SABRE PoP
Status report

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SABRE Collaboration meeting

LNGS October 4, 2017

SABRE: Sodium Iodide with Active Background Rejection Project

Goal:

1. Search for Dark Matter through the **annual modulation** of the experimental rate with **NaI (Tl) crystals detector with an active veto**.
2. **Test of DAMA results**

Strategy:

- **Lower background** (high purity crystals, low-radioactivity set-up, employ liquid scintillator veto/shielding)
- **Lower threshold** (high QE PMT directly coupled to crystals, lower HV to reduce dynode afterglow)
- **Twin Detectors** in Northern and Southern hemispheres (to reduce seasonal effects)

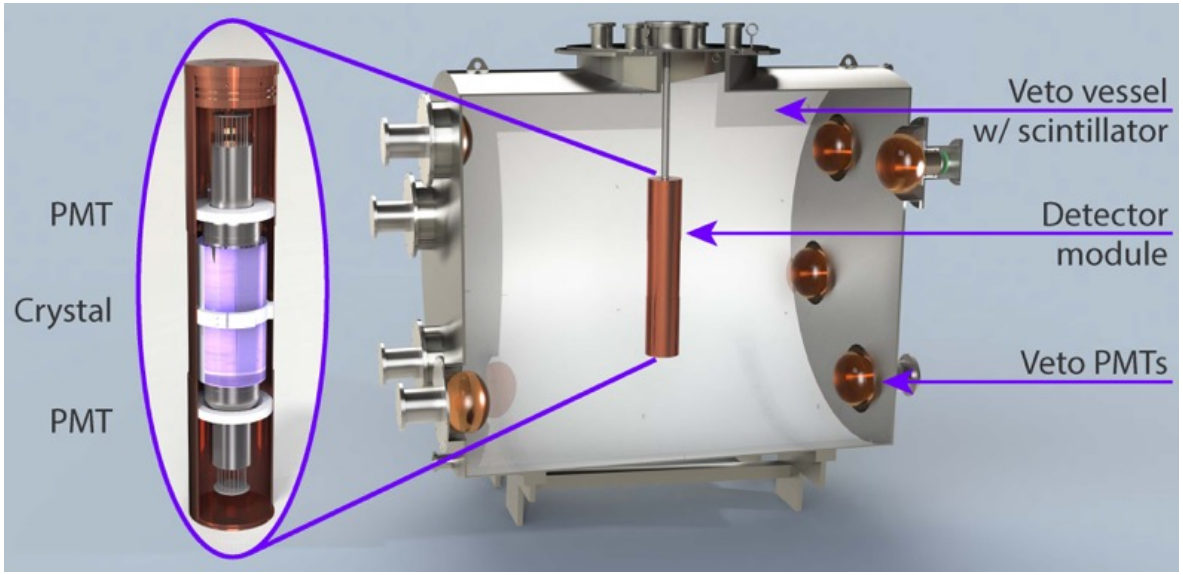
Project phases:

- PHASE I: **SABRE PoP** (1 crystal) - ongoing, funded by INFN (2 years: 2016-2017, now extended for a further year) and NSF
- PHASE II: **SABRE full scale experiment**
  - SABRE North @ LNGS (to be proposed after PoP)
  - SABRE South @ SUPL in Australia (underground lab and detector in preparation)

-> see talks of Greg, Tiziano, Lindsay, Francesco

PHASE I: SABRE PoP detector

- Crystal weight: ≈ 5.5 kg
- Crystal PMTs : High-QE 3" flat Hamamatsu R11065-20
- LS Veto PMTs: 8" Hamamatsu R5912 HQE LRI
- Vessel: 1.3 m diameter 1.5 m length
- Liquid scintillator: PC+PPO (3g/l) ≈ 2.25 m^3 Weight ≈ 2 ton



Target: ultra-pure NaI (Tl) crystals: $^{nat}K \leq 10$ ppb, Rb ≤ 0.1 ppb, U e Th < 1ppt
Goal achieved in 2 kg crystal (PU + RMD Company) grown with Astrograde powder, measured by ICP-MS

SABRE PoP responsibilities

Funding Agency	Institution	INFRASTRUCTURES	SHIELDING	FLUID HANDLING	SAFETY	CRYSTALS	PMTs	ENCLOSURE	CIS	VESSEL	ELECTRONINCS & DAQ	CALIBRATION SYSTEM	SLOW CONTROL	COMPUTING & SW	MC SIMULATIONS	DATA HANDLING & ANALYSIS	R&D
INFN	INFN	X	X	X	X			X	X		X	X	X	X	X	X	X
NSF	Princeton			X		X	X			X	X		X	X	X	X	X
DOE	PNNL																
ARC	Melbourne										X	X			X	X	X
	Adelaide										X		X			X	X
	ANU										X	X			X	X	X
	Swinburne																
	ANSTO																

MoU on PoP

Memorandum of Understanding

for the Construction and Operation

of the **SABRE** Experiment

between

Australian Nuclear Science and Technology Organisation, ANSTO, Australia

Australian National University, ANU, Australia

Istituto Nazionale di Fisica Nucleare, INFN, Italy

Pacific Northwest National Laboratory, PNNL, USA

Princeton University, PU, USA

Swinburne University of Technology, SU, Australia

University of Adelaide, UA, Australia

University of Melbourne, MU, Australia

Preamble

The SABRE project aims at searching for dark matter in the Galactic halo through the annual modulation effect. The plan of the SABRE project is to deploy twin detectors consisting of an array of ultra-pure NaI(Tl) scintillating crystals immersed in a liquid scintillator acting as a veto in two separate underground locations in the two hemispheres: at the Gran Sasso National Laboratory, LNGS, in Italy (SABRE North) and at the Stawell Underground Physics Laboratory (SUPL) in Australia (SABRE South).

As a first step towards the full SABRE project, a SABRE Proof of Principle (PoP) phase is envisaged. The PoP is intended to develop high-purity NaI(Tl) crystals and to test them using an active liquid scintillator veto. The goal of the PoP is to achieve an overall significant lowering of detector background in the energy region of interest, where the annual modulation is observed by the DAMA/LIBRA experiment at LNGS (namely 2-6 keVee). Nominally the goal is to achieve a factor of 10 lower, than that achieved in the DAMA/LIBRA experiment. The PoP setup will be deployed and operated at LNGS in Gran Sasso, Italy.

This document provides the Memorandum of Understanding (MoU) for the PoP preliminary project. Because planning is underway for both SABRE South and SABRE North, a preliminary MoU agreement for the full-scale SABRE South is also provided in Annex 7 in the form of an agreement to cooperate, with all financial commitments

SABRE PoP Funding

- NSF:
  Extended: 2016 Grant 320 k$
- DoE:
  2016 Grant 1 M$ per RMD (crystal growth)

- INFN:
  2016 (Total): 256,5 k€
  2017 (Total): 238,5 k€
  2018 (First Assignment): 158 k€ + 26 k€ anticipated to 2017
  -> see talk of Davide

  + in-kind ≈ 18 tons of Lead + Pb refurbishment (≈ 22 k€)
  + hosting laboratory + general infrastructures + technical support

SABRE PoP site @ LNGS

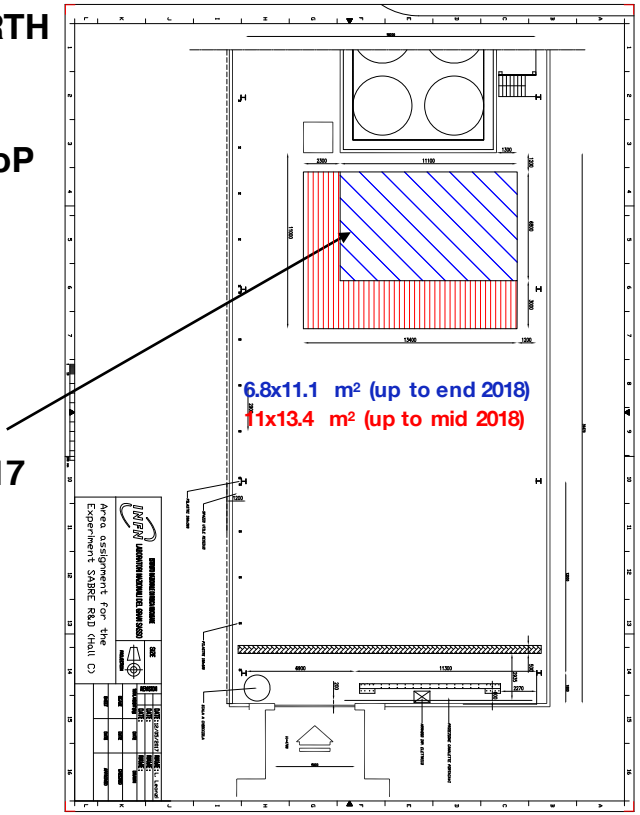
FIRST APPROVED SITE (Oct 2015): HALL B NORTH

AFTER UNDERGROUND LAB REORGANIZATION (February 2016) NEW LOCATION FOR SABRE PoP -> CHANGE OF SHIELDING DESIGN & INFRASTRUCURES

New site: Hall C near BX storage area, preferred location for safety and the use of BX plants.

OFFICIALLY DEFINED & ASSIGNED: May 12, 2017

SABRE PoP Hall C Site

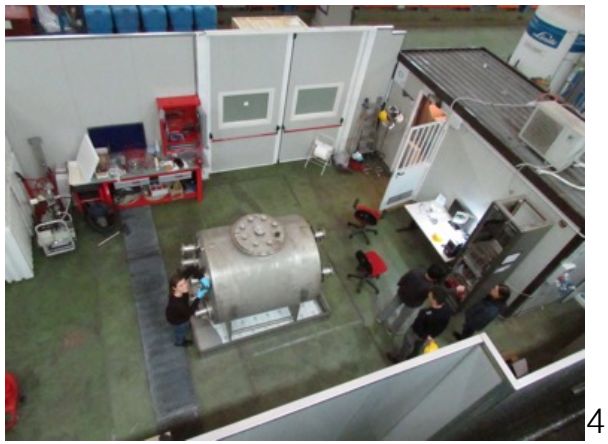


Temporary site: Hall B South, available for preliminary activities.

ASSIGNED: April 2016

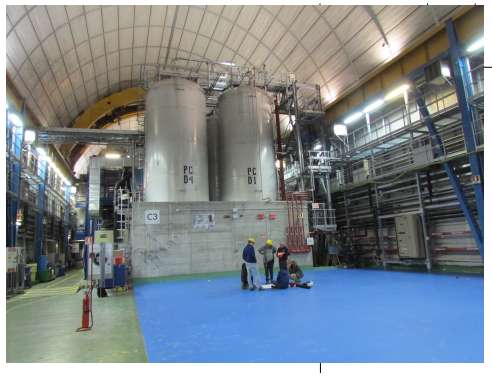
Hall B SABRE area was equipped with minimum tools and infrastructures: barrack, network, power cabinets, phone line.
Veto tests ongoing.

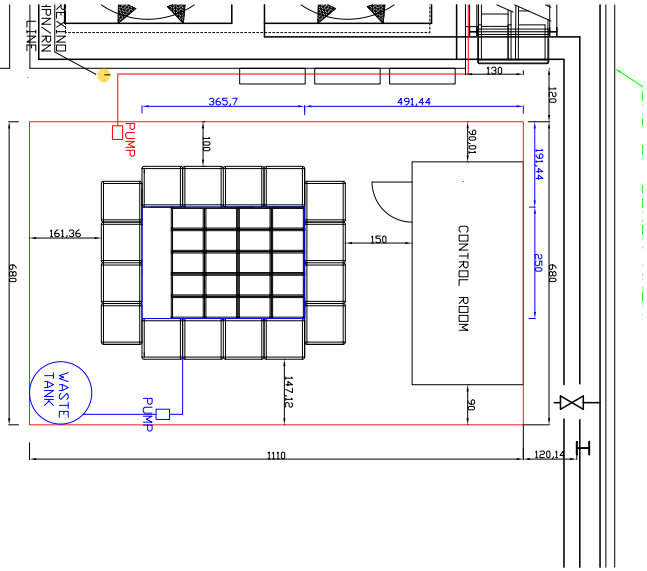
SABRE PoP Hall B temporary location

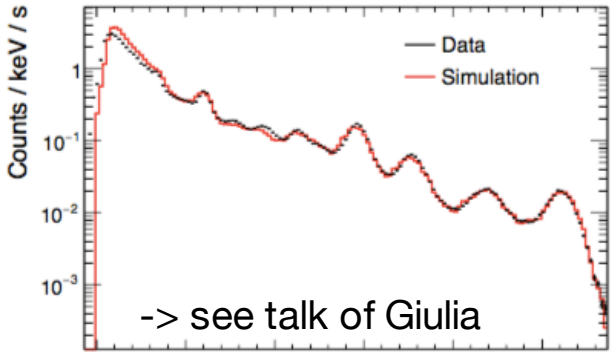


Hall C site preparation

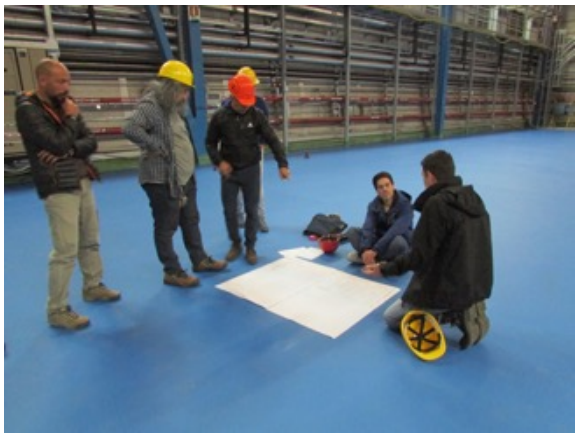
- "OPERA site" floor refurbishment: May 11, 2017.
- SABRE PoP final site definition and assignment: May 12.
- Floor planarity check, positioning of anchoring system and self-levelling resin: June 21.
- Barrack positioning: June 27.
- Installation shielding bottom (Pb): July 3.
- Electrical plant and network: ongoing.
- UPS plant: under discussion (missing)
- Hall C gamma BG characterization: done.







SABRE PoP Hall C Site occupation approved

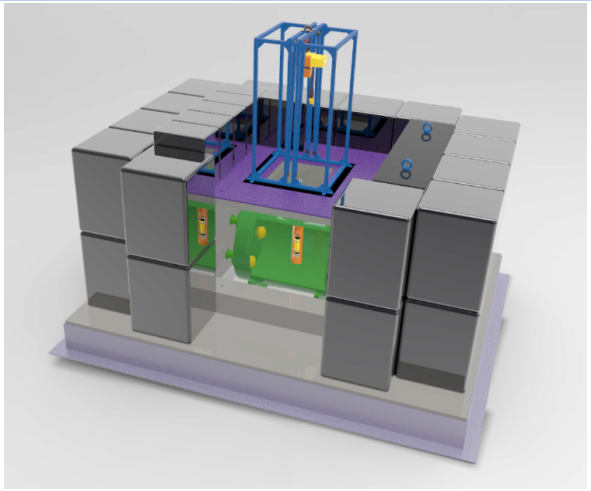


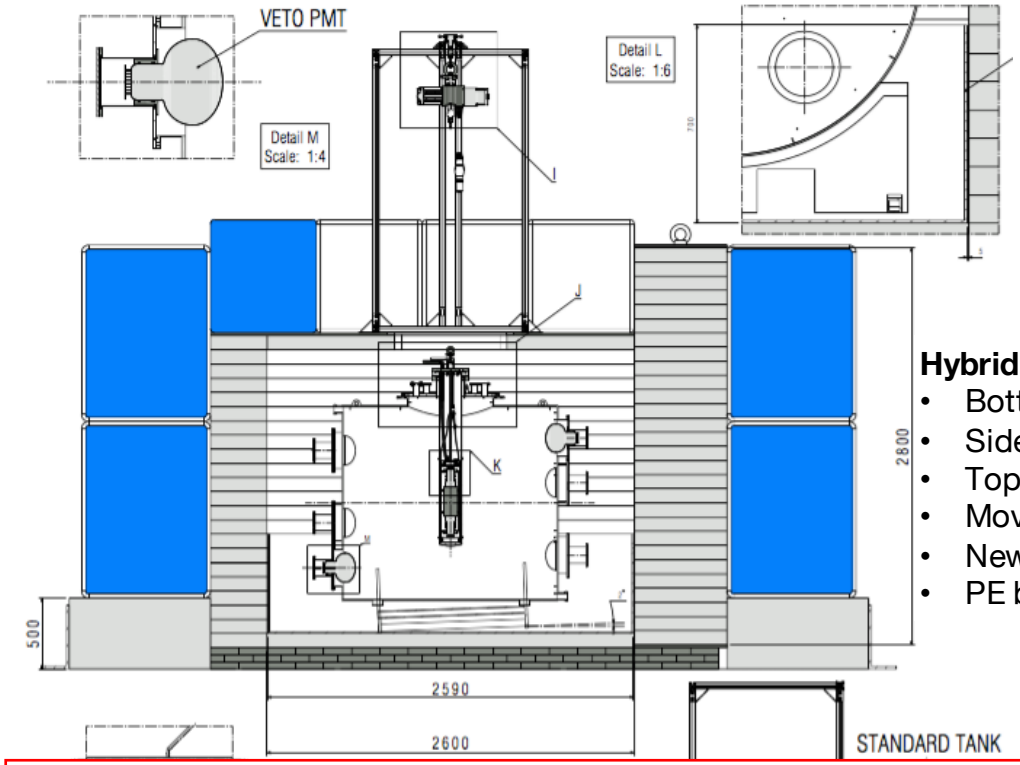
Available shielding components

SABRE PoP external shielding

Credit to D.Orlandi, C.Zarra & LNGS

FINAL DESIGN FOR THE HALL C SITE
INTEGRATED WITH CRYSTAL INSERTION SYSTEM AND NEW CATCH BASIN





Hybrid shielding (equivalent to ≈ 1.5 m of H_2O):

- Bottom: 15 cm Pb + 10 cm PE
- Sides: 40 cm PE + 90 cm water (tanks)
- Top: 10 cm PE + 2 cm SS + 80 cm water (tank)
- Moveable wall to ease interventions
- New: Inner catch basin (0.5 cm thick) for the whole PC volume
- PE box acts as Rn box flushed with GN2, monitored and safely vented

- CONTRACT SIGNED ON MAY 30, 2017 (YEAR 2016 TENDER AND FUNDS)
- WARP LEAD REFURBISHMENT COMPLETED (supported by LNGS)
  MATERIAL APPROVED (ACTIVITY MEASURED) AND MOUNTED
- PE MEASUREMENT COMPLETED & APPROVED, COMPONENTS MACHINED
- SS SAMPLE MEASUREMENT DONE, 2ND SAMPLE WORSE, 1ST APPROVED

PE + catch basin done, top SS plate to be produced
Expected delivery: October 15, 2017

Radioactivity measurement of shielding materials @ LNGS

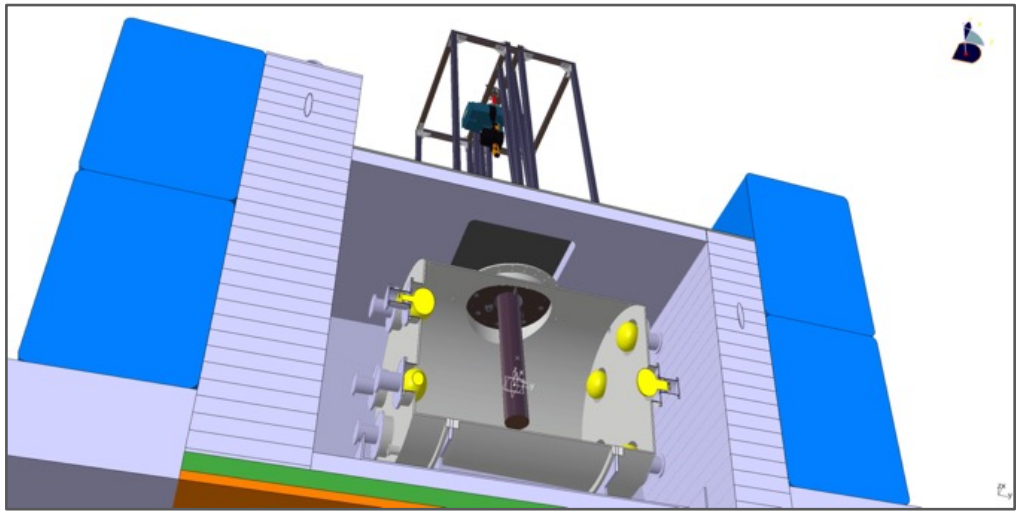
Credit to M. Laubenstein

Material	Refurbished Pb	PE	SS Sample n.1	SS n.2 Sample n.2
	[mBq/kg]	[mBq/kg]	[mBq/kg]	[mBq/kg]
Ra228	< 0.36	< 0.72	2.6 ± 0.5	2.8 +- 1.2
Th228	< 0.39	0.8 ± 0.2	7.7 ± 0.6	15.9 +- 1.5
Ra226	< 0.15	1.4 ± 0.3	2.4 ± 0.3	3.5 +- 0.6
Th234	< 4.7	< 9	< 63	< 400
Pa234m	< 9.7	< 4.4	29 ± 16	< 180
U235	< 56	< 0.81	1.0 ± 0.4	< 4.9
K40	< 1.8	< 5.9	1.5 ± 0.7	< 4.6
Cs137	< 2.0	< 0.28	< 0.26	< 0.62

-> see talk of Paolo

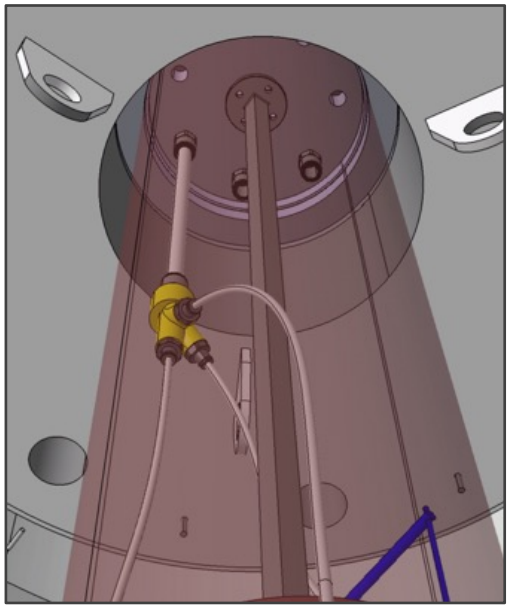
CIS (Crystal Insertion System)

-> see talk of Valerio Pettinacci

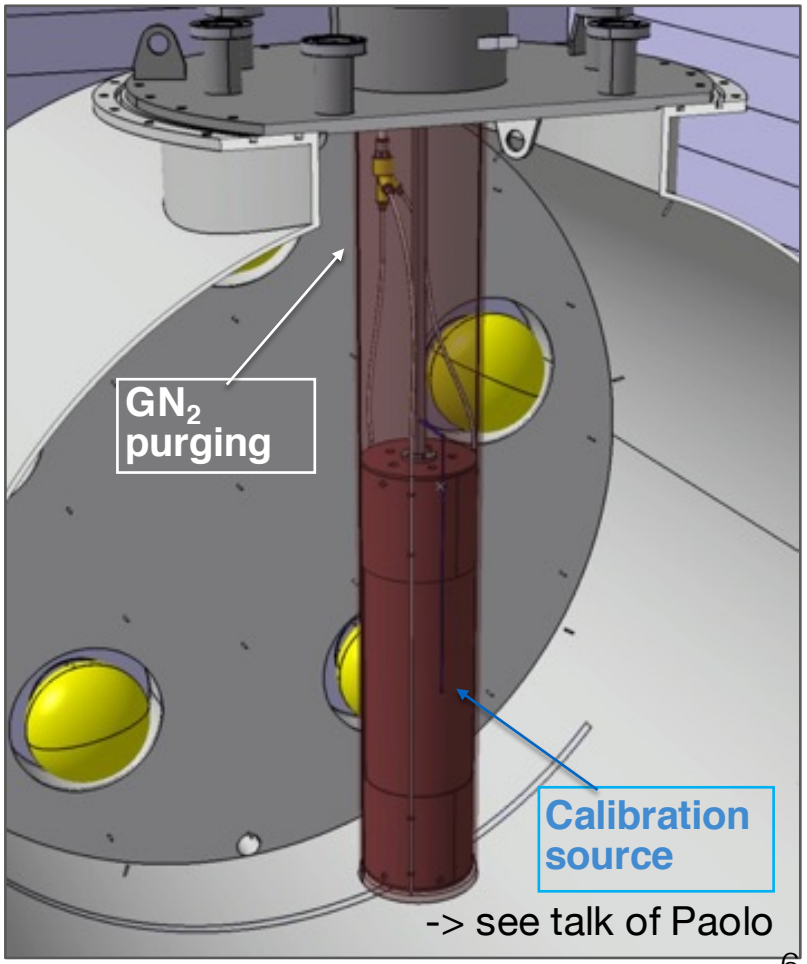


Dry solution: the enclosure is inserted in a copper tube connected to the top flange.

ALL THE CIS COMPONENTS READY, REFURBISHMENT OF TOP FLANGE COMPLETED



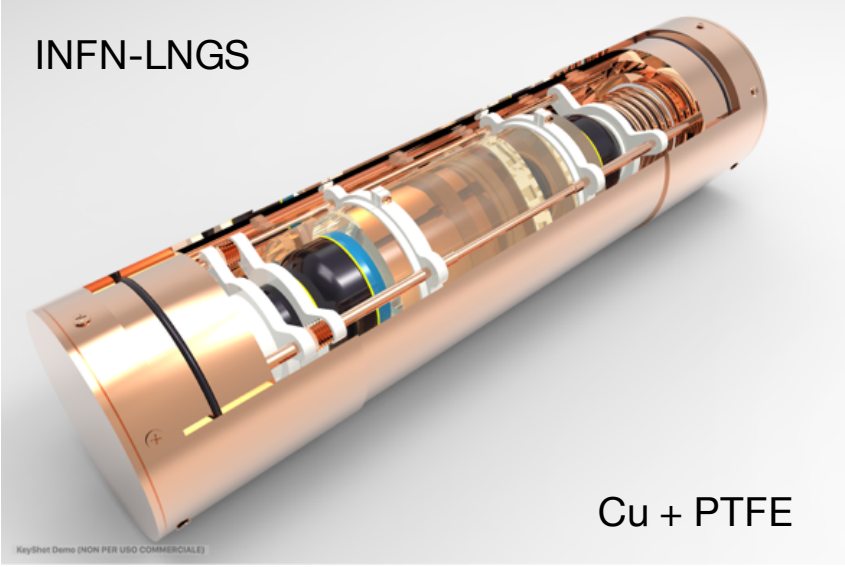
Most delivered at LNGS: end September, 2017



-> see talk of Paolo

Crystal Enclosure + Mock-up

-> see talk of Simone and Donato



High purity OFHC Cu (shell from CUORE Cu) enclosure:

- fit to the final 5-kg crystal with flexibility
- stable mechanical and optical coupling
- assembly in glove box
- vacuum tight / purgeable with GN_2 (Rn/H_2O removal)
- reduce material between crystal and LS veto

- **First crystal will be mounted at PU**
- **A glove box has just been funded by INFN (2018)**
- **A second enclosure too (for another crystal)**

Test with Mock-up: -> DESIGN UPGRADED

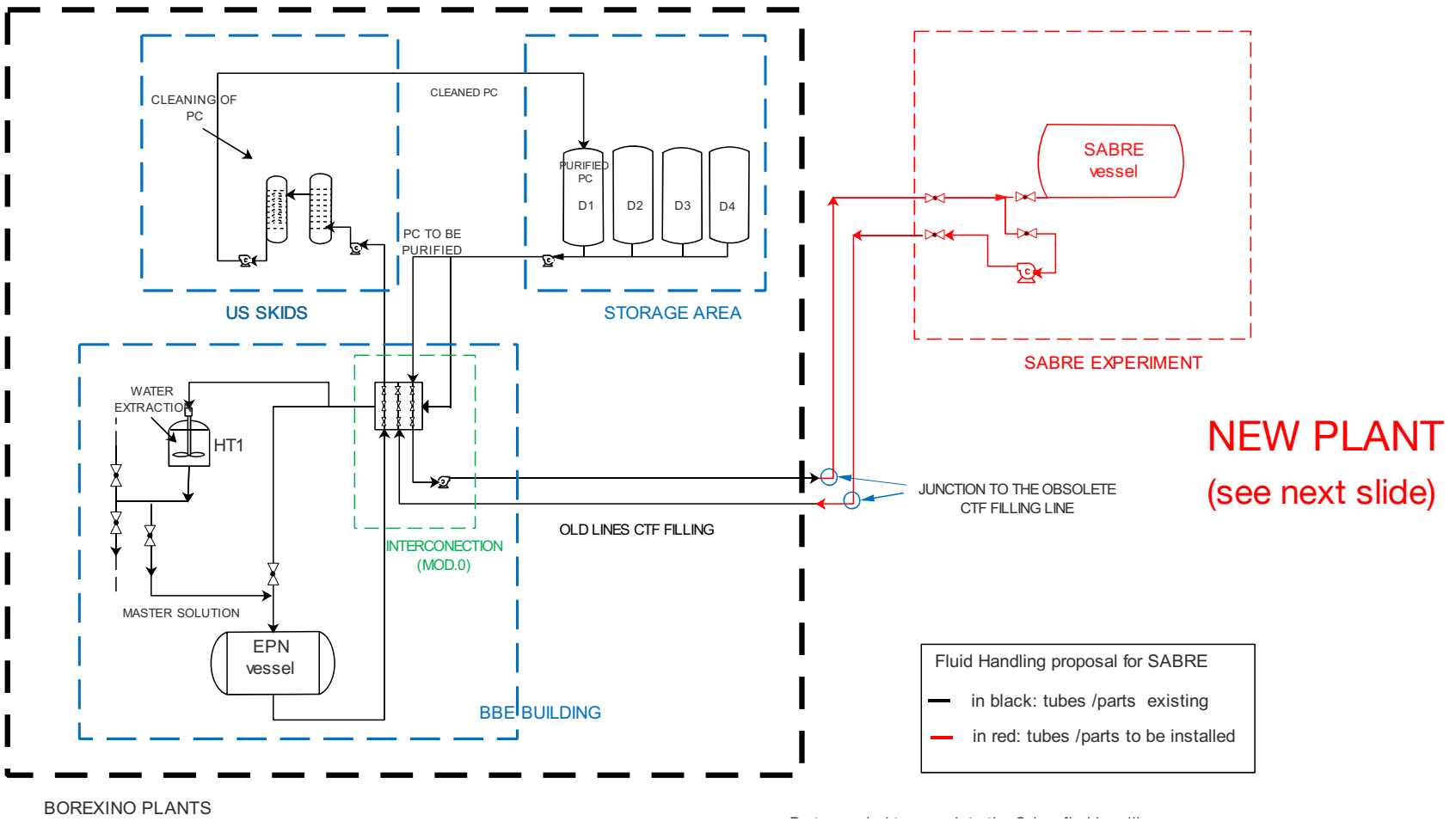
Cu shell in production.
Enclosure delivery: mid Oct 2017

SABRE PoP LS Fluid Handling: Borexino extension

-> see talk of Antonio

LNGS + PU

BOREXINO PLANTS



NEW PLANT

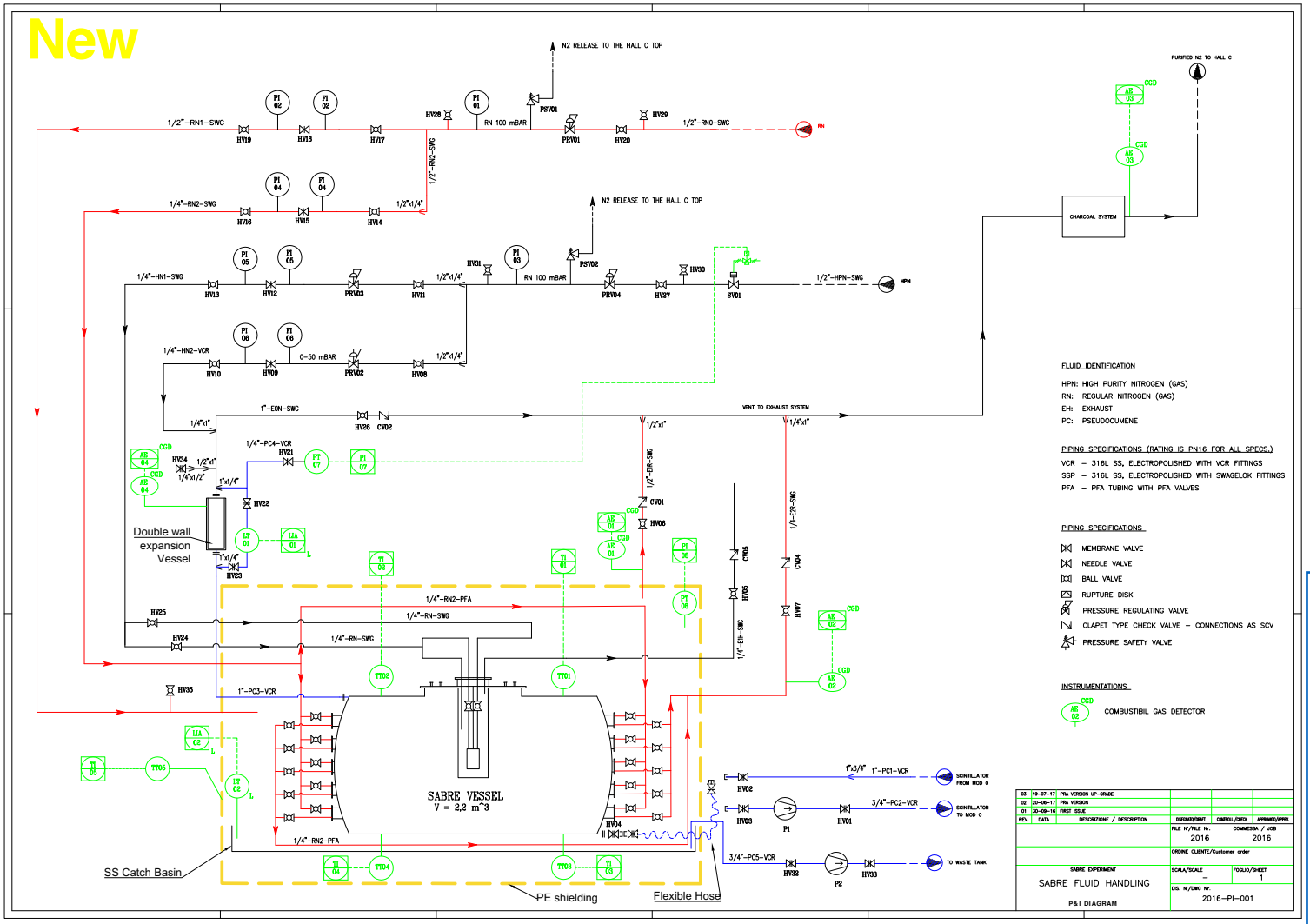
(see next slide)

- **Request to Borexino to use PC and LS plants. Formal approval needed (including all the plant requests)**
- **Safety review done (as required also by BX).**
- **Not increased PC quantity (PC already present in Hall C).**
- **SABRE decoupled from BX after commissioning.**

Credit to BX Collaboration

SABRE PoP plant P&I

-> see talks of Antonio and Lidio



New design, safety reviewed

Fluid Handling System:

- LS filling and drain
- GN_2 purging system (HPN &RN)
  - Rn box
  - Veto PMT cans
  - Enclosure
  - CIS tube
  - Veto vessel (expansion volume blanketing)
- Exhaust Line
- Emergency drain for catch basin

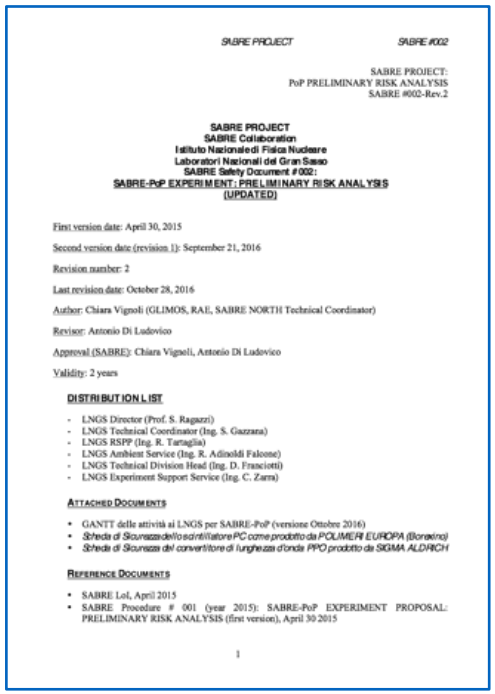
- **Most of the fluid handling system components ordered or purchasing procedure started.**
- **Still missing a decision on the GN_2 source and distribution system (discussion with LNGS ongoing)**
- **Slow Control system project in preparation, to be acquired.**

Credit to L.Ioannucci

SABRE PoP
Safety and Environment

-> see talks of Antonio

PRA (Preliminary Risk Analysis) documents APPROVED



SABRE PROJECT SABRE #002

SABRE PROJECT:
PoP PRELIMINARY RISK ANALYSIS
SABRE #002-Rev.2

SABRE PROJECT
SABRE Collaboration
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso
SABRE Safety Document # 002:
SABRE-PoP EXPERIMENT: PRELIMINARY RISK ANALYSIS
(UPDATED)

First version date: April 30, 2015
Second version date (revision 1): September 21, 2016
Revision number: 2
Last revision date: October 28, 2016
Author: Chiara Vignoli (GLIMOS, RAE, SABRE NORTH Technical Coordinator)
Revisor: Antonio Di Ludovico
Approval (SABRE): Chiara Vignoli, Antonio Di Ludovico
Validity: 2 years

DISTRIBUTION LIST

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- LNGS Technical Coordinator (Ing. S. Gazzana)
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- LNGS Ambient Service (Ing. R. Adinolfi Falcone)
- LNGS Technical Division Head (Ing. D. Franciotti)
- LNGS Experiment Support Service (Ing. C. Zarra)

ATTACHED DOCUMENTS

- GANTT delle attività ai LNGS per SABRE-PoP (versione Ottobre 2016)
- *Scheda di Sicurezza dello scintillatore PC come prodotto da POLIMERI EUROPA (Borealis)*
- *Scheda di Sicurezza del convertitore di lunghezza d'onda PPO prodotto da SIGMA ALDRICH*

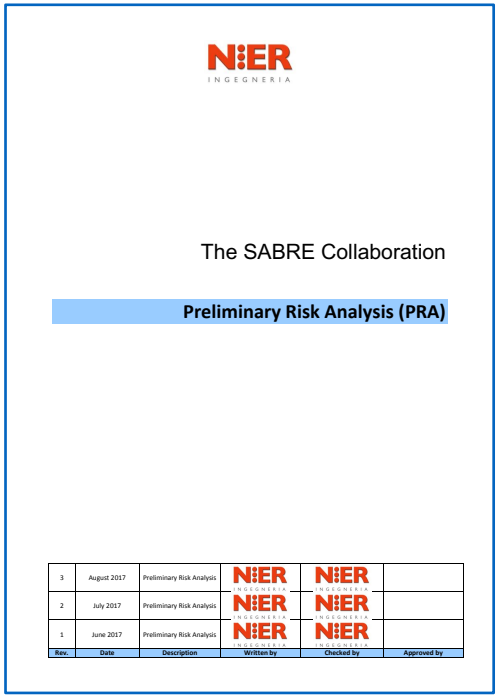
REFERENCE DOCUMENTS

- SABRE LoI, April 2015
- SABRE Procedure # 001 (year 2015): SABRE-PoP EXPERIMENT PROPOSAL: PRELIMINARY RISK ANALYSIS (first version), April 30 2015

1

INTERNAL PRA

Oct 28, 2016



NIER INGEGNERIA

The SABRE Collaboration

Preliminary Risk Analysis (PRA)

Rev.	Date	Description	Written by	Checked by	Approved by
3	August 2017	Preliminary Risk Analysis	NIER	NIER	
2	July 2017	Preliminary Risk Analysis	NIER	NIER	
1	June 2017	Preliminary Risk Analysis	NIER	NIER	

EXTERNAL PRA (NIER)

Aug 3, 2017

- **SABRE PoP approach to improve safety: no increase of PC underground, use of catch basin, dry solution for CIS.**
- **Approval for vessel shipment: Aug. 2016 (built in US)**
- Approval by Safety Service Head of catch basin for 1/3 of volume: Aug. 2016. A concern was raised later by Environmental Service Head.
- **Environmental Safety Review first audit: Feb. 8, 2017**
- **External Safety Review required** end 2016: contract assigned to Nier Company end of March 2017.**NIER PRA analysis** first version received on Jun 20, 2017. Revision 3: August 3, 2017:

1. Big simplification of SABRE safety plants if catch basin capacity is increased to the total PC volume
2. 3 top events: PC leak inside PE shielding or in Hall C, N_2 release in Hall C

   BELOW THE CREDIBILITY THRESHOLD
3. No suggestion of further analyses (QRA, Atex,...); fire event not credible; no need of a blow down system;

   ➢ New catch basin equipped with pump for emergency

   ➢ Expansion volume with double containment

   ➢ New version of DCS and P&I with few blocking valves

- **Positive feedback and PRA approval from LNGS (Sep 14, 2017), except minor details: New PRA Rev4.**
- **GN_2 system to be defined with LNGS Tech. Coord.**
- **Procedures to be presented ("Water protocol").**
- **Two more documents to be prepared for fire risk: "SCIA" & "Non aggravio di rischio" (ext consultant).**

SABRE PoP: PRA Top Events

-> see talks of Antonio and Lidio

ALARP matrix

CONSEQUENCE→ / FREQUENCY↓	LETHAL/IRREVERSIBLE EFFECTS	MAJOR EFFECTS	SERIOUS EFFECTS	MINOR EFFECTS	NO RELEVANT EFFECTS
FREQUENT ($> 1\ y^{-1}$)					
PROBABLE ($1\ e^{-1}\ y^{-1} - 1\ y^{-1}$)					
OCCASIONAL ($3\ e^{-2}\ y^{-1} - 1\ e^{-1}\ y^{-1}$)					Event 1b.1
REMOTE ($3\ e^{-3}\ y^{-1} - 3\ e^{-2}\ y^{-1}$)					
IMPROBABLE ($3\ e^{-4}\ y^{-1} - 3\ e^{-3}\ y^{-1}$)					
EXTREMELY IMPROBABLE ($< 3\ e^{-4}\ y^{-1}$)		Event 1a Event 1b.2 Event 1c.2 Event 1c.3 Event 1c.4	Event 1c.1	Event 1b.3	Event 2

ALARP matrix (*As Low As Reasonably Practicable*) risk evaluation criteria

- **Frequency:** event frequency of occurrence;
- **Consequence:** effects on human health and safety

the risk associated to an event is:

- **Unacceptable (red)**
- **Tolerable (yellow)**
- **Acceptable (green)**

Suggestions

Top Events		Considerations and suggestions
1a - Scintillator vessel overpressure	I	No additional devices/solutions could be considered for improvement
1b - Scintillator (PC+PPO) release inside PE Shielding	II	Disposal of the liquid scintillator released, carried out without opening the PE Shielding, should be ensured as fast as possible
	III	Constant nitrogen flushing, carried out also with nitrogen emergency supply through the manual valve HV35, should be ensured if a scintillator release happens
1c - Direct Scintillator (PC+PPO) release in Hall C	**IV**	**Disposal of the liquid scintillator released should be ensured as fast as possible**
	V	Valve with high performance packing should be used
2 - Direct Nitrogen release in Hall C	VI	Valves number on the nitrogen supply lines should be reduced as much as possible

For most events, the frequencies are lower than the credibility threshold and, for the "*Scintillator release in Hall C*", the expected consequences are also not critical because:

- the maximum quantity of scintillator could be released from double-walled expansion vessel is about 20 litres;

- the **potential scenarios** of pool fire or flash fire or VCE are characterized by a **frequency lower than the credibility threshold** (see Figure 6 – ETA Consequences of Scintillator direct release in Hall C).

This conclusion may be extended to the Top Event 2, although the value of frequency is higher than the credibility threshold and the fact that a direct release is ever-present during the normal operation. Indeed **the maximum nitrogen stream will be always much lower (2 m3/h) that ventilation rate guarantee by the ventilation system (7000 m3/h).**

SABRE PoP Veto tests

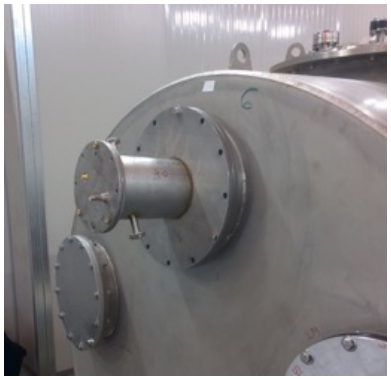
-> see talks of Suerfu, Simone and Davide

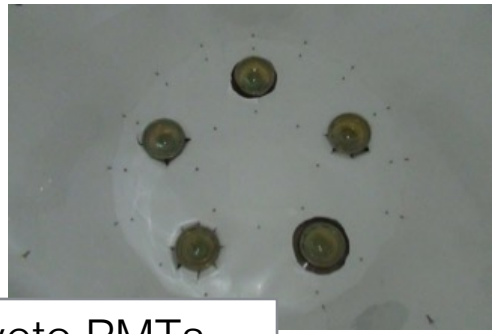
SABRE Vessel in Hall B

- **August 2016**: Vessel transport approval to LNGS
- **November 2016**: Vessel delivered to LNGS
- **Begin of March 2017**: Veto PMTs, electronics and DAQ delivered to LNGS and mounted
- **Since March 2017**: Dry test phase started with veto vessel equipped with 10 PMTs + lumirror, electronics and DAQ:
  1. Light tightness
  2. PMTs characterisation (dark counts, gain,…)
  3. Test with light source (LED+pulser)
  4. Scintillator cell/BGO crystal + NaI crystal tests
  5. Test of DAQ and trigger
  6. Reconstruction and SW tools developments
  7. Computing, data handling and storage

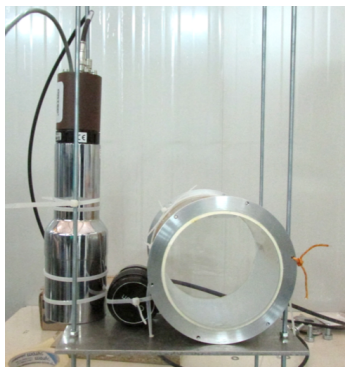
➢ **Water test to be discussed**

- ➢ Tightness test (PMT installation)
- ➢ Veto test with Cherenkov light





Mounting of veto PMTs



Hall B Crystal/PMT test facility

-> see talk of Simone

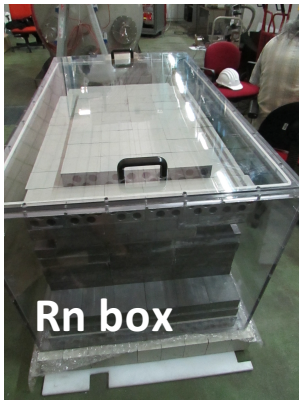
A passive shielding test facility was installed in Hall B.

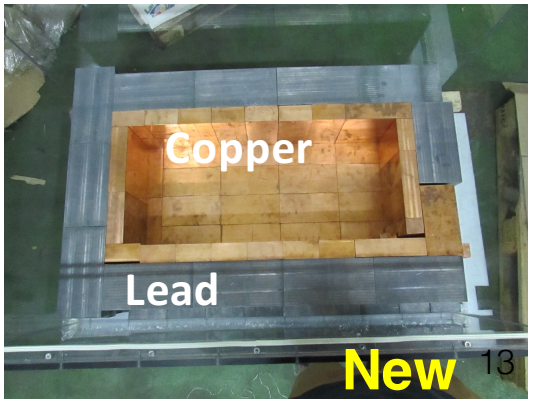
Versatile and flexible set-up to test:

- PMTs in the final configuration (dark count, afterglow,…)
- voltage dividers and pre-amp solutions
- DAQ options, trigger and digitizer tests
- new crystals (light yield, calibration, PSD, …)

It can hold up to two crystal enclosures —> possibility to perform crystal intrinsic background measurements in coincidence mode

Useful for pre-commissioning tests of crystal before inserting inside the veto





SABRE PoP NaI(Tl) Crystal

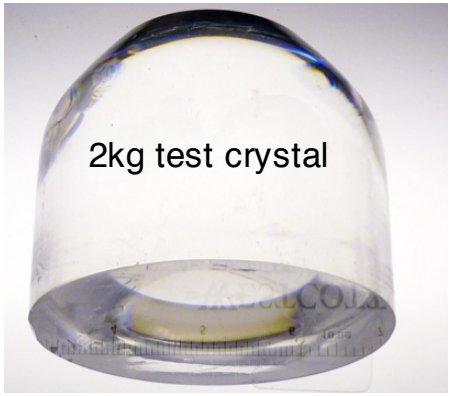
-> see talks of Frank and Suerfu

Producer: Princeton University & RMD Company (Boston)

- Starting point: Astrograde powder by Sigma Aldrich with 9 ppb in ^{nat}K.

- **In fall 2015 RMD has grown a 2 kg crystal (3.5" diameter) with:**
  - **9 ppb ^{nat}K (same as starting powder)**
  - **< 0.1 ppb ^{87}Rb**

  measured by ICP-MS, for the first time below DAMA ([K]~13 ppb, [Rb]<0.35 ppb)



- The activity since then has focused on:
  - **growing a full scale 5-kg crystal (≈ 4" diameter)**
  - **improving procedures for crystal growing (powder drying, crucible purity, …)**
  - **defining procedure for crystal handling** (polishing, crystal mounting and handling inside the enclosure in glove box)
    - Facilities at PU: new glove box installed inside Rn free clean room

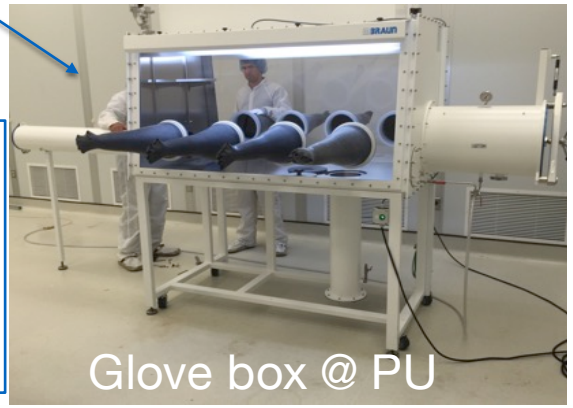
✓ Unfortunately experienced some setbacks, now understood and solved (crucible and crystal grade powder)

✓ RMD funded by DoE (1 M$) -> extra 50 kg of Astrograde powder 3 ppb in K

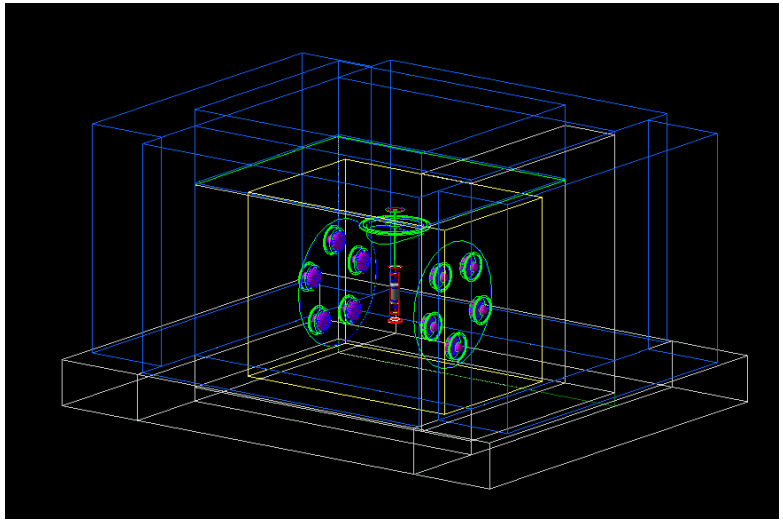
✓ Successful test of growth of full scale crystal in August 2017

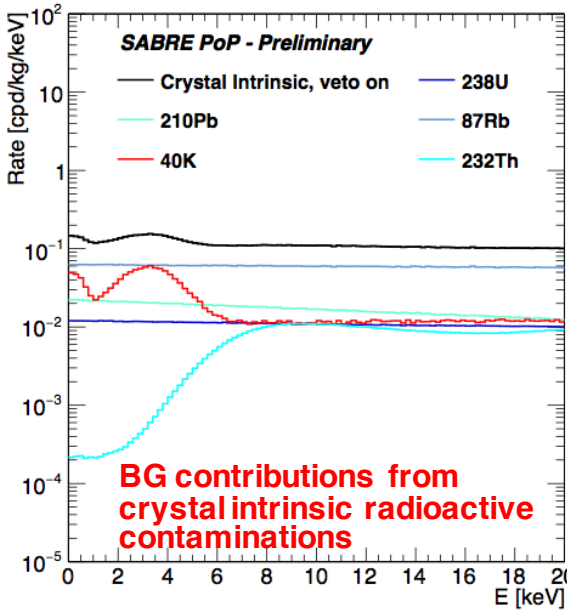
➢ **1st crystal with RMD standard grade crucible: Oct 3**

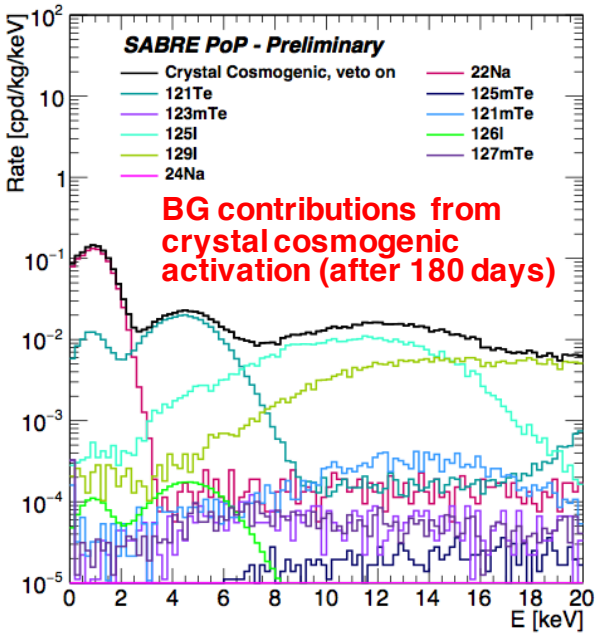
➢ **2nd crystal grown with PU high purity crucible: within Nov.**



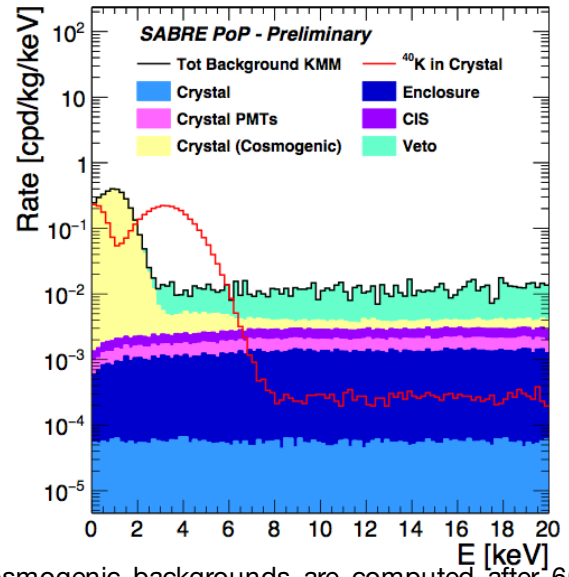
SABRE Montecarlo simulations



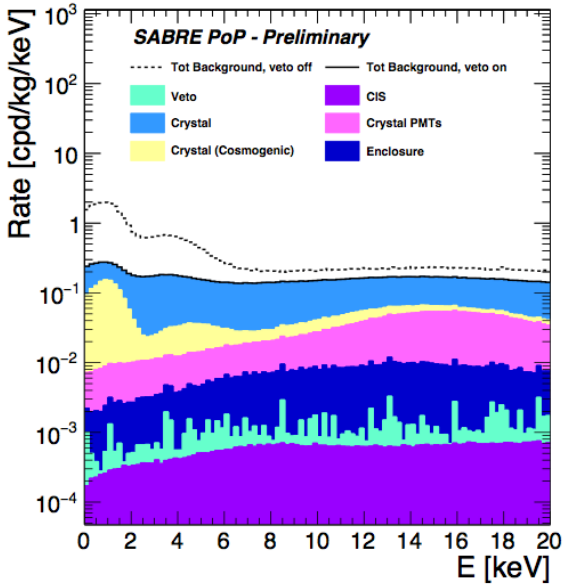




Potassium Measurement Mode



Dark Matter Measurement Mode



Full simulation of SABRE PoP

Cosmogenic backgrounds are computed after 60

PoP Milestones Schedule

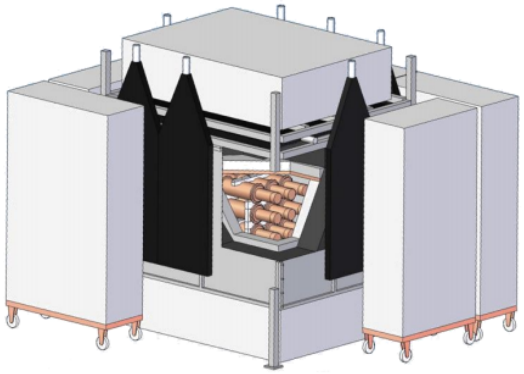
Milestones completion		Date
1.	Veto vessel dry commissioning (Hall B)	July 31st, 2017
2.	Hall C Site available	May 12th
3.	Lower Lead shielding	July 3rd
4.	PRA approval by LNGS	Sep 14th
5.	CIS delivery to LNGS	Sep 20th
6.	Crystal enclosure delivery to LNGS	Oct 15th
7.	PE + SS +catch basin+ water tanks shielding delivery to LNGS	Oct 15th
8.	PE shielding installation in Hall C	Oct 31th
9.	Veto vessel cleaning + Lumirror + PMTs installation in Hall C	Oct 31th
10.	Electronics + DAQ installation in Hall C	Oct 31th
11.	Crystal insertion system installation inside the veto vessel	Nov 10th
12.	Fluid handling installation in Hall C	Nov 30th
13.	5 kg crystal growth @ RMD	Oct 3nd
14.	Crystal enclosure delivery to PU	Oct 31th
15.	Crystal-PMT installation in enclosure in glove box @ PU	Nov 15th
16.	Crystal shipment to LNGS	Nov 30th
17.	Crystal installation in the vessel	Dec 10th
18.	LS preparation (to be done in advance, BX activity)	???
19.	Veto commissioning	End 2017
20.	PoP run	2018

SABRE PoP Conclusion & Future Prospects

- Setbacks in crystal growth, in combination with delay of site allocation and availability, and in purchase orders, such as external shielding, have introduced several months of delay.
- A new 5-kg crystal growth is expected to finish in early October, and a second in November, 2017.
- Fluid operations have been blocked by Laboratory management but the new agreement with Regional Authorities, should allow cleaning soon, and scintillator operations soon after that.
- The SABRE safety review is complete. With approval of existing fluid handling procedures, scintillator operations should be possible. .
- Most of the major components of the PoP set-up are either already available at LNGS, or ordered for delivery in October or November..
- **Provided there are no further delays, we expect to assemble the PoP detector and begin commissioning by the end of 2017.**
  - **A second crystal could be measured too.**
- **Milestone 2018: proposal of SABRE North Full Scale Experiment -> FSE start in 2019**
  - **SFE design, R&D and improvements**

International Competition

ANAIS-112 @ Canfranc (Spain)
Setup: 9 x 12.5 kg crystals (112.5 kg).
Muon tagging.
Gamma (lead, also ancient), Anti-Rn box and neutron (PE) shielding.
Data taking started Aug 2017



3x3 matrix of 12.5 kg cylindrical NaI(Tl) modules
(112.5 kg of active mass)

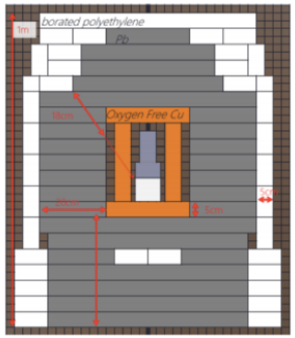
- Alpha Spectra crystals: 40K and 22Na peaks and 210Pb (bulk+surface) and 3H continua are the most significant contributions in the very low energy region.
- **bkg ~ 4 cpd/kg/keV (single hit)**
- Outstanding light collection: ~15 phe/keV
- threshold: 1 keV (trigger), 2 keV (sensitivity)

COSINE-100 @ YangYang (South Korea)
Joint collaboration between DM-Ice and KIMS
Setup: 8 crystals (TOT 106 kg).
Muon tagging.
Gamma (3cm Cu + 20 cm Pb) shield
LS veto (~ 2000 l LAB)
Data taking started Sep 2016

- **bkg 2-4 cpd/kg/keV (single hit)**
- Alpha Spectra crystals: depending on crystal —> limited by the intrinsic radio purity of the crystals
- threshold: 2 keV (goal is 1 keV)
- R&D for COSINE-200 powder purification and crystal growth facility @ IBS in Korea (mass production facility for purification under construction)

PICOLON @ Kamioka

- 3"ϕ x 3", 4"ϕ x 3" crystal for bkg reduction study
- 5"ϕ x 5" crystal for realistic DM measurement
- 5"ϕ x 5" x9 modules for test of DAMA signal
- 5"ϕ x 5" x42 modules inside KamLAND for DM search
- 1 PMT/crystal



- Only 3"x3" and 4"x3" detectors were tested so far. 5"ϕ x 5" NaI(Tl) is under crystallization.
- Concentration of 210Pb 24 ± 2 μBq/kg in 3"x3" crystal but not reproduced in 4"x3" one. 40K still high (~130ppb).
- **bkg 3-4 cpd/kg/keV in 4"x3" (single hit)**
- Development to Hamamatsu 4 " PMTs