DAMA powder [ppb]	DAMA crystals [ppb]	Astro-Grade [ppb]
K	100	~13	9
Rb	n.a.	<0.35	<0.2
U	~0.02	$0.5\text{-}7.5\times10^{-3}$	$<10^{-3}$
Th	~0.02	$0.7\text{-}10\times10^{-3}$	$<10^{-3}$

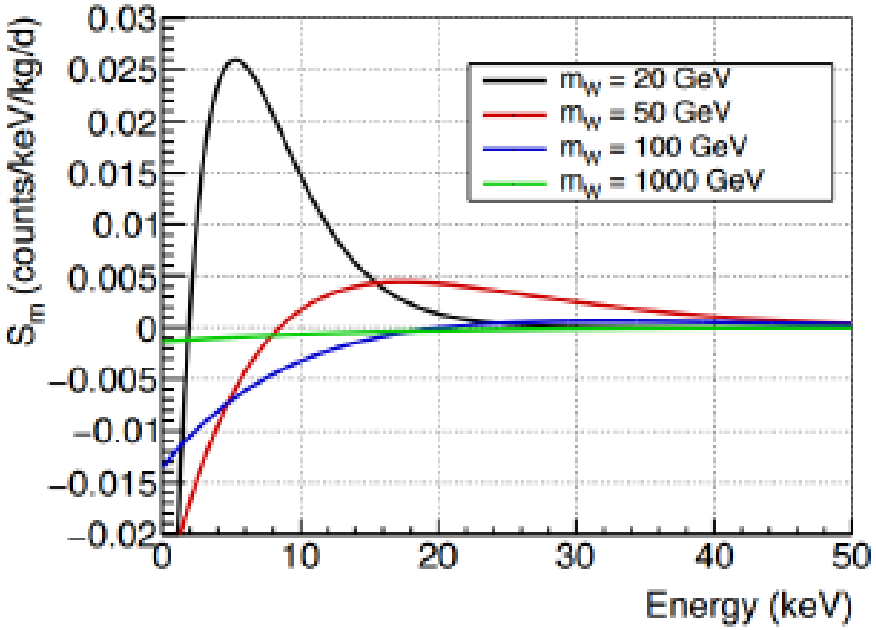
- And a light yield of ~10 photo-electrons/keV

Low energy threshold

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



Expected amplitude for $\sigma_{\chi N} = 10^{-5}$ 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

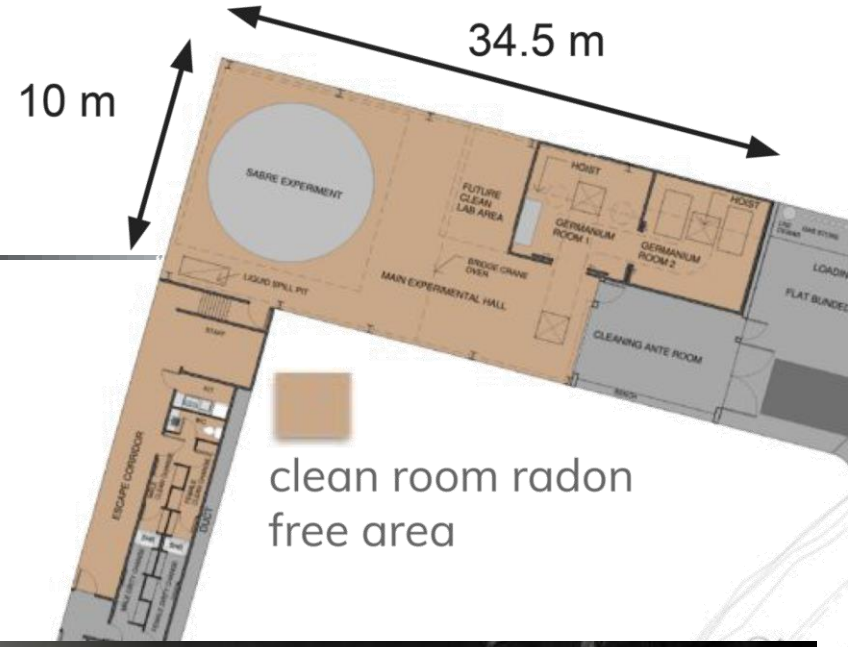
Double location

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 Physiscs 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

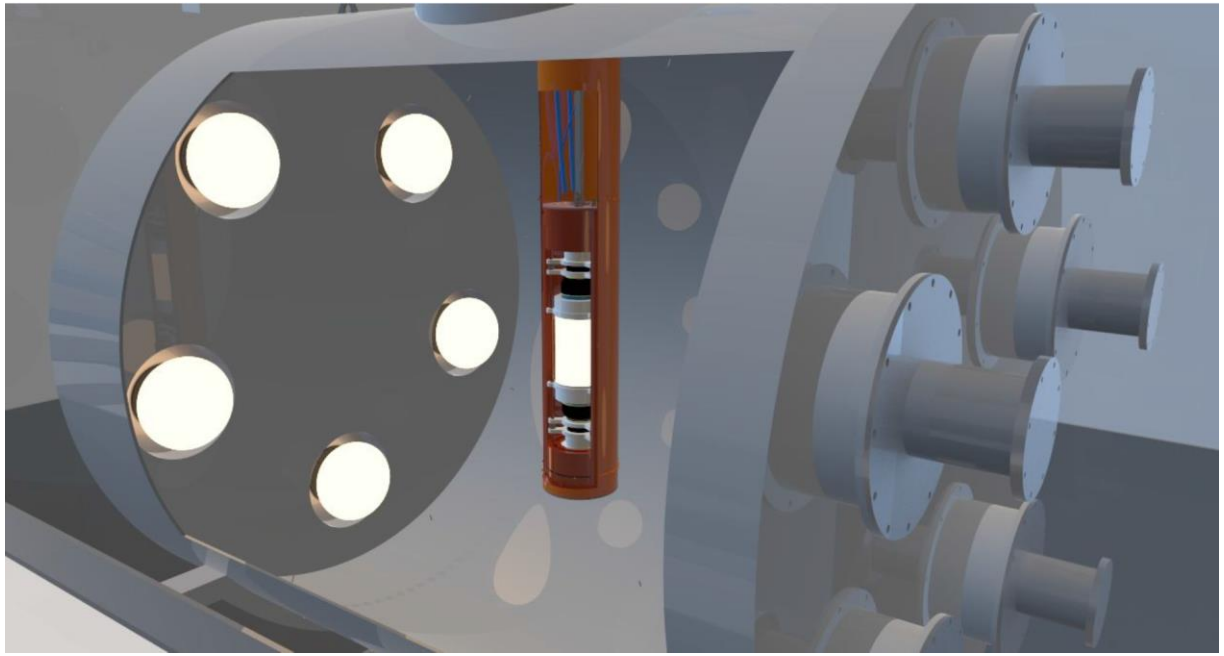
PMT
(one on
each side)

NaI crystal

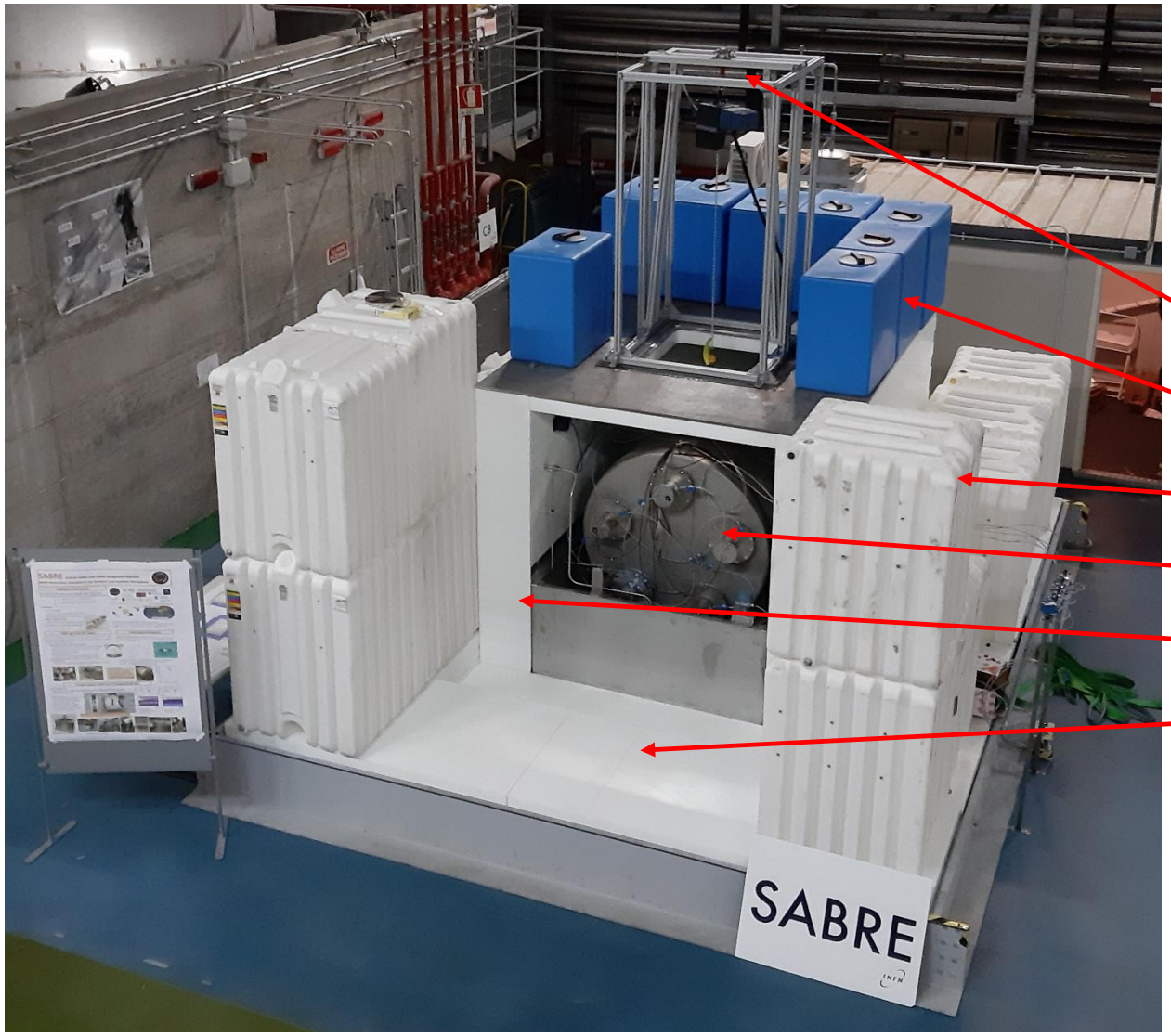
SABRE *Proof of Principle* at LNGS

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” Hamamtsu R5912-100 PMTs



SABRE *Proof of Principle* at LNGS



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

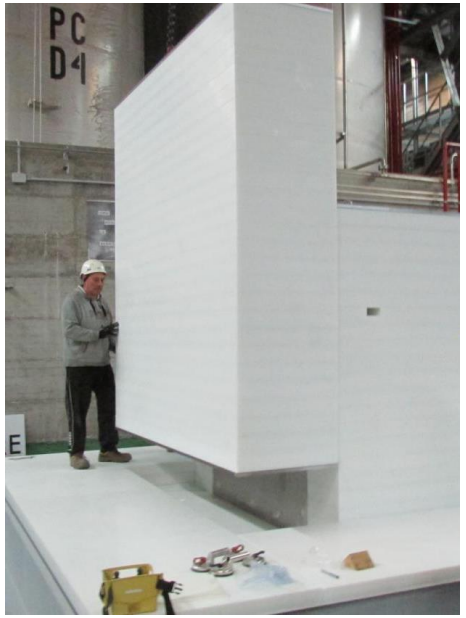
Top water tanks

Side water tanks

Veto vessel

Side PE

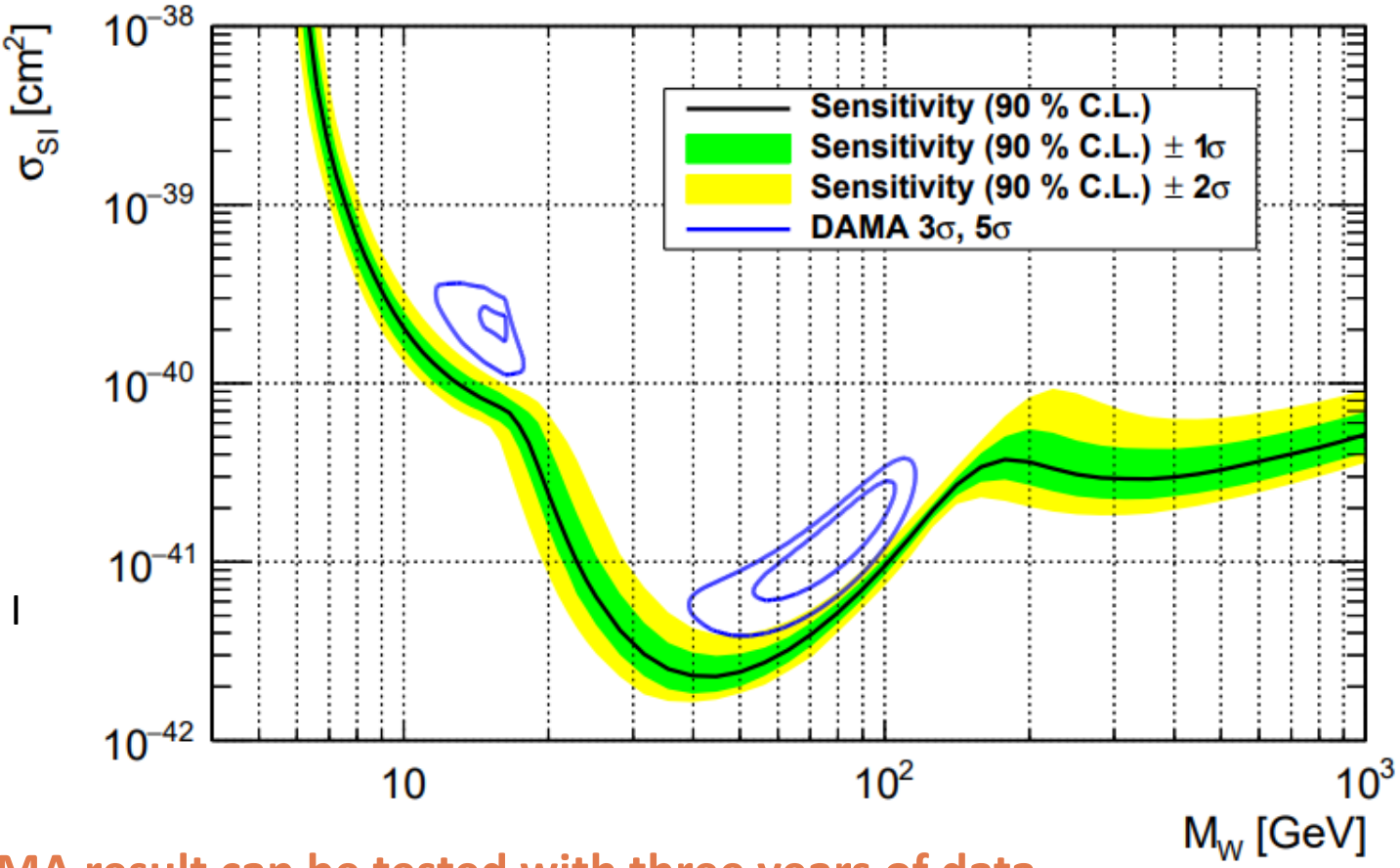
Bottom PE



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!