SABRE (SODIUM IODIDE WITH ACTIVE BACKGROUND REJECTION)

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for the SABRE coll. (and beyond)

CoEPP-CAASTRO Workshop
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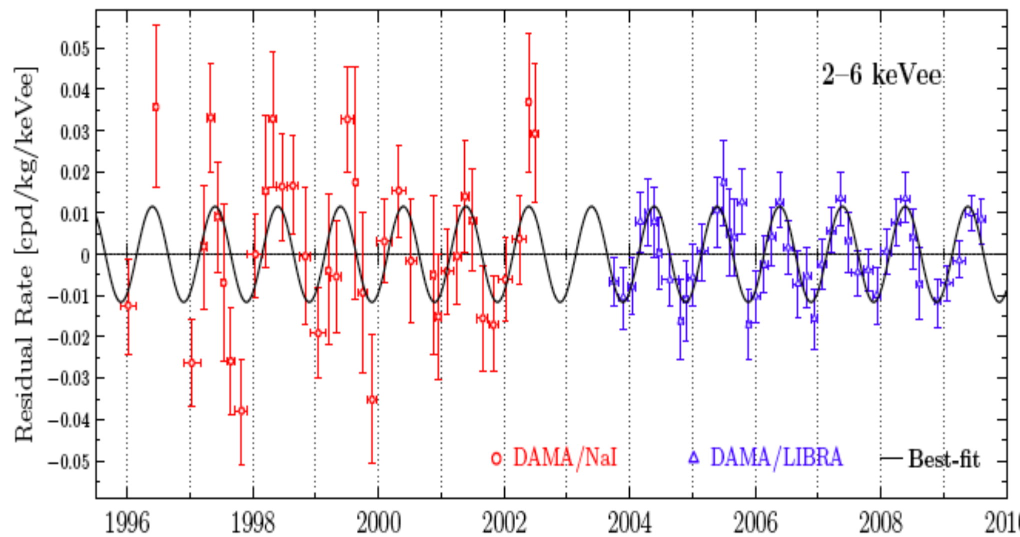
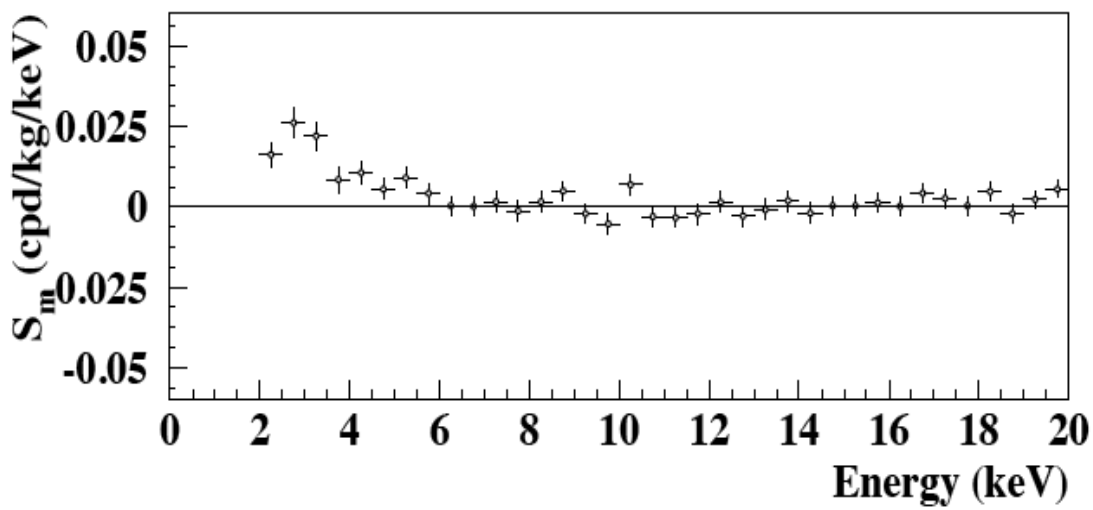
THE DAMA/LIBRA MODULATION

Modulation
- 1 year period
- Peaked end of May
- WIMP signal peaked beginning of June
- 9σ significance

Amplitude
- Peaked at ~3 keV_e
- Prominent in 2-6 keV_e

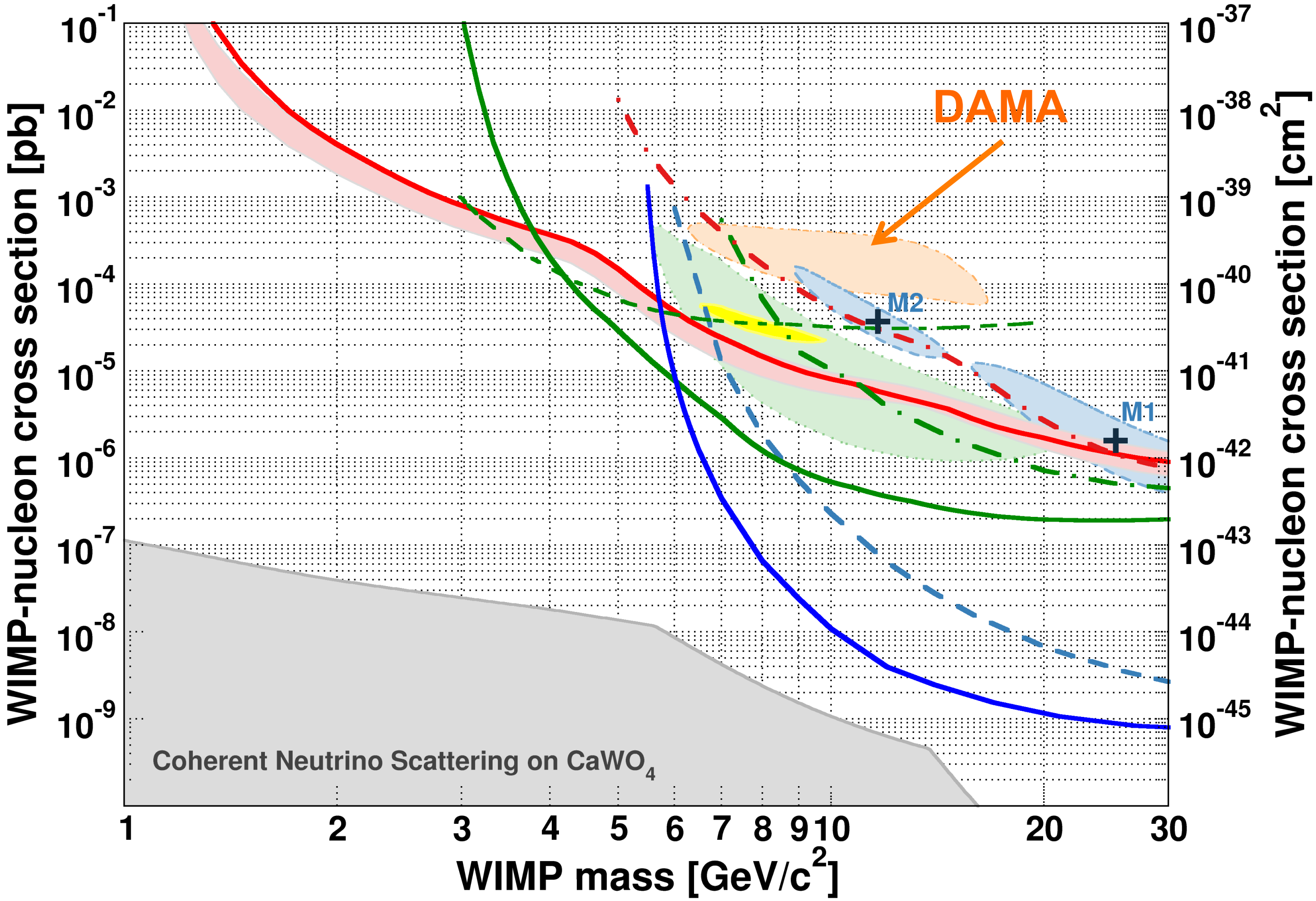
Remarks
- Detector makes use of an array of 250 kg high purity NaI (unique)
- Observation can be explained in the WIMPs framework





R. Bernabei et al. (DAMA coll.), EPJ C (2013) 73:2648.

THE LOW-MASS STRUGGLE



arXiv:1407.3146v1

A COMPLEX SCENARIO

- DAMA/LIBRA (DL) results (and other positive low mass results) are *"excluded"* by several other experiments.
- DL (and CoGeNT) observes DM annual modulation, while all others are counting experiments.
- No other experiments is using NaI as target material.
- **Theoretical** attempts to let DL coexist with other results:
  NO clear conclusion.
- Attempts to explain DL in terms of **background** have been made
  - ^{40}K
  - cosmogenic (and environmental) background

  NO clear conclusion
- DL has done an excellent job. Strong arguments to sustain the result.
  NO trivial mistake.

A COMPLEX SCENARIO

Low-mas compatibility

H. Hooper, J. Collar, J. Hall, D. McKinsey, C. Kelso, PR D 82 (2010) 123509.

C. Savage et al., JCAP 04 (2009) 010.

P.W. Graham et al., PR D 82 (2010) 063512.

D. Hooper, Phys. Dark Univ. 1 (2012) 1.

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Instrumental backgrounds (^{40}K)

J. Pradler, B. Singh and I. Yavin, PL B 720 (2013) 399-404

R. Bernabei et al. (DAMA coll.), (2012) arXiv:1210.6199 and arXiv:1211.6346;

J. Pradler and I. Yavin, (2012) arXiv:1210.7548.

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Environmental backgrounds (Cosmic muons)

J. P. Ralston, (2010) arXiv:1006.5255

K. Blum, (2011) arXiv:1110.0857

E. Fernandez-Martinez and R. Mahbubani, JCAP 07 (2012) 029

S. Chang, J. Pradler and I. Yavin, PR D 85 063505 (2012)

J. Pradler, (2012) arXiv:1205.3675

R. Bernabei et al. (DAMA coll.), IJMP A 28 (2013) 1330022

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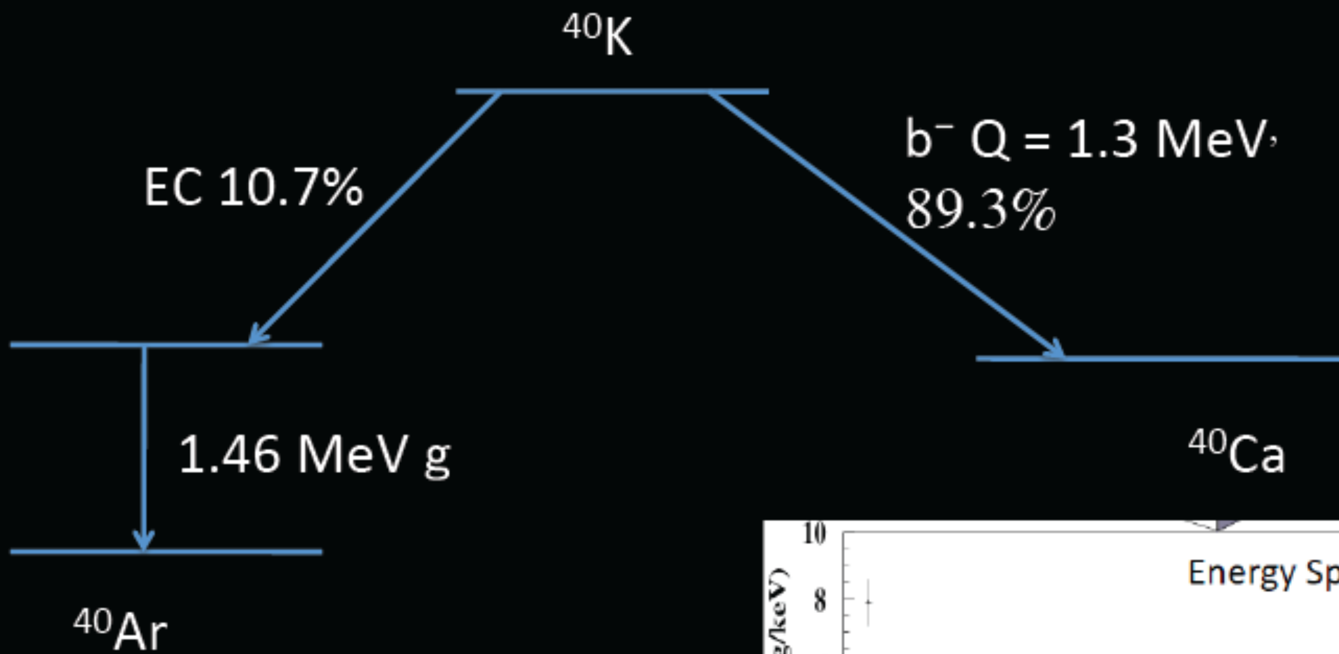
Another NaI measurement is needed!

SABRE KEY FEATURES

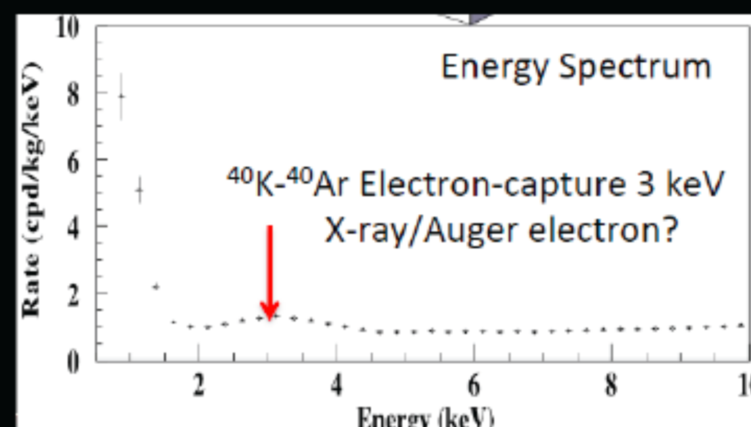
Detect Dark Matter annual modulation in NaI crystals

1. **New radio-pure NaI crystals**
    1. Higher purity NaI powder than ever achieved
    2. Further purification during crystallization
    3. Low background methods (used in Borexino and DarkSide) in handling and processing
2. **New low-background and high-QE photosensors**
    1. 3” PMTs. Hamamatsu R11065-20 (< 10mBq of gamma from U and Th) or upcoming 4” version.
    2. SiPM. Should be below 1mBq. R&D in progress.
3. **Active Background rejection with liquid scintillator.**

THE ^{40}K ISSUE



EC decay produces 1.46 MeV g and hole in ^{40}Ar K-shell, which then fills giving 3 keV X-ray/Auger electron.



RADIO-PURE POWDER
(USA WAY)

4-year work at Princeton University.

Purify precursors of NaI: Na_2CO_3

Element	MV laboratories	Sigma Aldrich "Astro-Grade"	DAMA powder
K	12ppb	3.5 ppb (18 ppb)	<100ppb (13 ppb in crystal)
Rb	14ppb	0.2 ppb	not reported
Th	<200ppt ~ 3.5ppt*	<1700ppt <1ppt*	20ppt
U	<100ppt <1ppt*	<500ppt <1ppt*	20ppt

* Preliminary by means of ICP-MS dilution method at PNNL

<u>STD-purity crystal grown at RMD, high-purity in process</u>

RADIO-PURE CRYSTAL
(ITALIAN-CHINESE WAY)

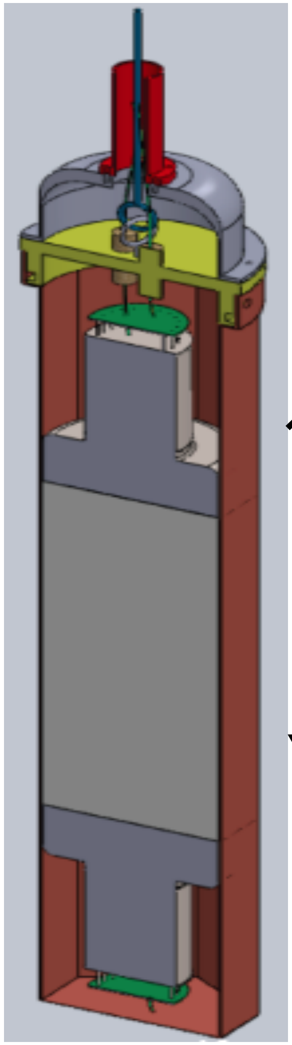
Contacts taken with SICCAS company in Shanghai (China).
Excellent experience in TeO_2 for CUORE ββ decay experiment.
Now starting a facility for high-purity NaI crystals.
R&D on powders started in collaboration with I.N.F.N.
Test crystal growth funded in 2015.

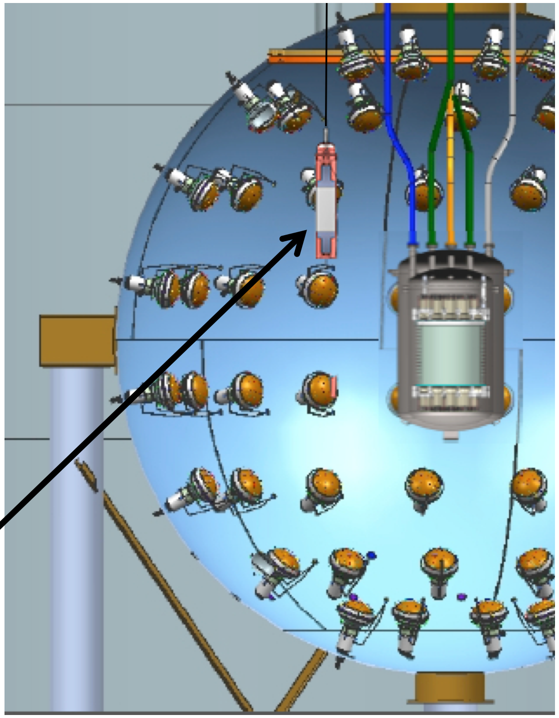
WORK PLAN

- **Test background rejection in liquid scintillator using DarkSide neutron-veto:**
  - Module insertion system is being finalized in Princeton.
  - 1° deployment with standard NaI crystal scheduled before end of 2014.
  - 2° deployment with high purity NaI by RMD (Boston, USA) scheduled beginning of 2015.
  - 3° deployment with high purity NaI by SICCAS (Shanghai, China), mid 2015?
- **Make a demostrator to test final design**
- **Make SABRE detector**

CRYSTALS TEST IN DARKSIDE

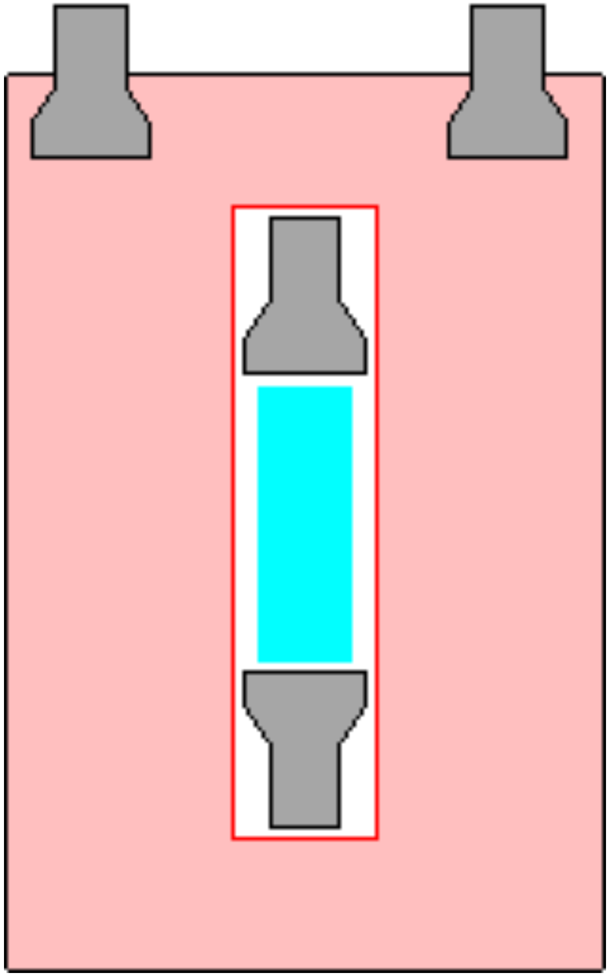
- Coincidence with neutron-veto detector
- 2-PMTs coincidence signal ORed with TPC trigger.
- NaI crystal inside water Cherenkov and active scintillator shielding
- 3" diameter x 4" length cyclindrical NaI crystal





Low radioactivity copper housing: U, Th < μBq/kg

DEMONSTRATOR

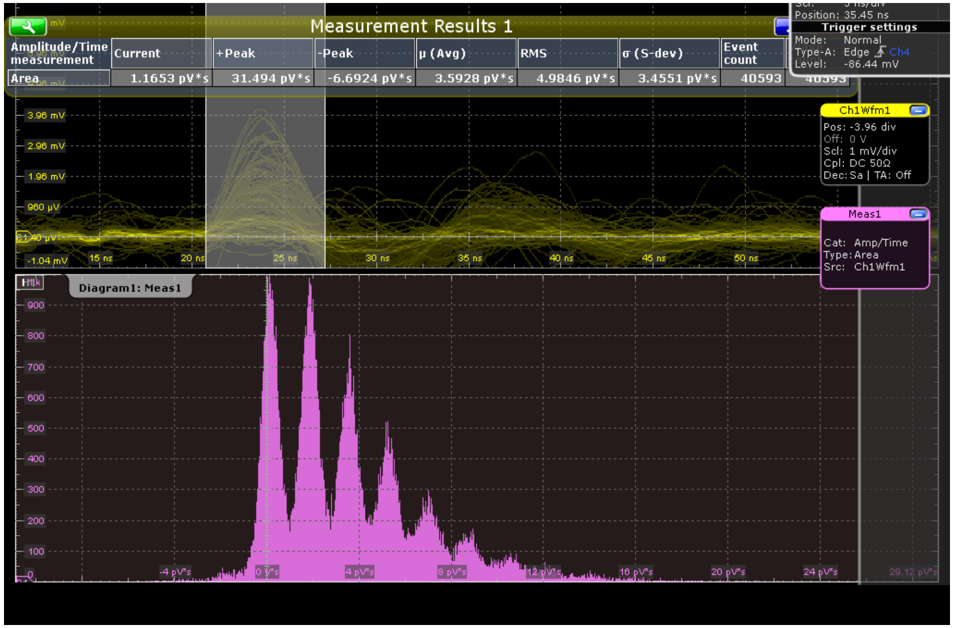


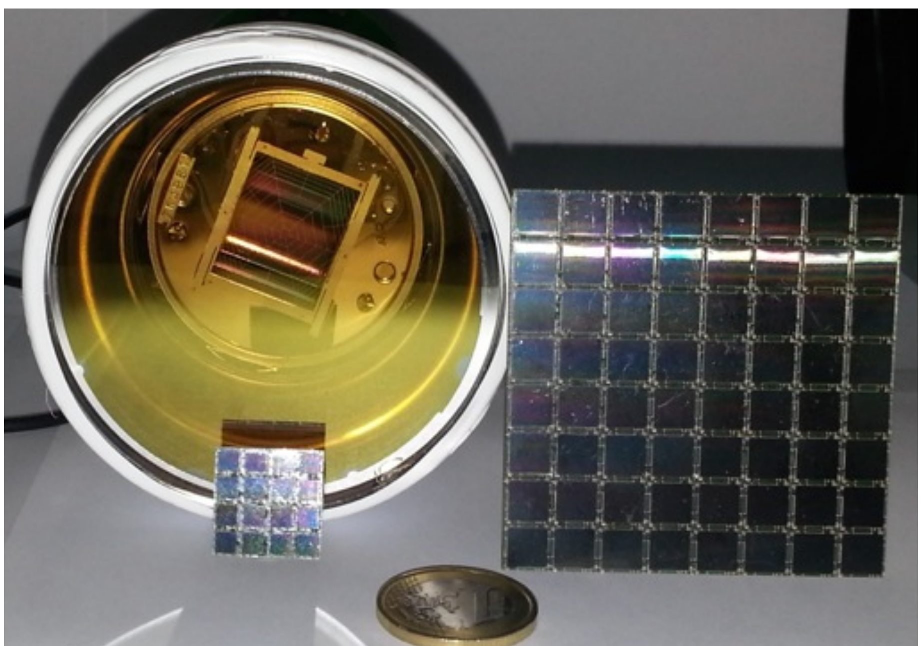
One SABRE detector in an active veto

- Installed in DarkSide-10 water shield
- VETO based on LAB scintillator
- 4 high radiopurity PMTs.

The device will allow to

- Study the purity of different crystals
- Study the optical read-out
  - PMTs vs SiPMs.





USING SIPM

SiPMs exibts high QE

> 40-50 % (limited only by fill factor)

SiPMs exibit HIGH pe resolution

Up to 5 % (compared to 30 % from PMT)

Low dark rate at T < -50 ⁰C

Better than 1 cps/mm² at 10^6 gain ~2kHz for a surface equiv to a 3”PMT.

Radiopurity to be tested

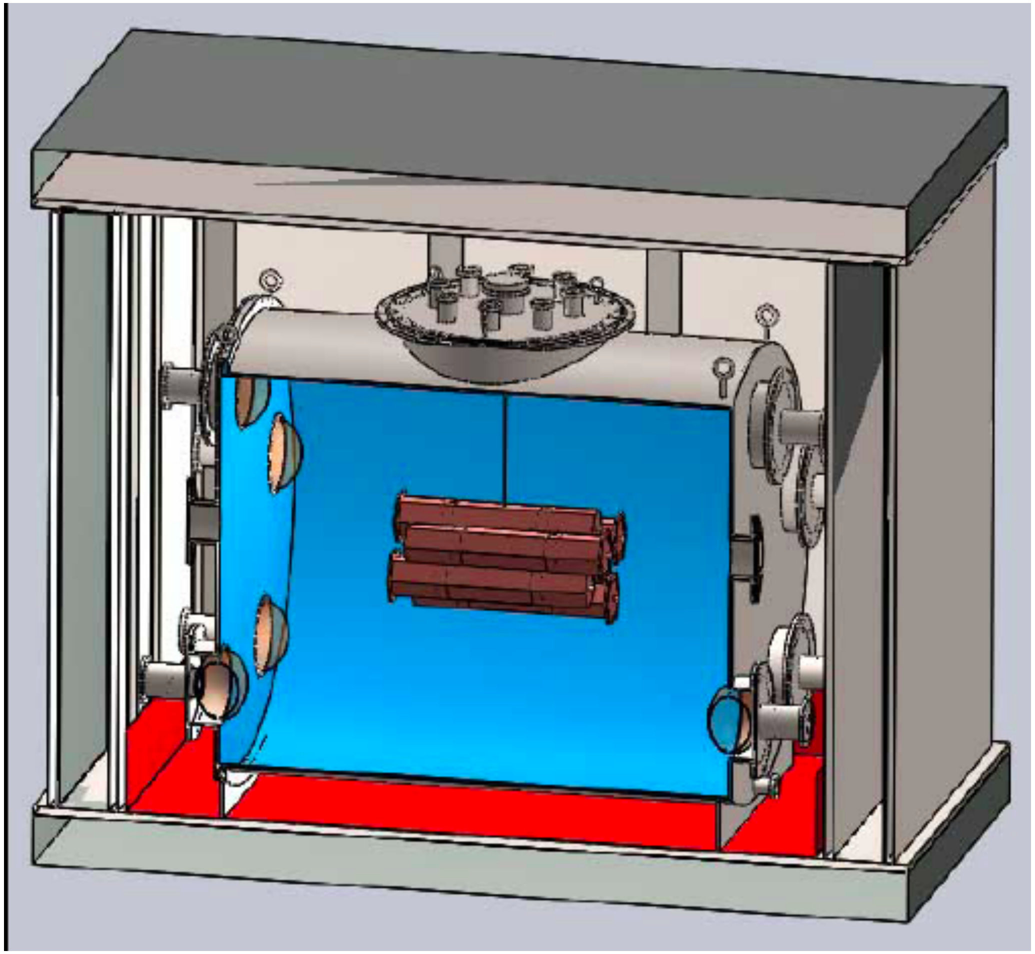
In principle can be very good: it is only high purity Si

Cryogenic amplifiers can be used to sum up all the cells

- Radioclean electronics already available

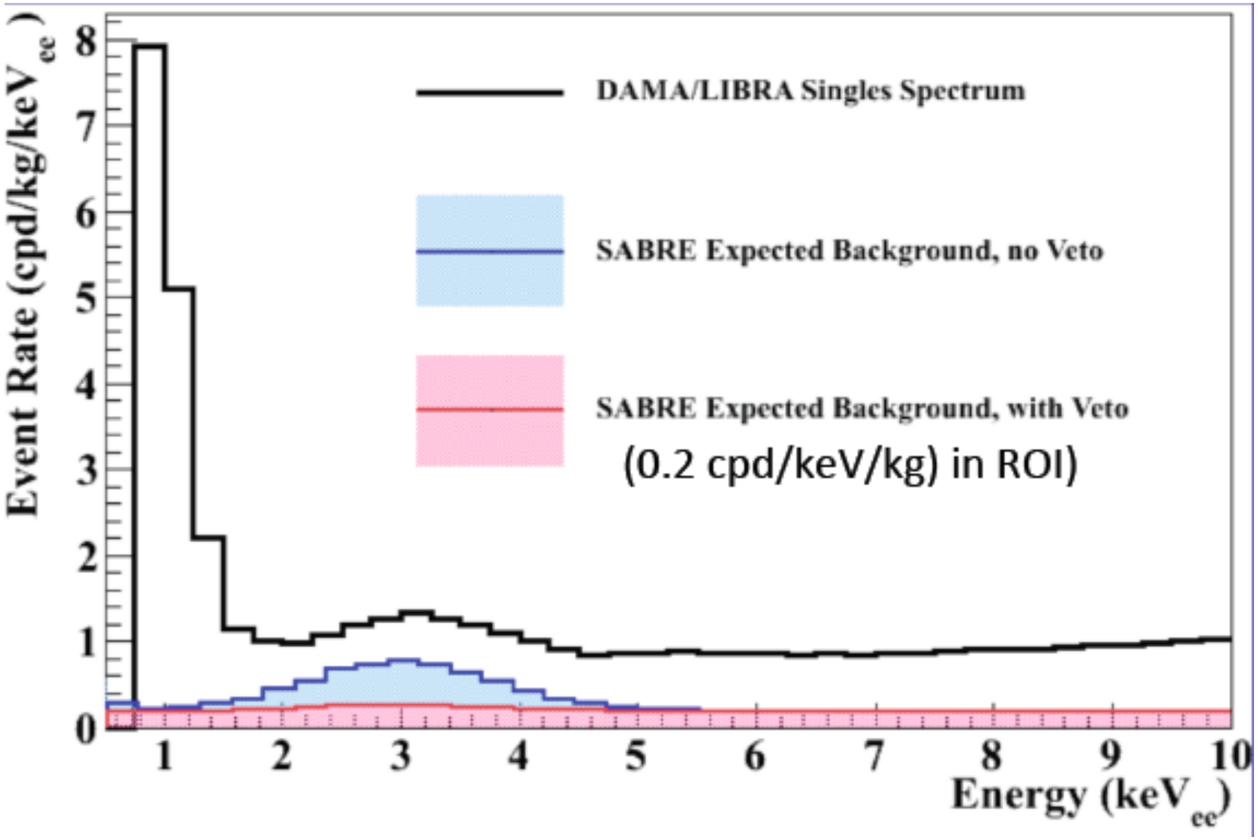
DETECTOR SCHEME

- Cylinder : 1.5 m x 1.5 m
- 2 tons LAB scintillator
- 10 8-inch PMTs
- Reflector in inner surface (>95%).
- Expected: 0.22 p.e./ keV
- Shielding: 25cm Pb
- Portable
- Minimum crystal array: ~50kg (7x8kg)



BACKGROUND SIMULATION

Based on radio-purity of NaI powder
(after crystal growth one could reach lower background rate)

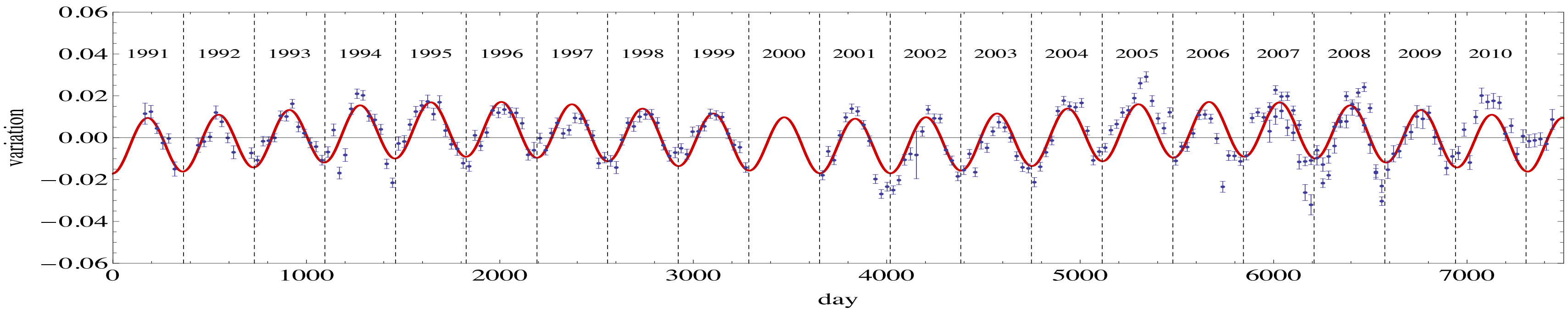


SABRE COLLABORATION

3 USA Institutions

4 INFN sections (Milano, Roma, Napoli, LNGS)

BEYOND SABRE: DOUBLING THE EFFORT



Combined MACRO+LVD+Borexino muon flux modulation

Hypothesis: can the DAMA/LIBRA results be explained in term of environmental and/or cosmogenic background?

- Tens of papers written on the subject, No clear conclusion

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Need to perform the new measurement in *two* separate underground sites, using *twin* detectors.

Ideally the second location should be in southern hemisphere.

LNGS + STAWELL MINE would do the trick.

SABRE project is proceeding well with US and INFN efforts and has been approved by LNGS scientific comete.

New collaborators could benefit from expertise in low-radioactivity techniques and results of R&D (crystals, photo-sensors, liquid scintillators). Welcome!