SABRE-PoP results and CDR for the physics phase

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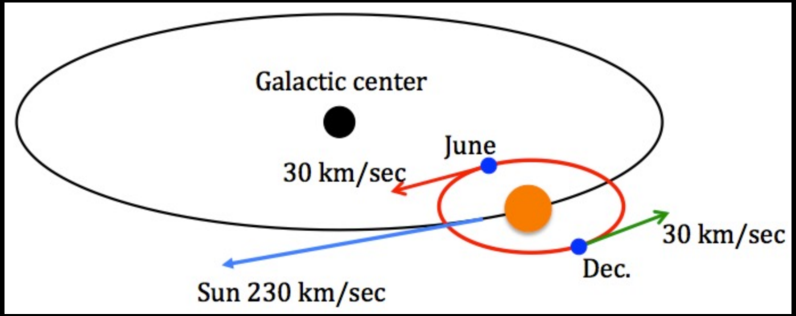
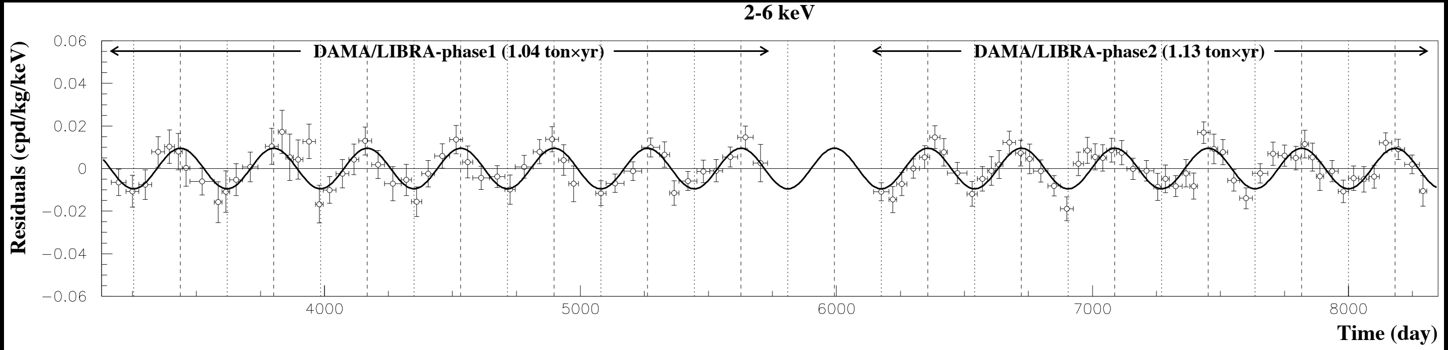
Milano CdS - 09.07.2021

Dark Matter Annual Modulation

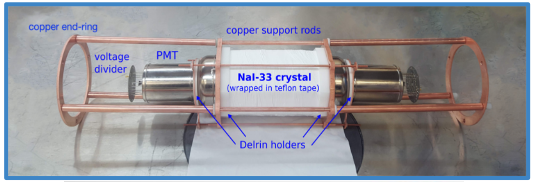


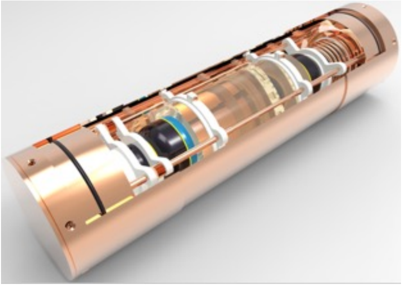


- Observed by DAMA on NaI(Tl) scintillating crystals (250kg) @LNGS
- 20 annual cycles - 12.9σ significance
- Period + Phase + Amplitude compatible with Dark Matter
- NOT observed with other techniques -> model dependent comparison
- Strong need to verify it with NaI(Tl) and better sensitivity

SABRE PoP

- SABRE was approved by INFN in 2016 as Proof-of-Principle phase (PoP).
- Commissioned in early 2020 at LNGS – Hall C (next to Borexino)
- Data taking until September 2020, before being stopped due to technical maintenance
- Decommissioning in 2021.

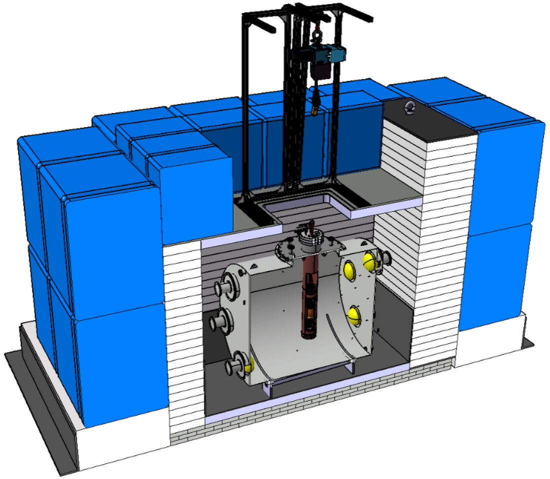




- **Goal:** full characterization in liquid scintillator veto of at least 1 crystal with lower backgrounds w.r.t. DAMA
- **1 detector module** at a time:

  5kg NaI(Tl) crystal wrapped with PTFE coupled to 2 PMTs in a copper enclosure;

- **2 ton liquid scintillator (LS) active veto**;
- **Passive shielding:** polyethylene and water.



Despite the short acquisition time, **several important results obtained.**

Results from SABRE PoP crystals

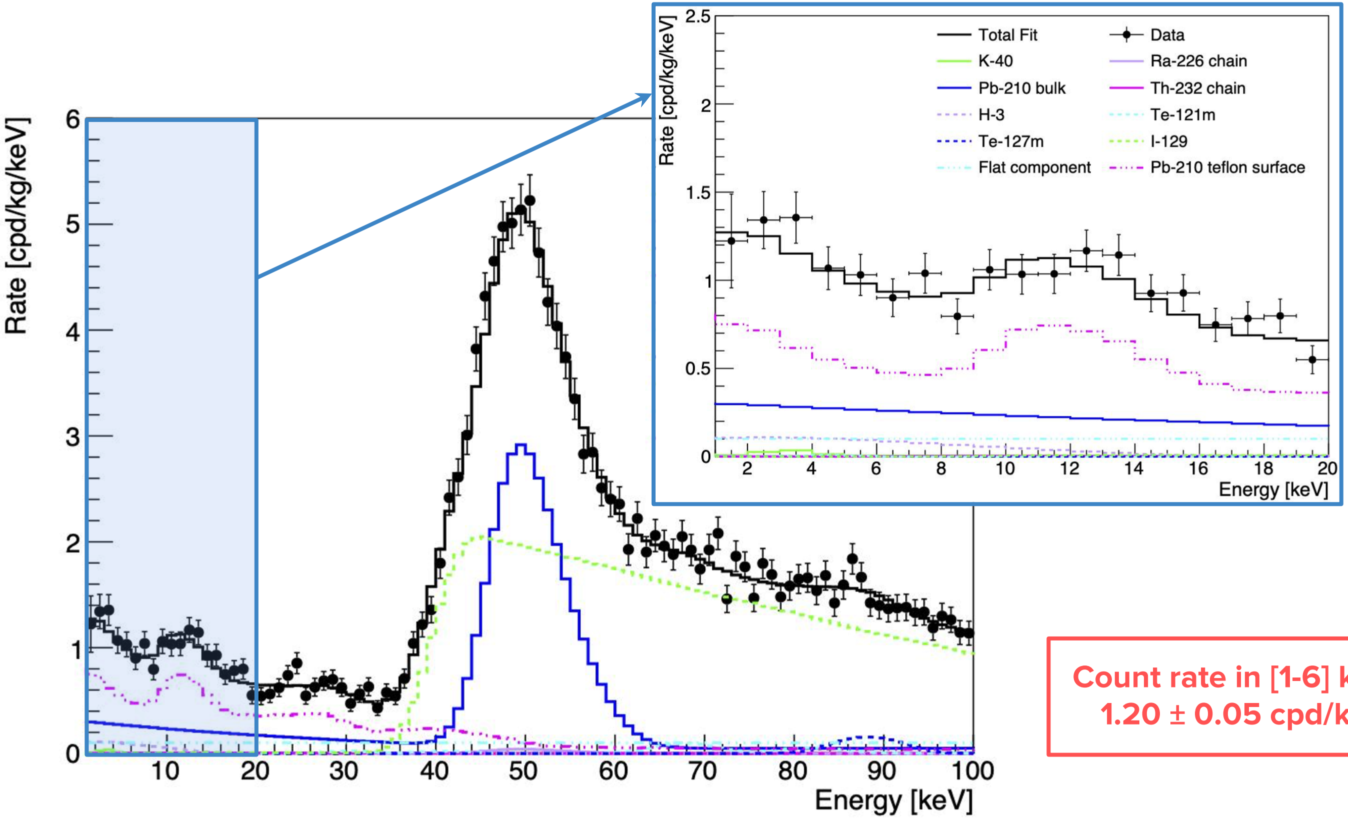
- Light yield (LY) and energy resolution (FWHM/E) competitive with other NaI(Tl)-based experiments;
- **Direct counting of radioactive ^{40}K using coincidences with LS veto confirmed ICP-MS measurements** for both NaI-31 and NaI-33 crystals:
  - ^{nat}K in NaI-31: 15.7 ± 3.2 ppb;
  - **^{nat}K in NaI-33:** 2.2 ± 1.5 ppb, or < 4.7 ppb at 90% CL (direct gamma counting!)
- Alpha rate still higher than DAMA, but lower than ANAIS and COSINE crystals.

	NaI-31	NaI-33	DAMA/LIBRA crystals	ANAIS crystals	COSINE crystals
LY [phe/keV]	9.1 ± 0.1	12.1 ± 0.2	6-10	15	15
FWHM/E @59.5 keV	14.1%	13.2%	15.8%	11.2%	11.8%
^{nat}K [ppb]	17.7 ± 1.1	4.6 ± 0.2	< 20	17-43	17-82
^{3}H [mBq/kg]	-	0.012 ± 0.007	< 0.09	0.09-0.20	0.05-0.12
Alpha rate [mBq/kg]	1.02 ± 0.07	0.54 ± 0.01	0.08-0.12	0.7-3.15	0.74-3.20

Lowest level ever achieved in NaI(Tl) crystals

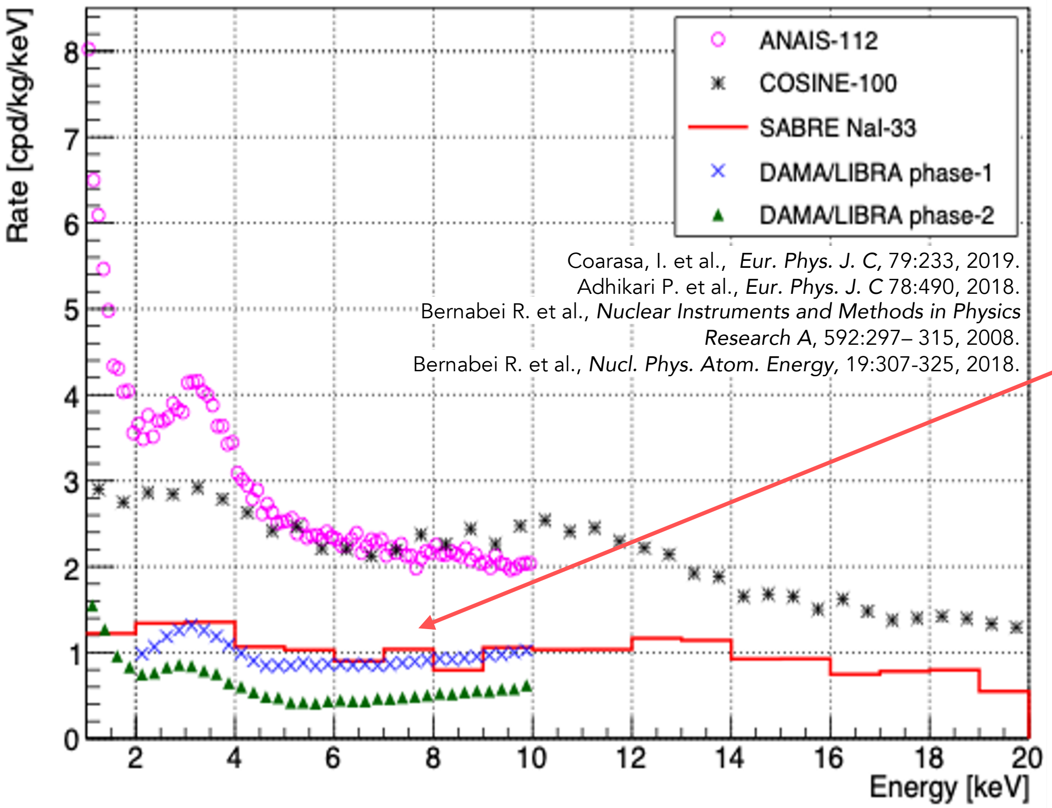
Results from SABRE crystals characterization in comparison with other NaI-based experiments.

SABRE PoP NaI-33 background model



Count rate in [1-6] keV ROI: 1.20 ± 0.05 cpd/kg/keV

Comparison with other NaI(Tl)-based experiments



Background level comparable (for the first time) with that of DAMA/LIBRA-phase1

SABRE PoP NaI-33 background model

Source	Activity	Rate in ROI [cpd/kg/keV]
^{40}K	(0.14 ± 0.01) mBq/kg	0.018 ± 0.001
^{210}Pb (bulk)	(0.41 ± 0.2) mBq/kg	0.28 ± 0.01
^{226}Ra	(5.9 ± 0.6) μBq/kg	0.0044 ± 0.0005
^{232}Th	(1.6 ± 0.3) μBq/kg	
^{3}H	(12 ± 7) μBq/kg	≤ 0.12
^{129}I	(1.34 ± 0.04) mBq/kg	≤ 0.011
^{121m}Te	≤ 84 μBq/kg	
^{127m}Te	(16 ± 6) μBq/kg	
^{210}Pb (PTFE)	(1.1 ± 0.2) mBq	0.63 ± 0.09
Flat component		0.10 ± 0.05
Total		1.16 ± 0.10

Tab. 2 - Background components in NaI-33 from the spectral fit and current rate in ROI (1-6 keV). Upper limits are given as one-sided 90% CL. Rates are conservatively calculated using upper limits.

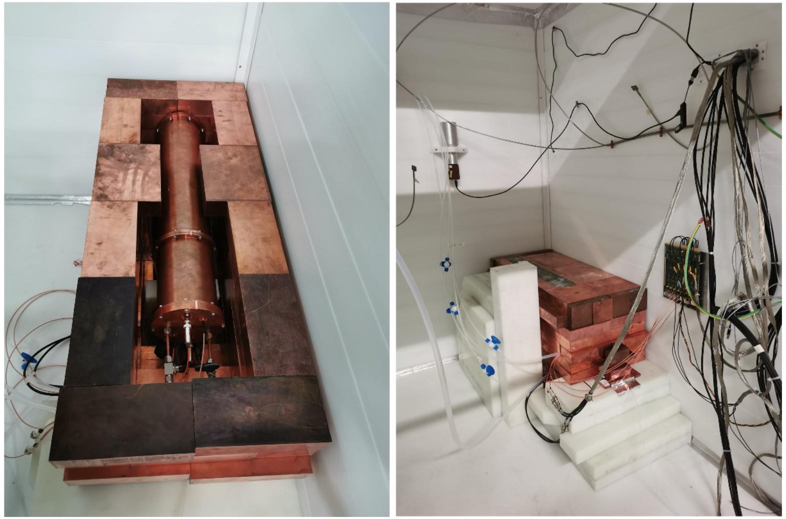
The background model indicates that the **count rate in the [1-6] keV ROI** is **mostly due to a ^{210}Pb contamination in the PTFE reflector** wrapped around the crystal.

Recent publications related to SABRE PoP activity

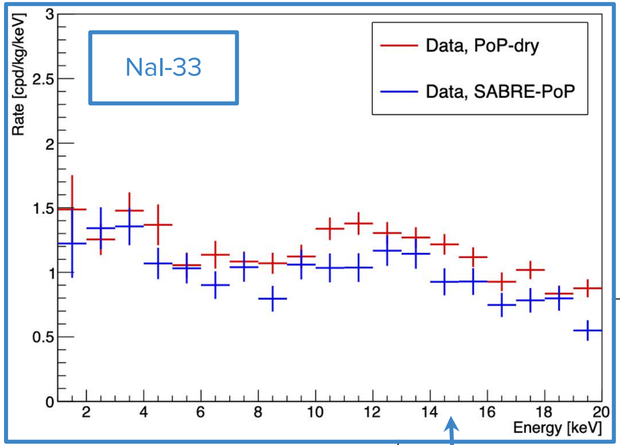
1. High sensitivity characterization of an ultra-high purity NaI(Tl) crystal scintillator with the SABRE proof-of-principle detector,
   accepted by PRD, e-print 2021
2. Characterization of SABRE crystal NaI-33 with direct underground counting,
   Eur. Phys. J C 81 (2021) 4, 299

PoP-dry

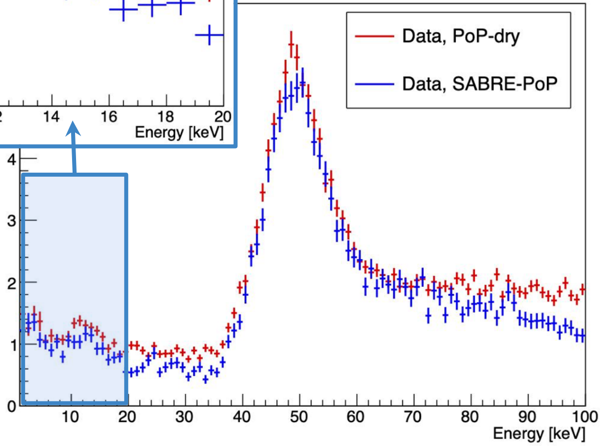
In 2021 we modified the Hall C PoP setup to restart crystals characterization without the liquid scintillator veto.



SABRE detector modules in a low radioactivity copper shield inside the passive PoP shielding.



BKG level in the ROI comparable with that of PoP setup



It is possible a full-scale experiment without active veto

SABRE North CDR

We just presented to CSN2 the CDR for the physics phase of SABRE

Outlined:

1. The physics case and motivations
2. The proposed detector design and its ancillary "parameters"
3. Requests to host laboratory
4. Project management
5. Time schedule and milestones
6. Costs

Presentation at CSN2:
Mon Jul 12th – 5pm
(open session)
A. Ianni for SABRE

INFN
Istituto Nazionale di Fisica Nucleare

DocID	Rev.	Validità
INFN-PM-QA-503	1.0	Rilasciato

Date 02/07/2021

SABRE North
Conceptual Design Report (CDR)

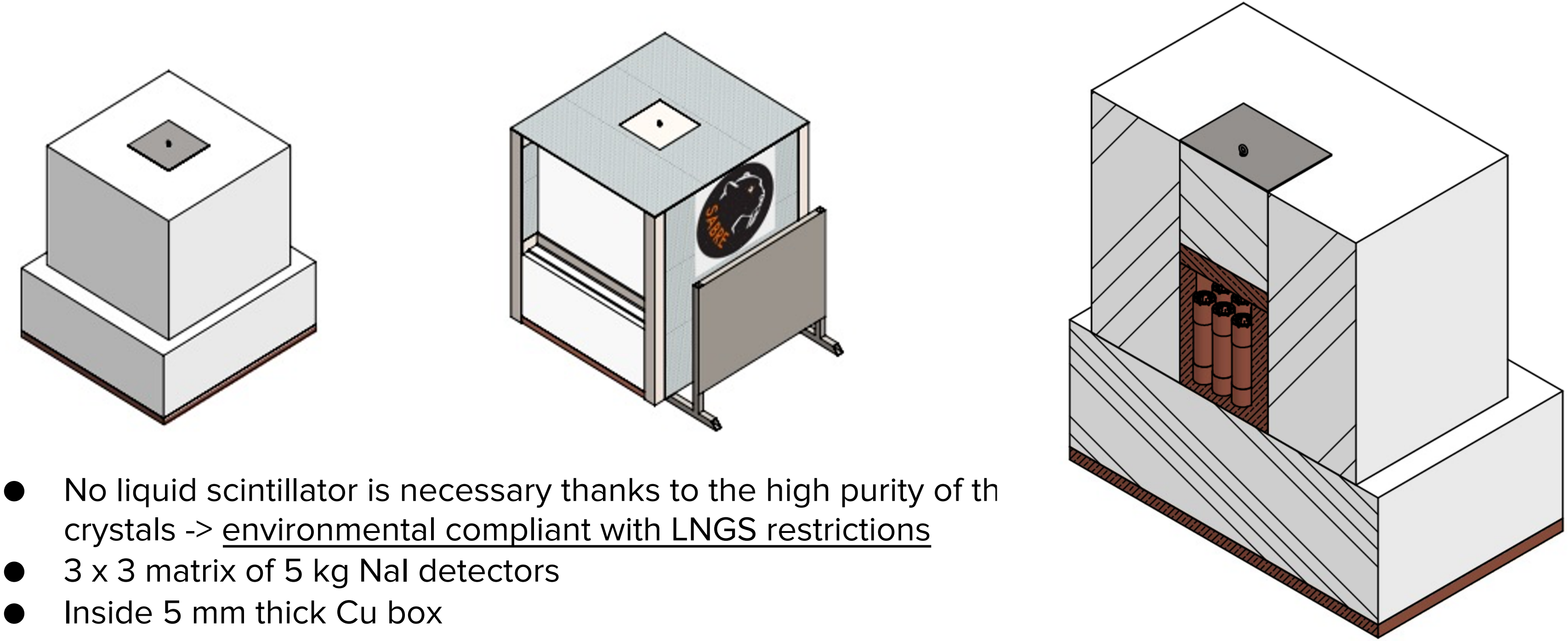
This document outlines the conceptual proposal for the next physics phase of the SABRE North experiment. The new detector conceptual design is described, detailing all subsystems and the steps required to get to the start of data taking, within two years after the project approval.

Autore	Verificato da	Approvato da
SABRE North Collaboration	SABRE North Group Leaders	Chiara Vignoli (RN)

Lista di distribuzione:
- Commissione Scientifica Nazionale 2 (CSN2) INFN

1

Design SABRE North



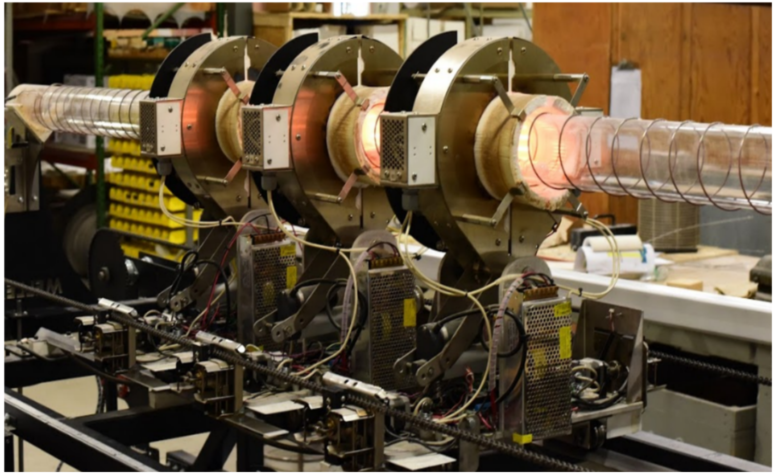
- No liquid scintillator is necessary thanks to the high purity of th crystals -> <u>environmental compliant with LNGS restrictions</u>
- 3 x 3 matrix of 5 kg NaI detectors
- Inside 5 mm thick Cu box
- 15 cm Cu and 80 cm PTFE shielding structure
- Vertical crystals deployment
- Optimized re-use of existing material from PoP

Crystal production strategy

1. NaI powder treated with Zone Refining purification metod
   - Equipment already owed and tested by the collaboration
2. Growth by Radiation Monitoring Devices Inc. (Boston, USA)
   - Grew NaI-33 and others since several years.
3. Specially produced PTFE with low radioactivity

   already used in:
   a. CUORE: ~ 130 μBq/kg
   b. DarkSide-50: < 38 mBq/kg

Isotope	Impurity concentration (ppb)					
	Powder	S_1	S_2	S_3	S_4	S_5
^{39}K	7.5	<0.8	<0.8	1	16	460
^{208}Pb	1.0	0.4	0.4	<0.4	0.5	0.5
^{85}Rb	<0.2	<0.2	<0.2	<0.2	<0.2	0.7
^{24}Mg	14	10	8	6	7	140
^{133}Cs	44	0.3	0.2	0.5	3.3	760
^{138}Ba	9	0.1	0.2	1.4	19	330

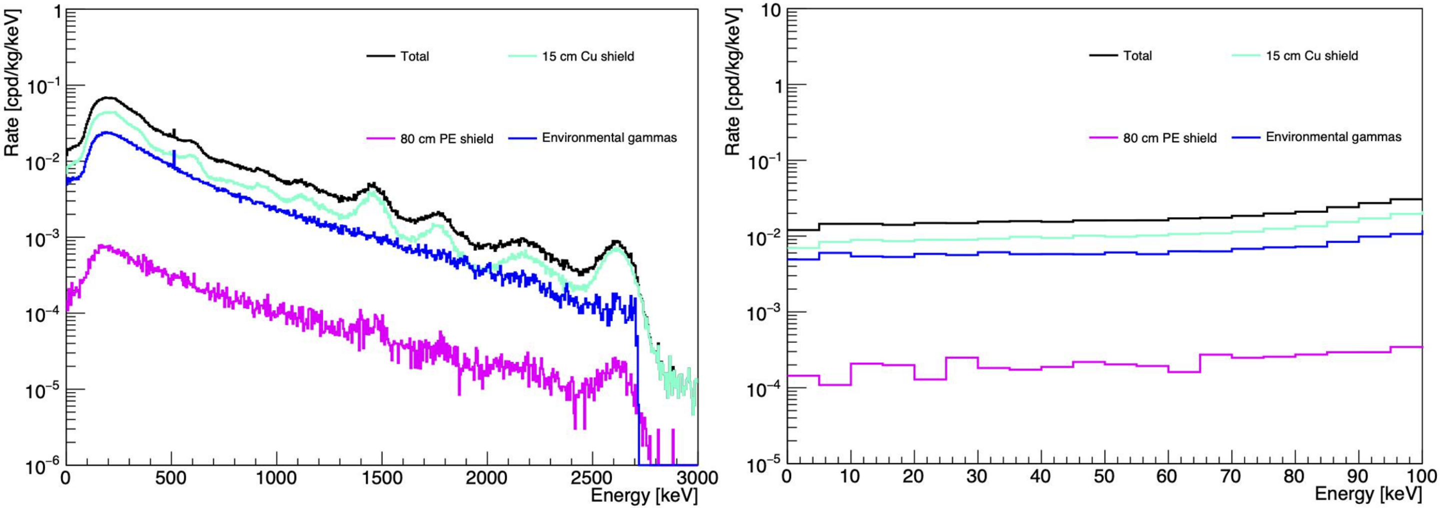


Simulations of SABRE North passive shielding

The PoP measurement, backed up by simulations, provides a very good understanding of the background from the detector module (crystal + PMTs + enclosure)

We ran additional simulations to estimate the background contribution due to the new passive shielding configuration:

- external gammas (input flux: 1 gamma/cm^2/sec from SABRE measurements)
- radioactive contaminants in the shielding materials (input from screening measurements)



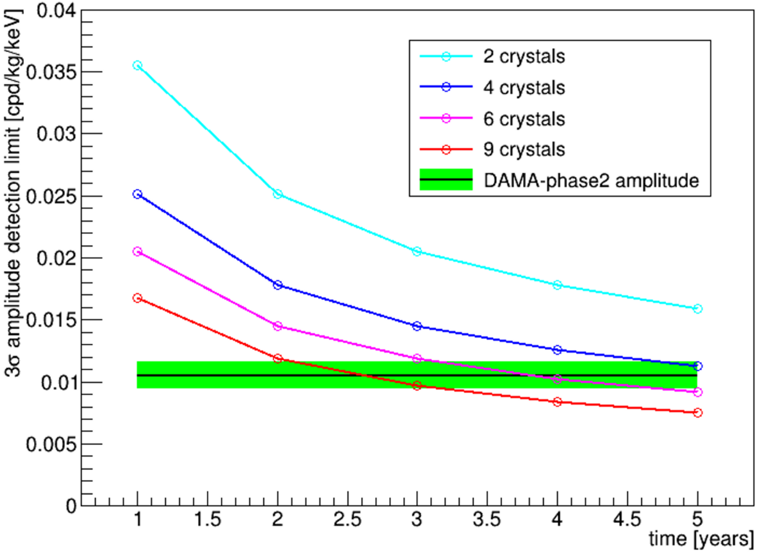
Predicted contribution:
~ 0.01 dru in ROI

Compatible with the SABRE North background goal

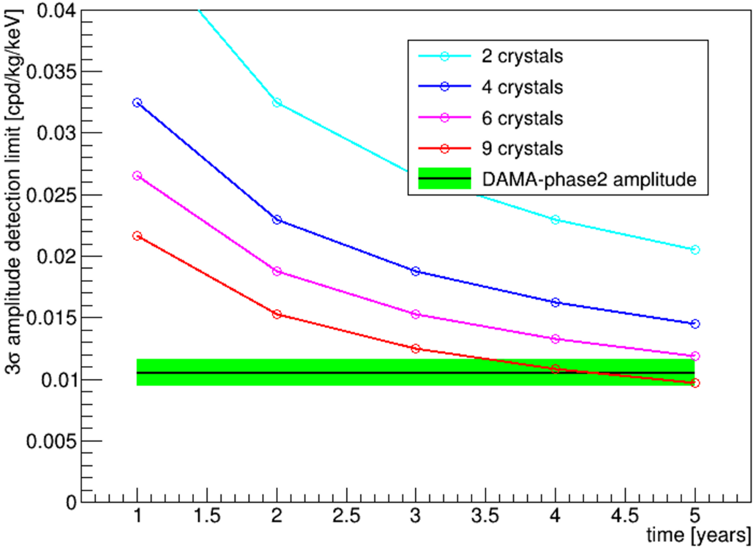
SABRE North Sensitivity

- Crystal nominal mass = 5 kg

Baseline option with 0.3 cpd/kg/keV in ROI (also Zone Refining)



Conservative option with 0.5 cpd/kg/keV in ROI (only PTFE replacement)



(Statistical method detailed in Eur Phys J C 79 (2019))

WP & Gantt Chart

Validation and construction

			Year 1		Year 2		Year 3	
WP		Item	1 sem	2 sem	1 sem	2 sem	1 sem	2 sem
WP1	Crystals and Detector module	Clean PTFE procurement						
		Crystal NaI 34 production						
		Test of clean PTFE, of NaI-34, of australian crystal		M1.1 - M1.2				
		Array production (x9)			M1.3 - M1.4			
		Enclosures (x7)						
		PMTs procurement and tests						
		Assembly of detector modules and tests						
		Source procurement						
WP2	Shielding and site logistics	Copper +PE basement		M2.2				
		PE shielding		M2.2				
		Copper shielding				M2.3		
		Extrenal Al house						
		Glove box installation	M2.1					
		Fluid handling and slow control						
		Paperwork						
WP3	Electronics and DAQ	Electronics procurement and test						
		DAQ software				M3.1		
WP4	Simulations and data analysis	Detailed simulation of the shielding						
		Simulation of the full array			M4.1			
		Data analysis framework				M4.2		
		Data analysis						
TDR					M0			

involved

Milano responsible

involved

+2yr running?

Data taking starts

Budget

Full size experiment: short of 800k thanks to:
no liquid scintillator
reuse of existing equipment

Not included: running costs, missioni and 2x2yr post-doc (junior AdR)

Subsystem	Item	Sub-item	# of sub-items	Quantity/set per unit	Total quantity	Available quantity	Exposed Cost (keuro)
Detector Modules	Crystal	Astrograde Powder + ZR	9 + 1 spare	≈ 10 kg	≈ 100 kg	30 kg	400
		Crucible, RMD: Growth + Cut + Polishing	9 + 1 spare	1	10	0	
	Crystal enclosure	Cu enclosure + crystal holders + accessories	9 + 1 spare	1	10	3	120
	PMTs	2 x 3" Hamamatsu PMTs + 2 x bases + accessories	18 + 4 spare	2	20	10	60
	Calibration system	Sources	4	-	4	3	5
Shielding	Cu box	Cu box (50x50x80 cm3)	1	1	1	0	5
	Inner Cu shielding	Cu bricks (20x10x5 cm3, 9 kg each)	15 cm layer	-	504	270	60
	Outer PE shielding	Polyethylene	80 cm layer	-	20 m3	20 m3	0
	Cu basement	Cu bars (295x280x10 cm3, 7.35 t)	10 cm layer	-	0.8 m3	0.8 m3	0
	Outer box	Aluminum	1	-	1	1	10
	Shielding machining and mounting	PE slab refurbishment,...	-	-	-	-	20
	Services	Installation and transport					25
Electronics and DAQ	HV System	HV CAEN V6534N (6ch)	18 ch + spares	3brd + 1 spare	4	1	10
	Digitizers	Digitizers CAEN V1720/1730 (8 ch)	27 channels	4brd + 1spare	5	3	15
	Amplifiers custom 8ch	Amplifiers	18 channels	3brd + 1 spare	4	1	5
	Workstations and disks	Workstations and disks	2 WS + disk	2	2	0	15
Area infrastructure	Gas handling & Slow control	SCADA programming,...					10
	Temperature stabilization	PID, sensors,heating,...					10
	Utilities and control room	Power, UPS, network, cooling				avaliable	-
	Glove box	Installation and comissioning	sensors, gas panel				10
	Authorization documents	SCIA,...					10
						Total (structural)	**790**
Running costs (per year)	GN2 consumptions	shielding + GB					15
	Consumables	GB consumables, sensors,...					20
	Maintenance	plant maintenance					5
	Services and transports	crane operators, mapower,...					10
						Total RC per year	**50**

2022 anagrafica e richieste Milano

Milano	FTE
Davide D'Angelo (resp. loc.)	0.4
Andrea Zani	0.4
Maddalena Antonello	0.5
Totale Milano	1.3

(invariata)
richiesto AdR a partire dal 2023

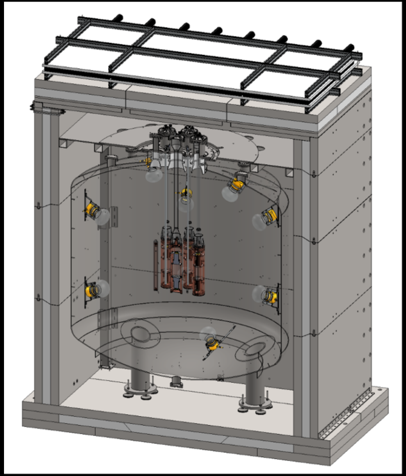
Totale nazionale (LNGS + Milano + Roma1): 6.7 FTE
resp. naz. Chiara Vignoli (LNGS)

Responsabilità di Milano:
WP3 Electronics and data taking
Altre attività: test PMTs, data recontruction framework

Richieste finanziarie 2022 da definire

Richieste servizi:
Elettronica: 0.5 m.u.

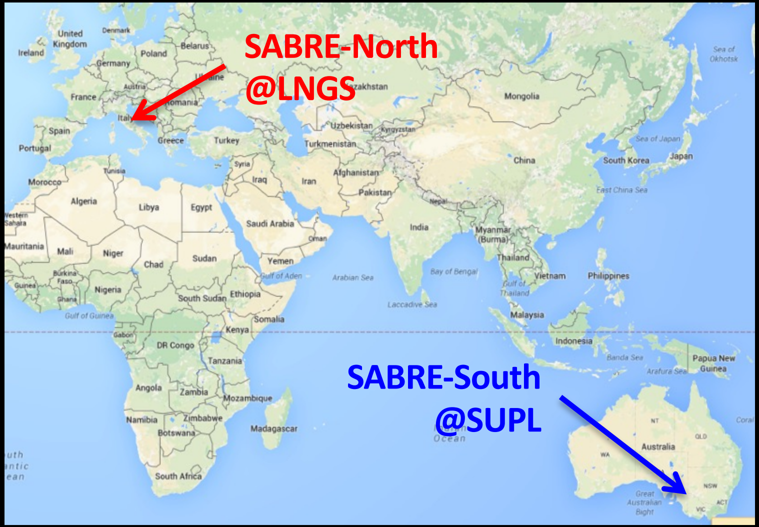
Sabre South twin experiment



- SABRE Full scale experiment in two different laboratories

→ on opposite hemispheres

- Twin detectors for reduced systematics
- SUPL laboratory completing installation
- SABRE-South detector under construction



Any season- or site-related contribution to the modulation can be identified buy phase and amplitude