NDM 2018

6th Symposium on Neutrinos and Dark Matter in Nuclear Physics 2018

2018. 6. 29 (Fri) – 7. 4 (Wed) | IBS HQ, Daejeon, Korea

The SABRE experiment

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on behalf of the SABRE collaboration

GRAN SASSO SCIENCE INSTITUTE

SCHOOL OF ADVANCED STUDIES

Scuola Universitaria Superiore

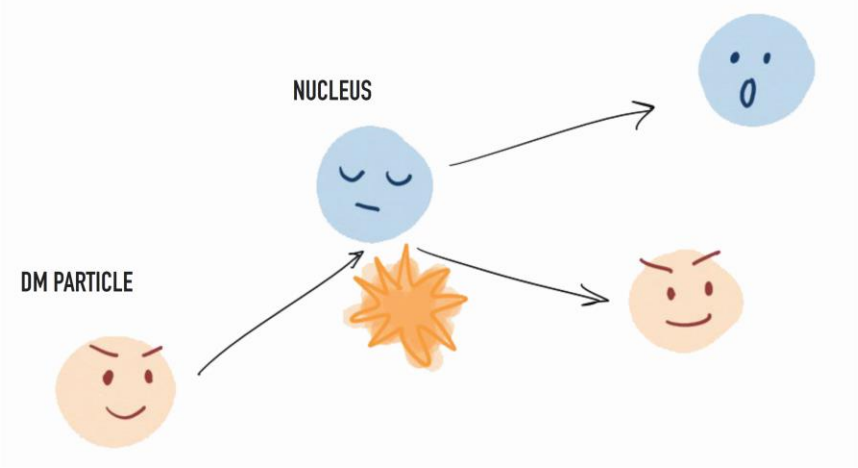
Daejeon, Korea - July 2nd 2018

Outline

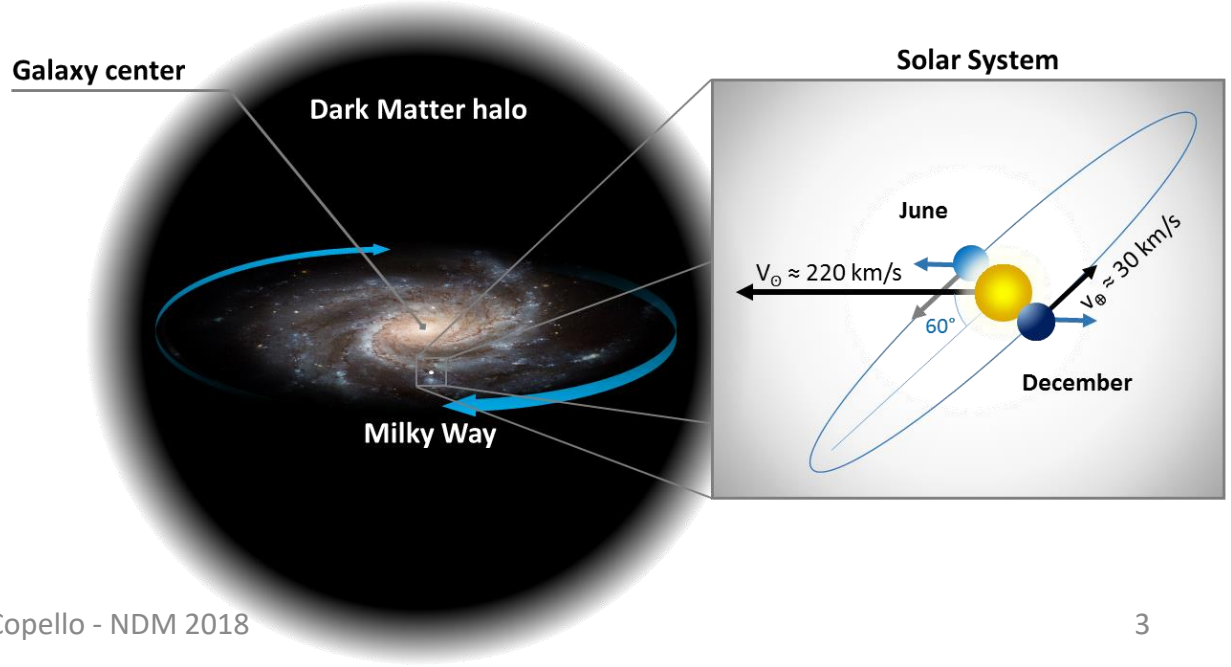
- Annual modulation signature
- The SABRE project
- SABRE Proof of Principle (PoP)
- SABRE PoP status & perspects
- Conclusions

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 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 surrounded the galaxy, with a local mass density of ~0.3 GeV/c^2/cm^3
- Sun velocity ~220 km/s
  - WIMP velocity (with respect to Earth):

    [220 + 15 cos ω(t-t0)] km/s

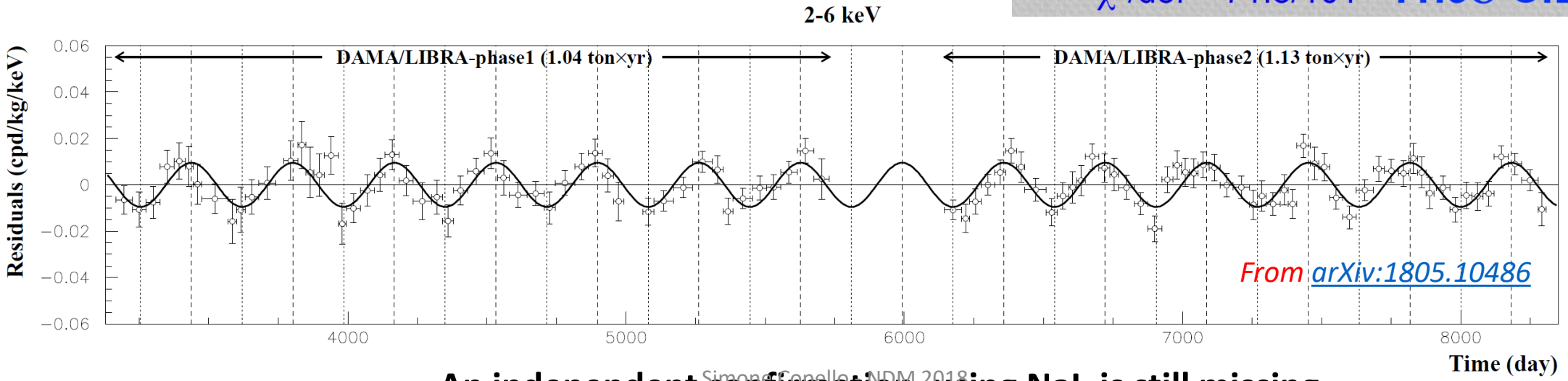
- A signal has been observed by the DAMA/LIBRA experiment at LNGS, Italy.

$A\cos[\omega(t-t_0)]$;
continuous lines: t_0 = 152.5 d, T = 1.00 y

2-6 keV

A=(0.0095±0.0008) cpd/kg/keV

χ^2/dof = 71.8/101 **11.9σ C.L.**



An independent confirmation, using NaI, is still missing

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

High purity crystal

Ultra pure NaI crystal:

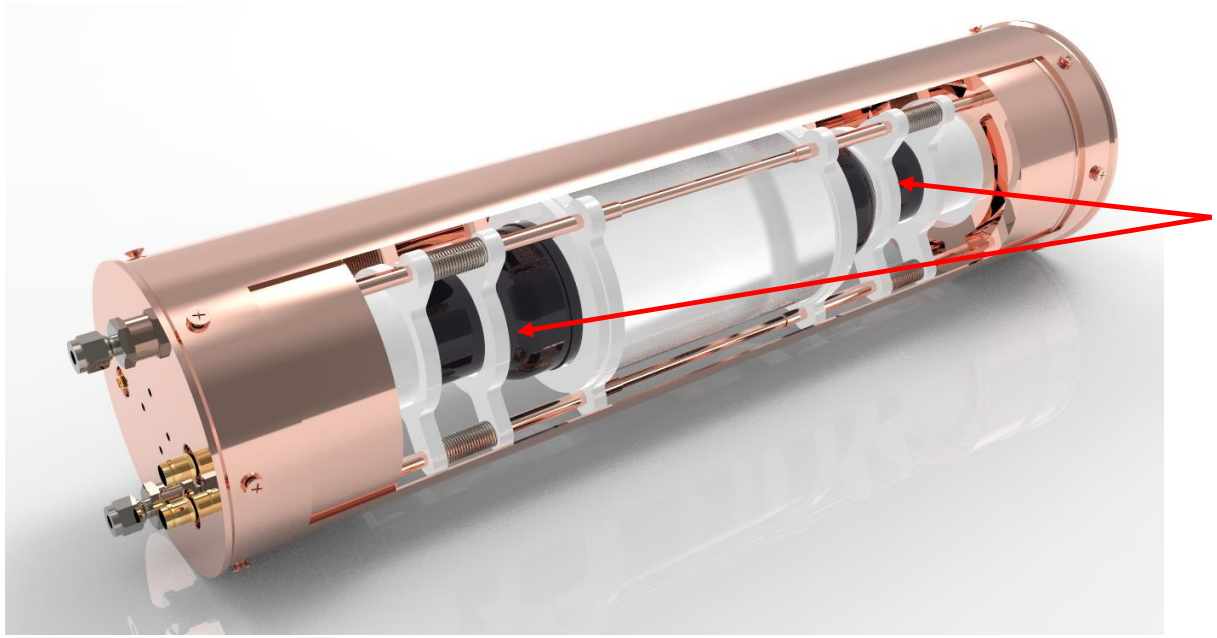
- Low contamination Astro Grade NaI powder (by Sigma Aldrich)
- Crystal growth procedure developed by Princeton University and Radiation Monitoring Devices in Boston: **a crystal of 3.6 kg** (6 kg before cut) **has been produced recently** (131 mm length x 98 mm diameter)
- Low radioactivity PMTs

Element	DAMA powder [ppb]	DAMA crystals [ppb]	Astro-Grade [ppb]	SABRE crystal [ppb]
K	100	~13	9	9
Rb	n.a.	<0.35	<0.2	<0.1
U	~0.02	$0.5\text{-}7.5\times10^{-3}$	$<10^{-3}$	$<10^{-3}$
Th	~0.02	$0.7\text{-}10\times10^{-3}$	$<10^{-3}$	$<10^{-3}$

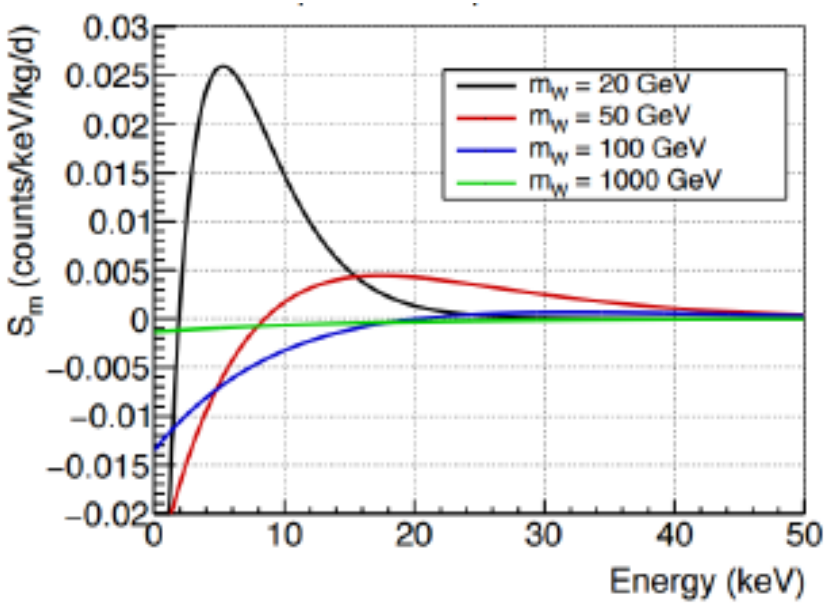
Target crystals are 4” in diameter and 8” in length (mass ~5 kg)

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

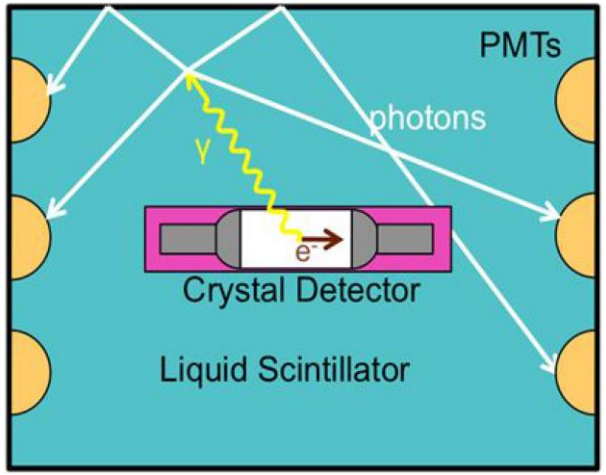
Active veto

Achieved by means of:

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

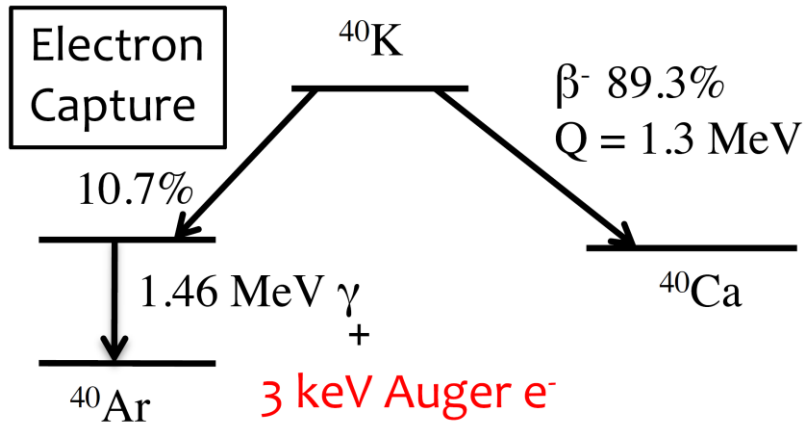
In addition to:

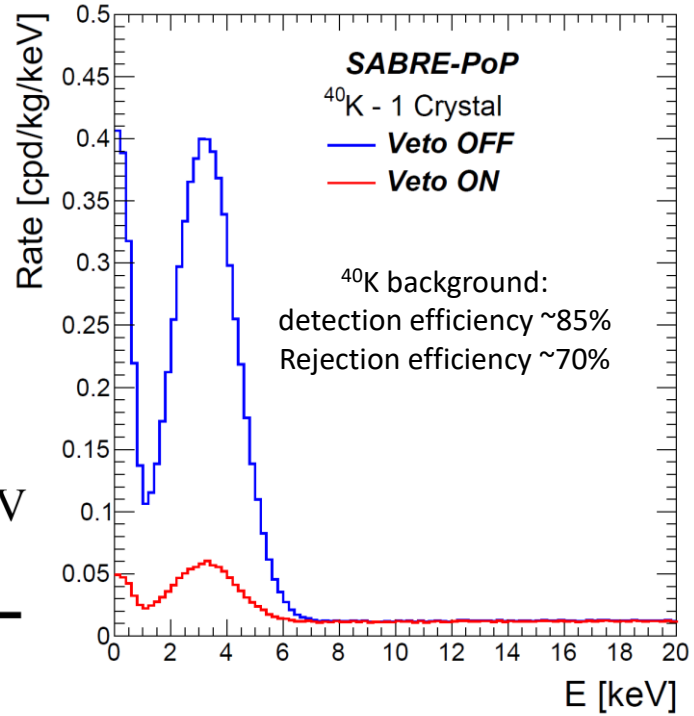
- Additional **passive shielding** against external backgrounds
- Selection of **radiopure materials** to reduce intrinsic background
- Low background PMTs
- **Underground laboratories** against cosmic rays



^{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.





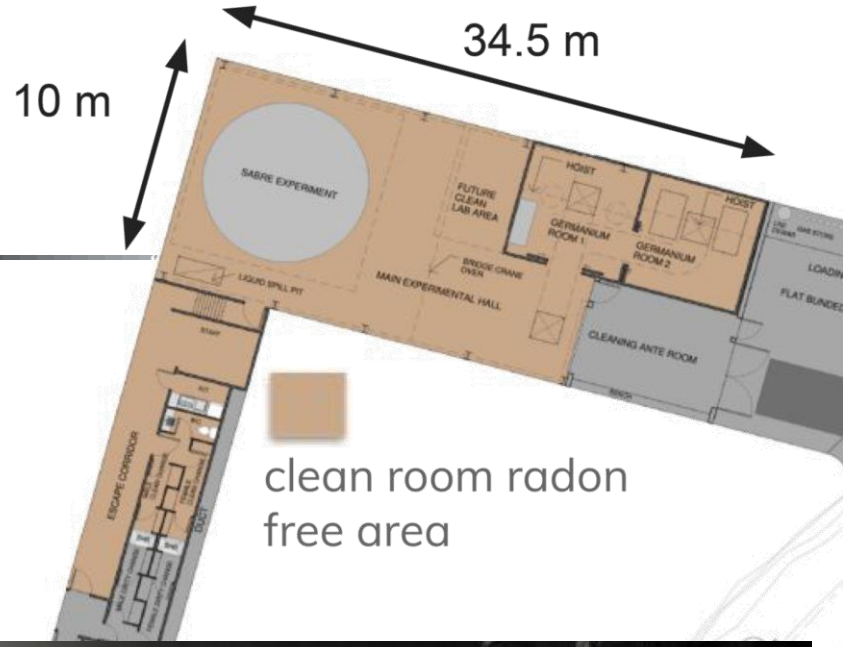
Double location

Seasonal effects have opposite phases

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

Laboratori Nazionali del Gran Sasso (LNGS), Italy.

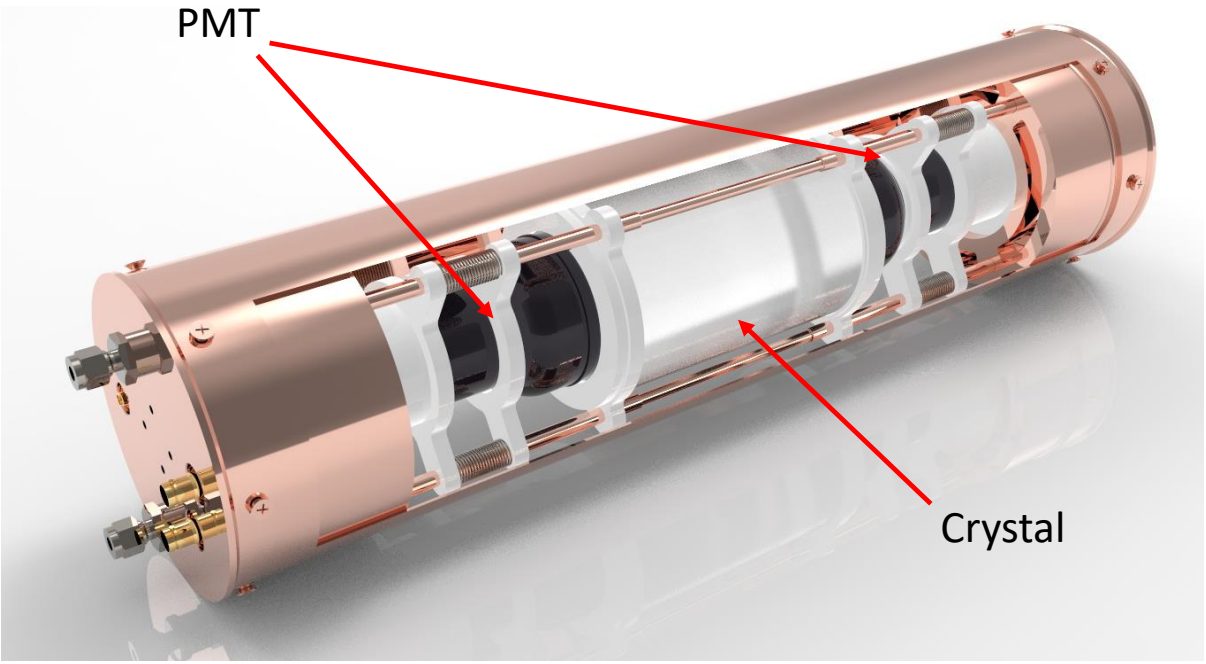
Stawell Underground Physiscs Laboratory (SUPL), Australia.



SABRE *Proof of Principle* at LNGS

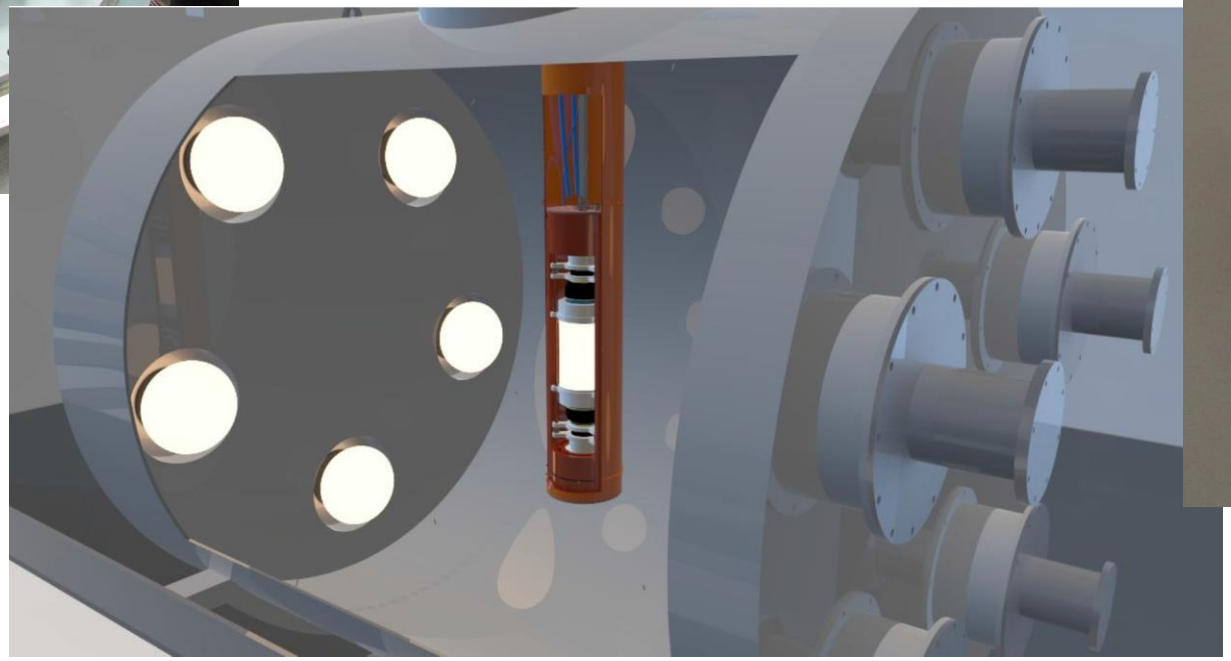
Main goal: **validate the crystal growth procedure and the rejection power of the active veto**.

A single detector module will be used

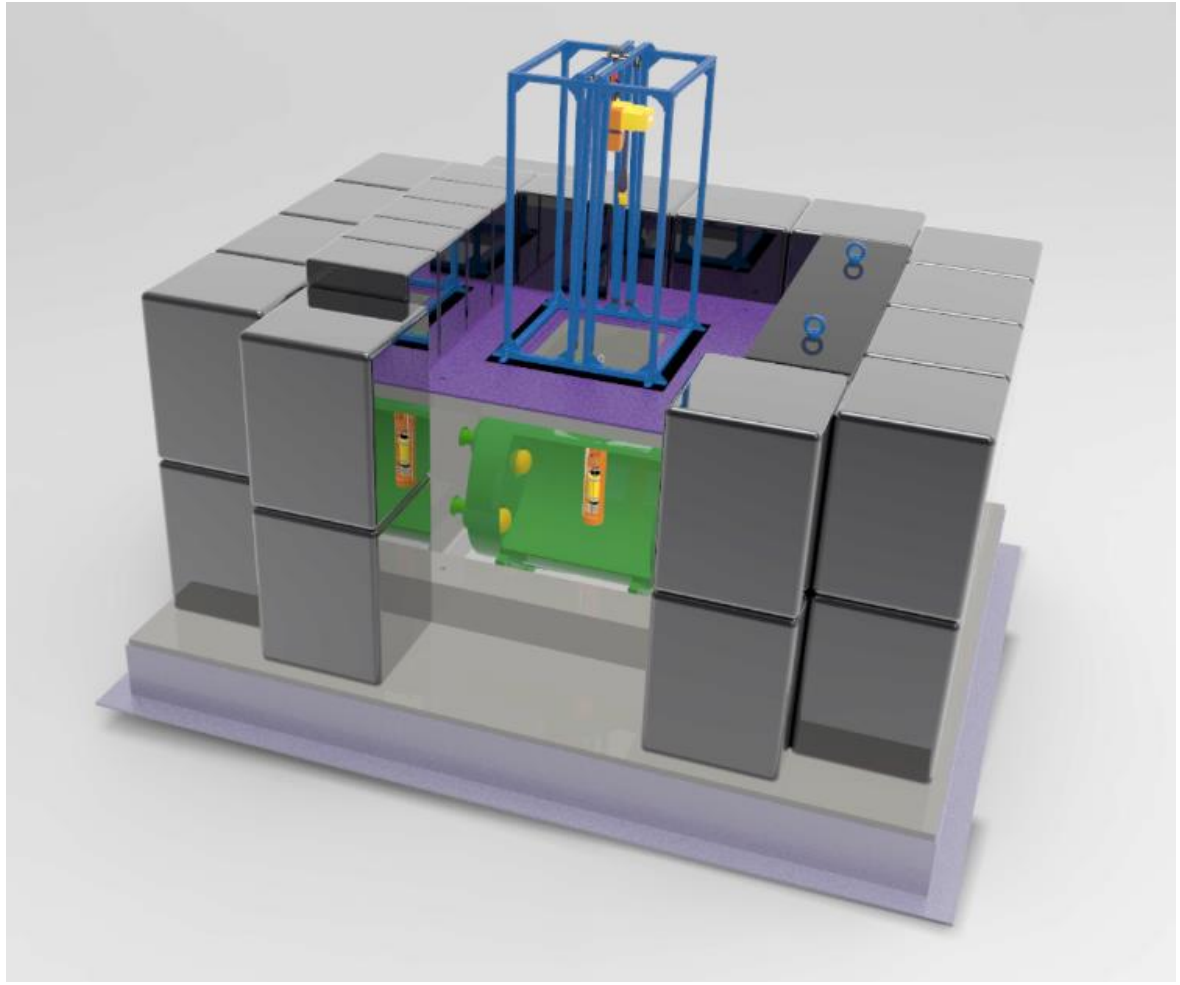


SABRE *Proof of Principle* at LNGS

The detector module, placed into the veto detector, will be isolated by the liquid scintillator by means of a copper tube.



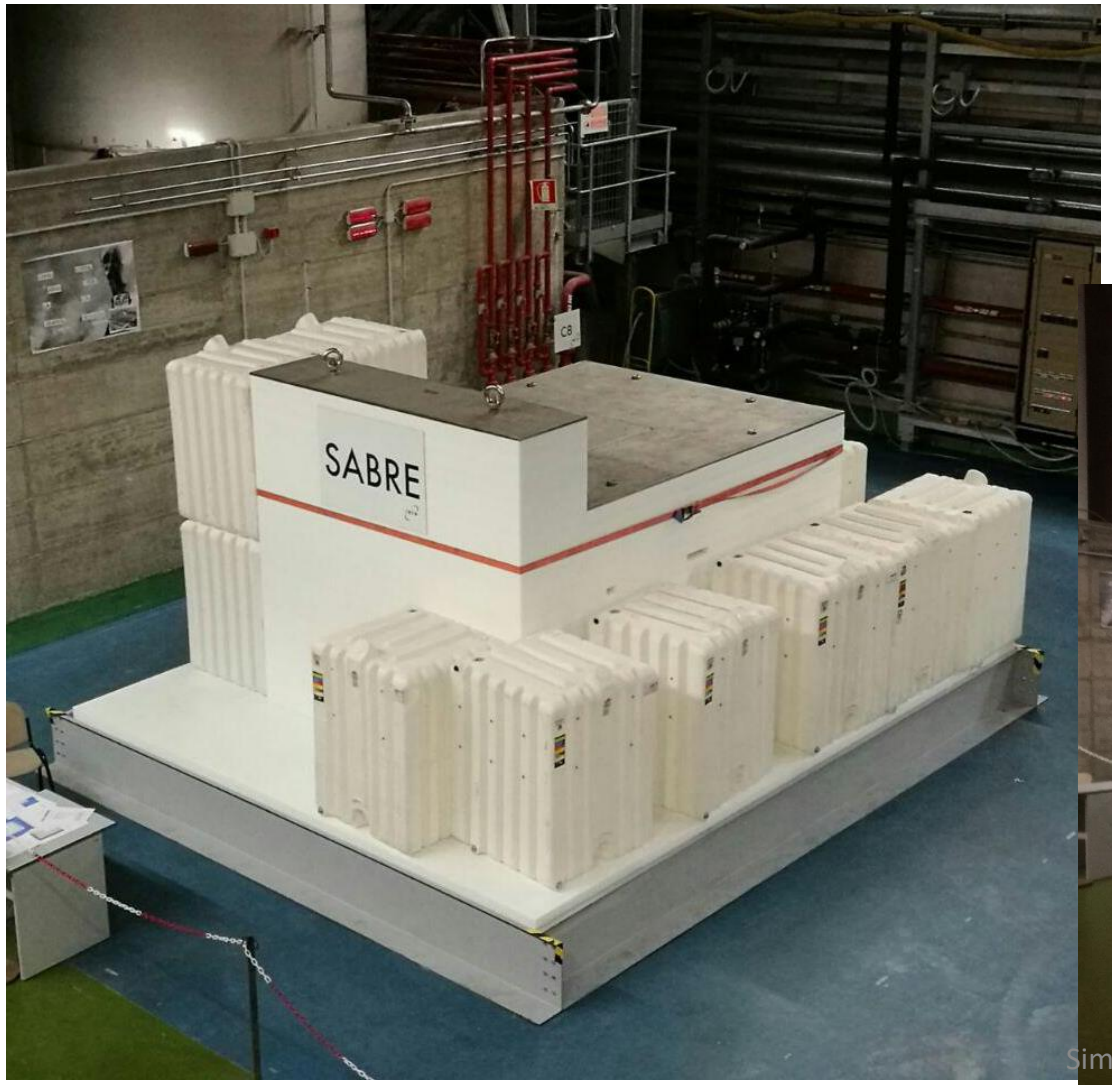
SABRE *Proof of Principle* at LNGS



- The veto is composed by a tank, filled with ~2 ton of liquid scintillator, equipped with 10 Hamamtsu R5912-100 PMTs.

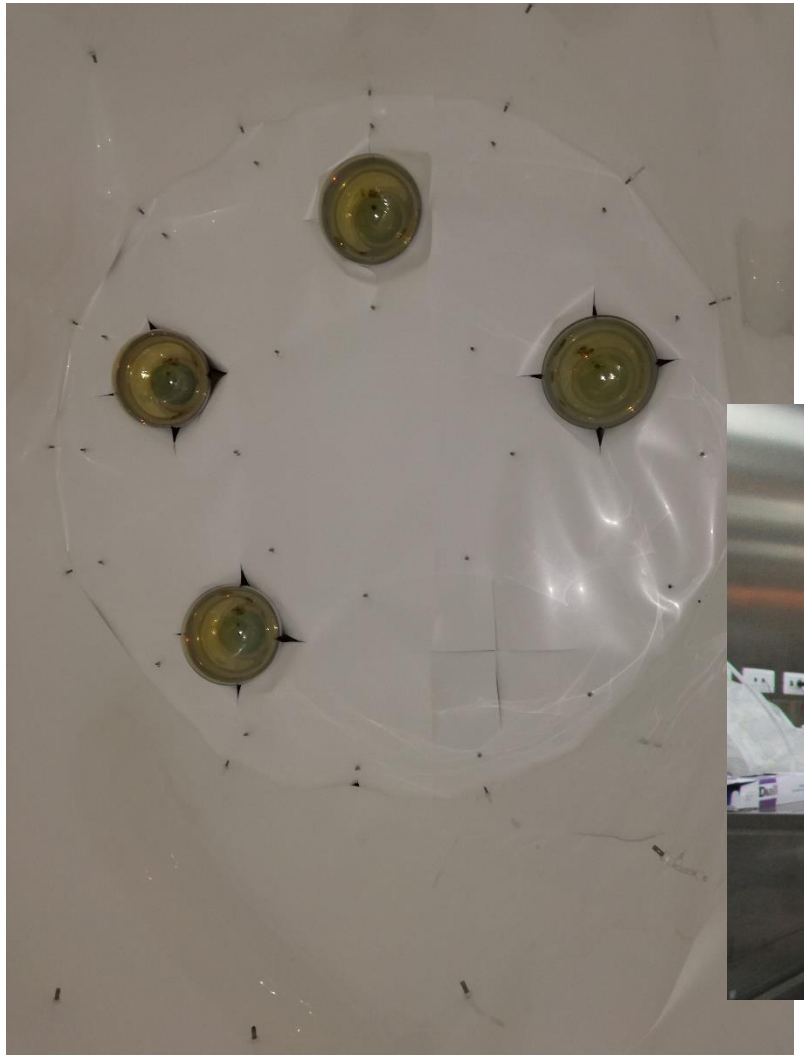
- The tank is surrounded by a shielding of polyethylene (≥40 cm) and water (≥80 cm) placed on a layer of 15 cm of lead.

SABRE *Proof of Principle* at LNGS



The **shielding** is almost ready in the experimental hall C

SABRE *Proof of Principle* at LNGS



The **veto tank** has been cleaned, internally covered with lumirror® and equipped with PMTs.

SABRE *Proof of Principle* at LNGS

Next commissioning steps are:

@ LNGS

- The fluid handling system (liquid scintillator)
  - Slow control and safety system
- Readout electronics and DAQ (DAQ already tested)

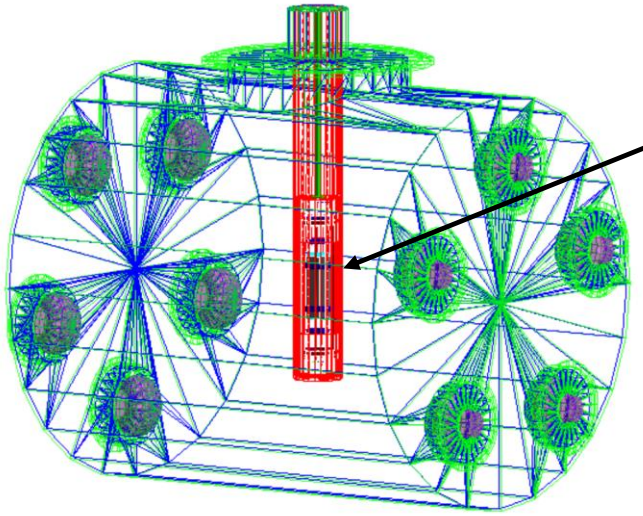
@ Princeton University

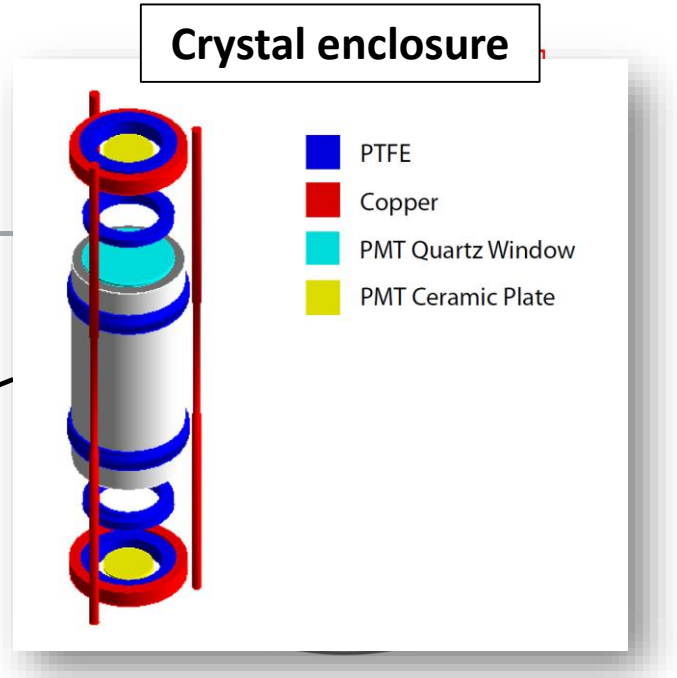
- Crystal preparation: cut and polishing
  - First light yield measurement
  - Detector module assembly

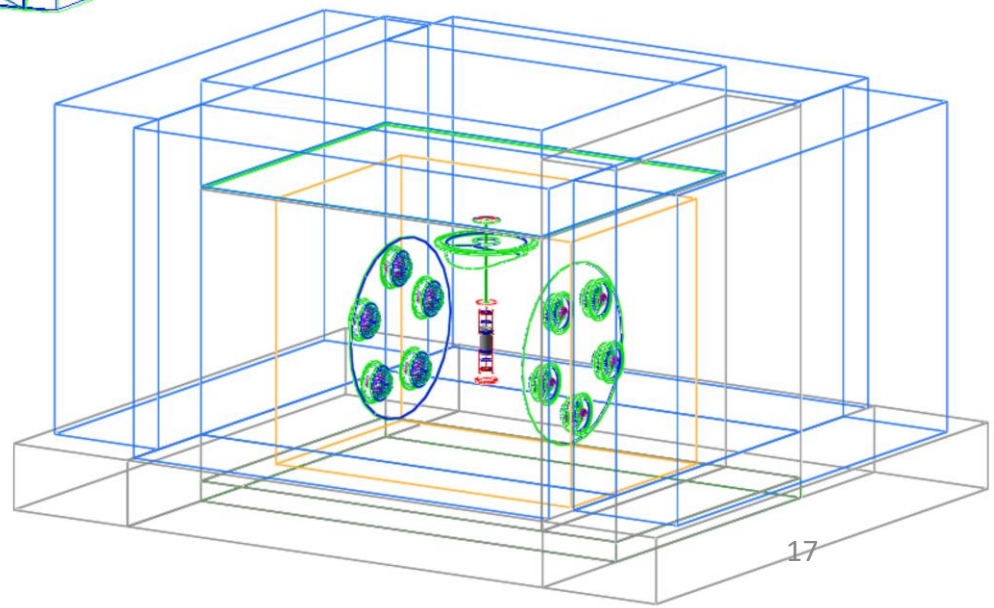
Data taking is expected to start this fall.

Background simulation of PoP

- GEANT4 based simulation code
- Components:
  - Crystal
  - Crystal enclosure:
    - crystal wrapping (PTFE), structure (PTFE and Cu) and PMTs (window, body and feedthrough)
  - Copper tube
  - Veto vessel:
    - stainless steel, liquid scintillator and PMTs
  - Shielding:
    - polyethylene, steel, water and lead







More detail about SABRE PoP simulations in: arXiv:1806.09344

^{40}K measurement

Goal: evaluate the ^{40}K content in the crystal

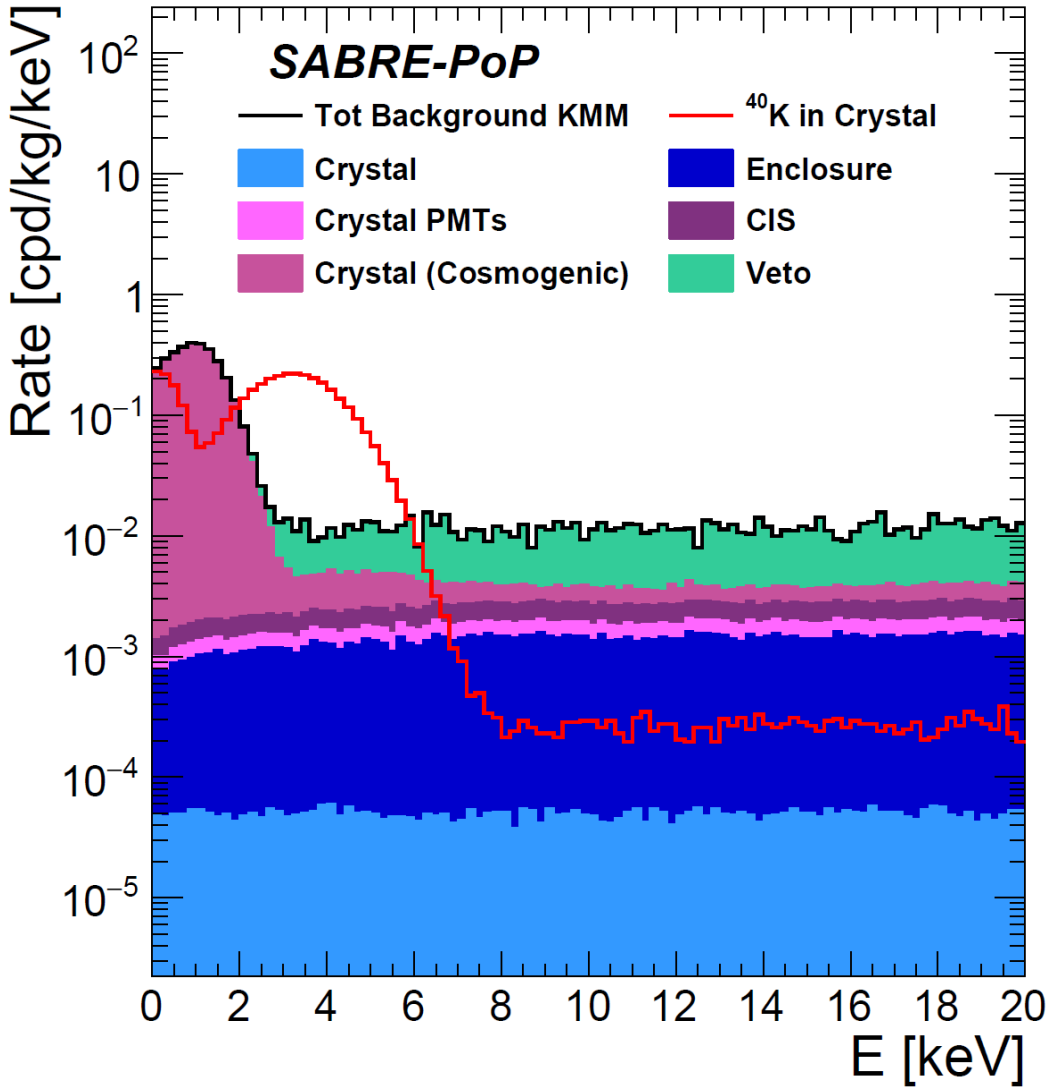
Target: ^{40}K in the crystal, emitting 3 keV Auger e^- + 1.46 MeV γ

Trigger: E_{veto} in [1280; 1640] keV AND $E_{crystal}$ in [2; 4] keV

	Rate KMM [cpd/kg/keV]
Crystal Cosmogenic	$1.8 \cdot 10^{-2}$
Veto	$6.2 \cdot 10^{-3}$
Enclosure	$1.3 \cdot 10^{-3}$
Crystal PMTs	$1.1 \cdot 10^{-3}$
CIS	$7.7 \cdot 10^{-4}$
Crystal (no ^{40}K)	$5.1 \cdot 10^{-5}$
Total	$2.7 \cdot 10^{-2}$
Crystal ^{40}K	$1.9 \cdot 10^{-1}$

* Cosmogenic sources are considered after two months underground

Sensitivity: 10 ppb can be measured, with 1 ppb of precision, in about two months



More detail about SABRE PoP simulations in: arXiv:1806.09344

Dark Matter mode

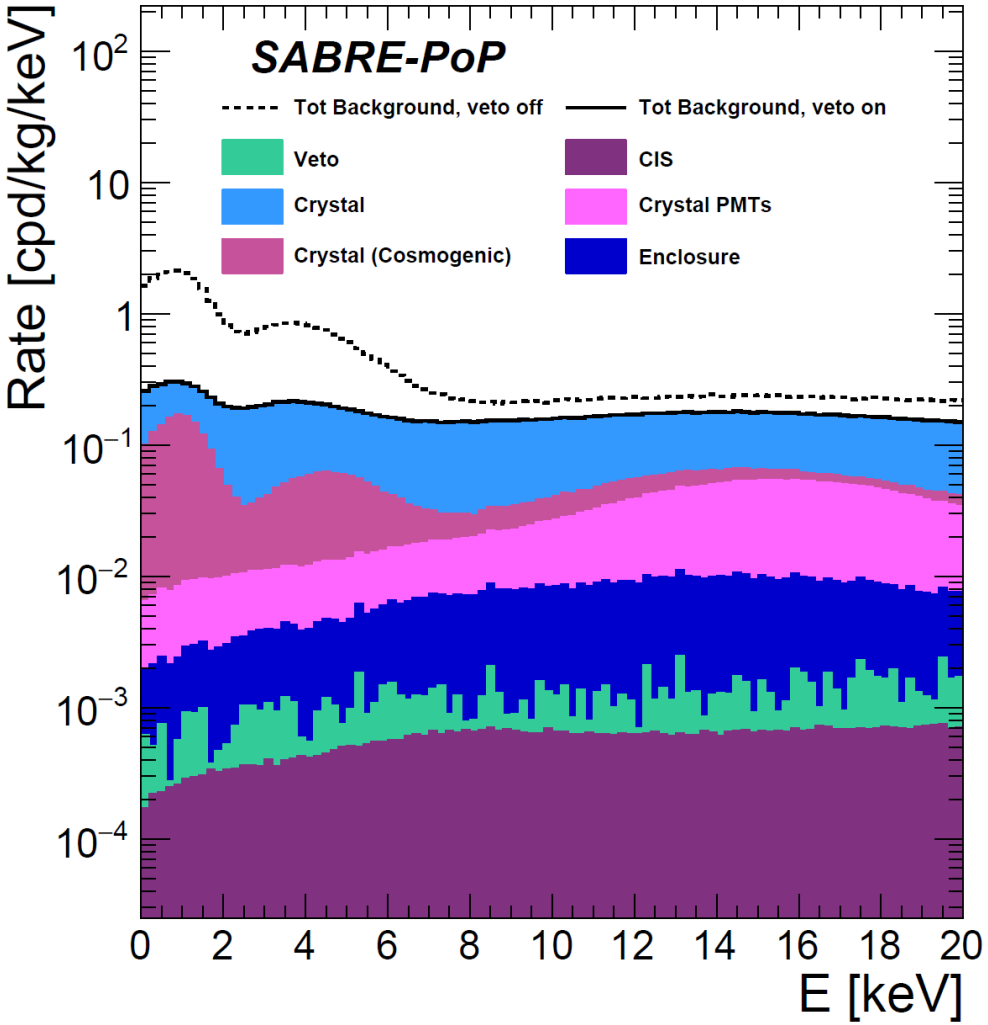
Goal: test the rejection capability of the veto and measure the background in the ROI

Trigger: E_{veto} > 100 keV (anticoincidence) AND $E_{crystal}$ in [2; 6] keV

	Rate, veto OFF [cpd/kg/keV]	Rate, veto ON [cpd/kg/keV]
Crystal	$3.5 \cdot 10^{-1}$	$1.5 \cdot 10^{-1}$
Crystal Cosmogenic	$3.0 \cdot 10^{-1}$	$3.9 \cdot 10^{-2}$
Crystal PMTs	$4.3 \cdot 10^{-2}$	$3.5 \cdot 10^{-2}$
Enclosure	$9.5 \cdot 10^{-3}$	$3.6 \cdot 10^{-3}$
Veto	$3.0 \cdot 10^{-2}$	$5.7 \cdot 10^{-4}$
CIS	$3.7 \cdot 10^{-3}$	$4.6 \cdot 10^{-4}$
Total	$7.4 \cdot 10^{-1}$	$2.2 \cdot 10^{-1}$

Veto rejection efficiency ~70%

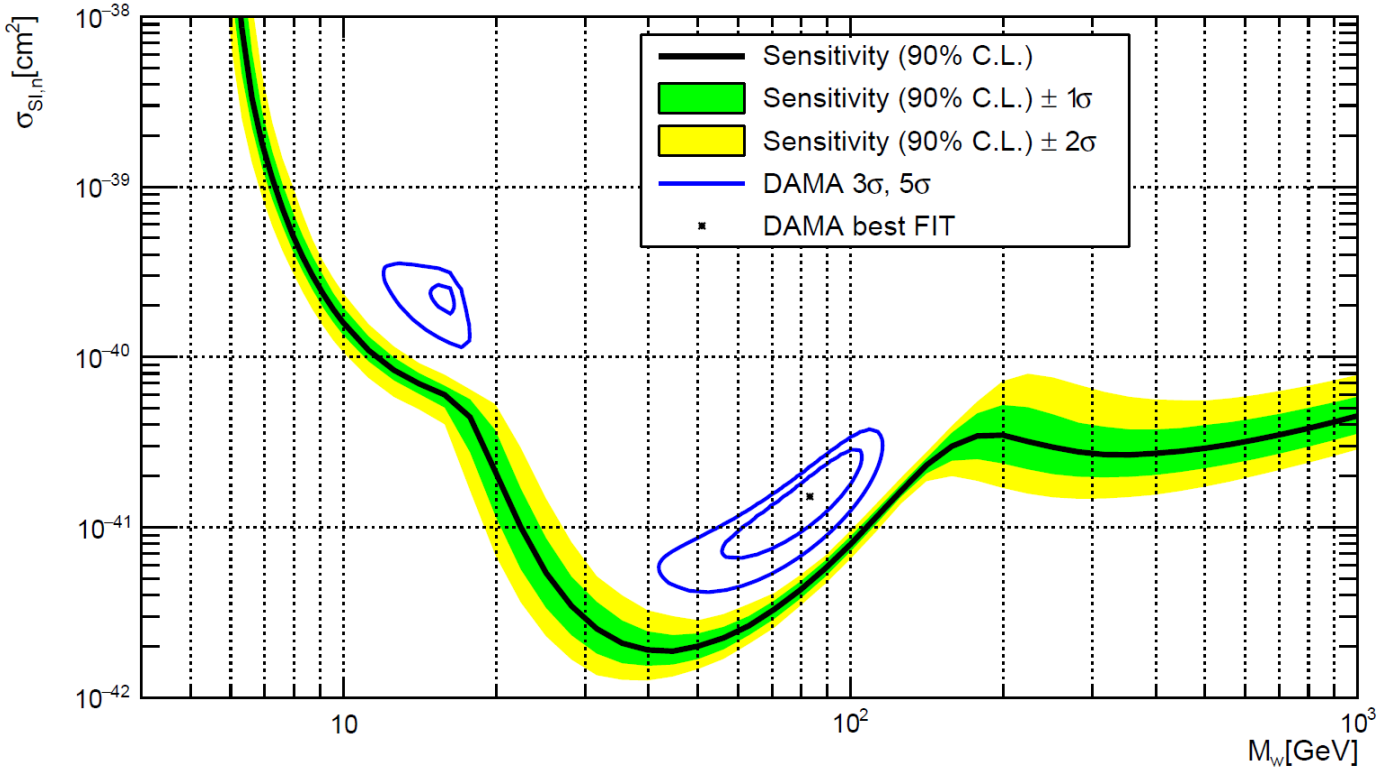
Total background in the ROI: 0.22 cpd/keV/kg (~50% due to ^{87}Rb)



More detail about SABRE PoP simulations in: arXiv:1806.09344

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 0.22 cpd/keV/kg (from MC)
  - Quenching: [0.13; 0.21] for Na and 0.09 for I



- Results:
  - DAMA results can be confirmed at 6σ or rejected at 5σ
  - Minimum of exclusion plot close to 10^{-42} cm^2

Sensitivity study 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 for background reduction.
- The current stage, Proof of Principle, has the purpose to verify the background expectations and the crystal purity in few months.
- SABRE PoP will start data taking this fall at LNGS.

Thank you for your attention!