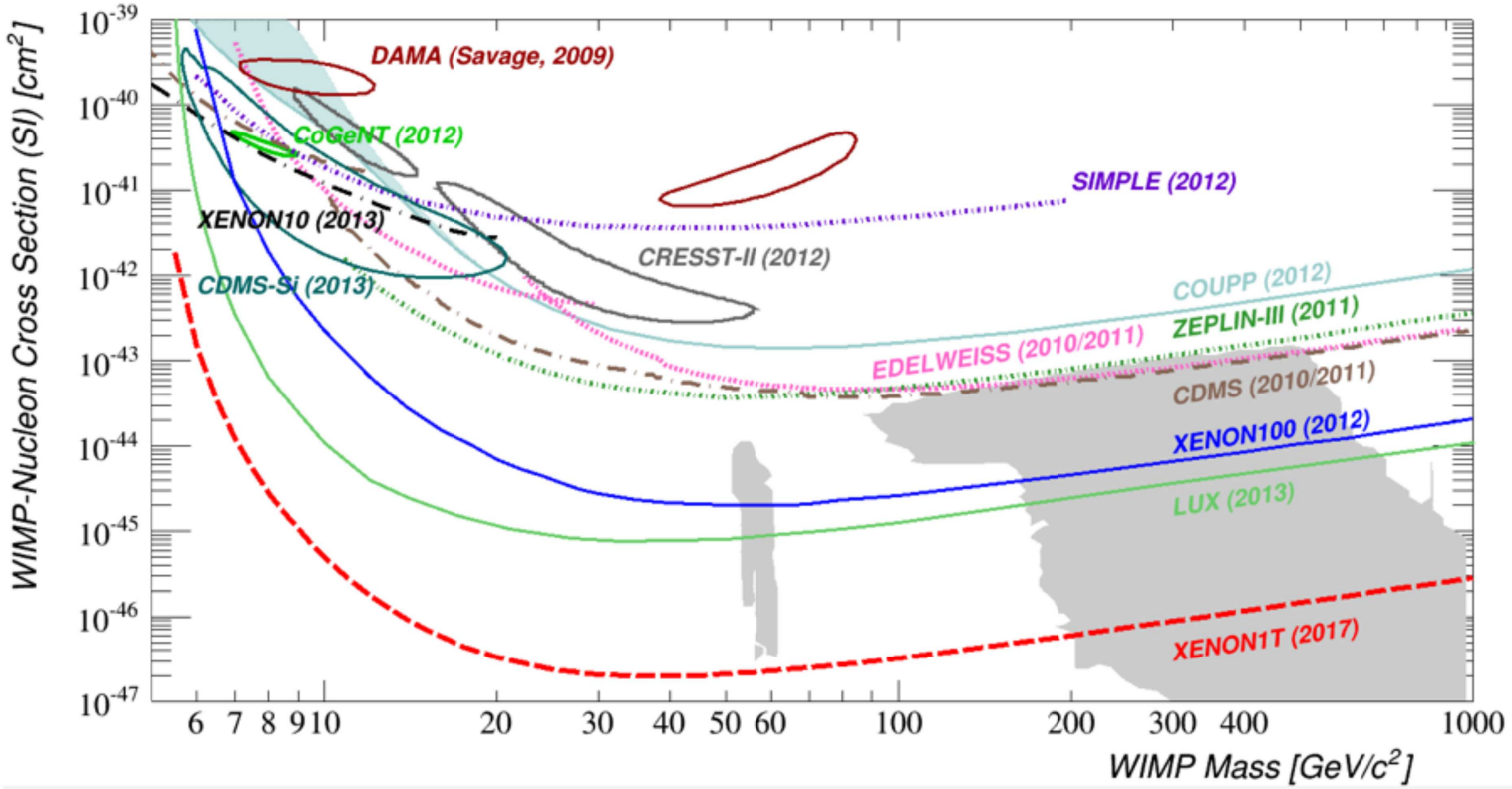
SABRE: WIMP Modulation Detection in the Northern and Southern Hemisphere

Francis Froborg
For the SABRE Collaboration

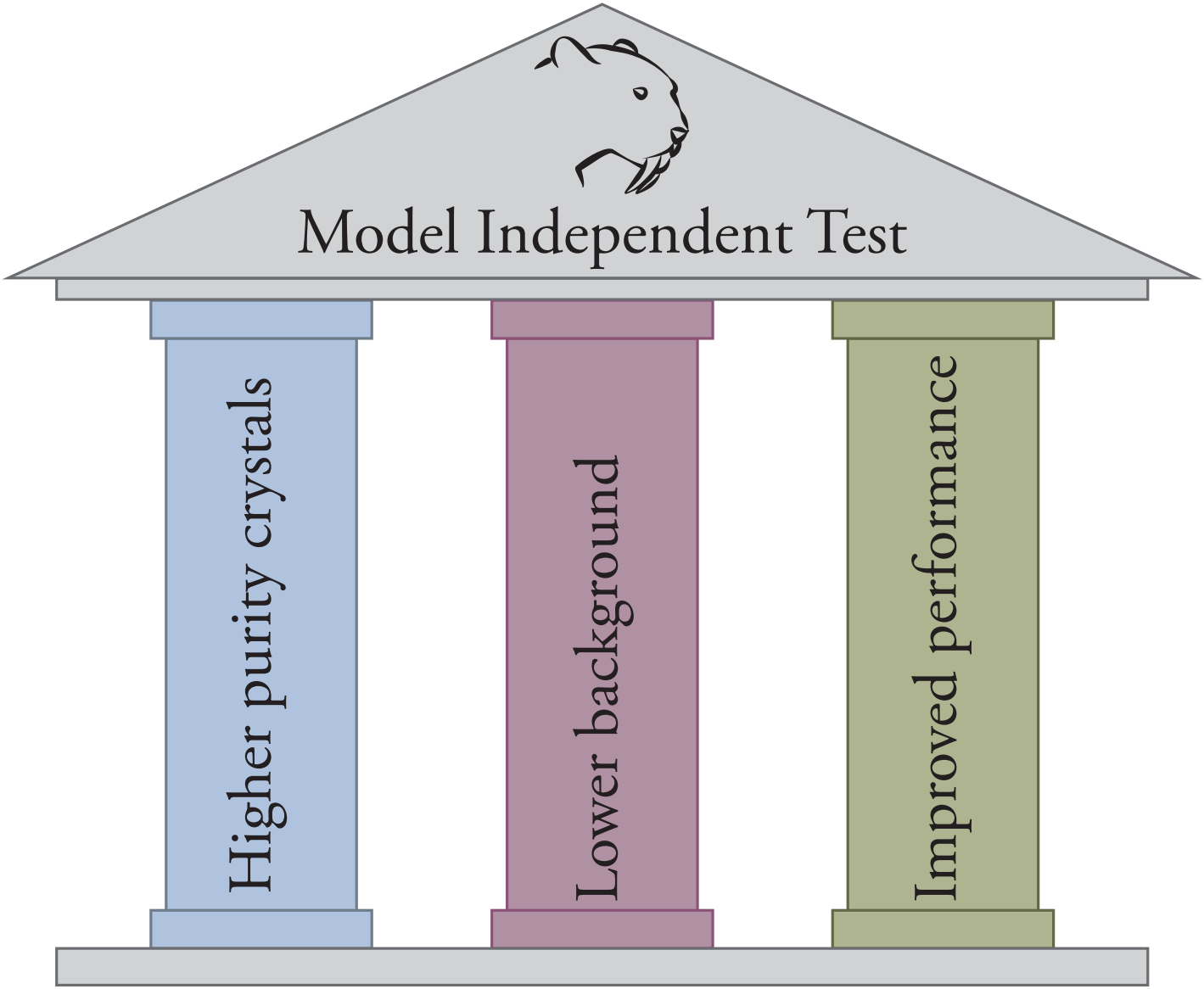
TAUP
09 September 2015

The Tension


WIMP-Nucleon Cross Section (SI) [cm²]
WIMP Mass [GeV/c²]
DAMA (Savage, 2009)
CoGeNT (2012)
SIMPLE (2012)
XENON10 (2013)
CRESST-II (2012)
CDMS-Si (2013)
COUPP (2012)
ZEPLIN-III (2011)
EDELWEISS (2010/2011)
CDMS (2010/2011)
XENON100 (2012)
LUX (2013)
XENON1T (2017)

The Sodium-iodide with Active Background REjection Experiment

The Pillars



Higher Purity Crystals

The NaI Powder

Development of Ultra High Purity Powder

- Collaboration with 2 industrial partners for production
- Independent high sensitivity impurity measurements
- R& D on further purification ongoing

Element	Sigma-Aldrich [ppb]	DAMA Powder [ppb]	DAMA Crystal [ppb]
K	3.5 (18)*	100	$\sim$13
Rb	0.2	n.a.	< 0.35
U	< 1.7 ($< 10^{-3}$)**	~ 0.02	0.5 –7.5×10^{-3}
Th	< 0.5 ($< 10^{-3}$)**	~ 0.02	0.7 –10×10^{-3}

* Independent measurement
** Preliminary measurement at PNNL; full validation needed.
Bernabei et al., NIM A592 (2008) 297-315

Higher Purity Crystals

Crystal Growth

Crucible Tests

- Test growth of small crystals in different crucibles and ampules
- Careful material selection
- Precision cleaning

Test Results

- Procedure found not introducing impurities
- Confirmed by blank test without powder

Higher Purity Crystals

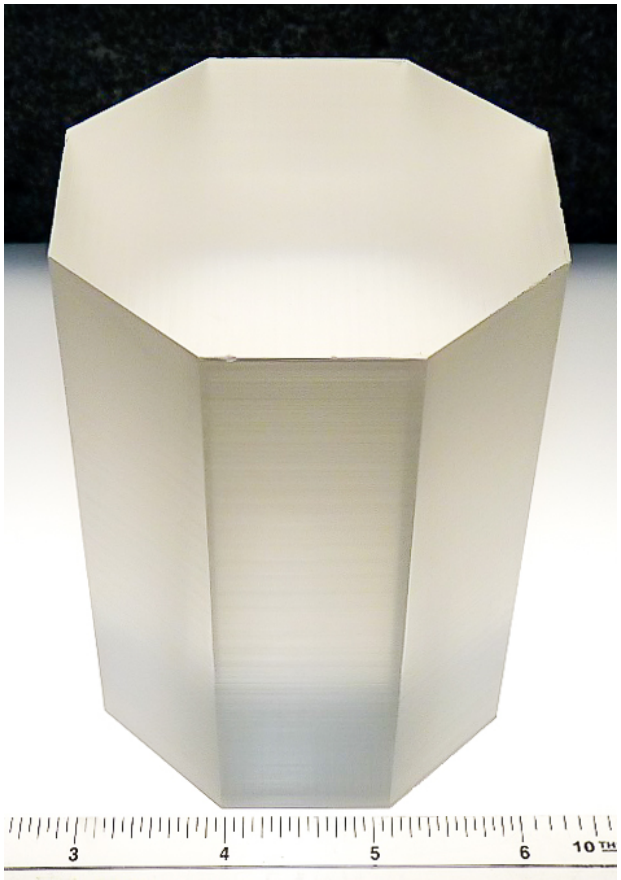
Crystal Growth

Big Standard Purity Crystal

- Grow crystal with $\sim$ 8.5 cm diameter, 10 cm length
- Same growth method as small high purity crystals

The Goal

- Validate growth method for big crystals
- Grow big ($\sim$ few kg) crystal with very good scintillation properties



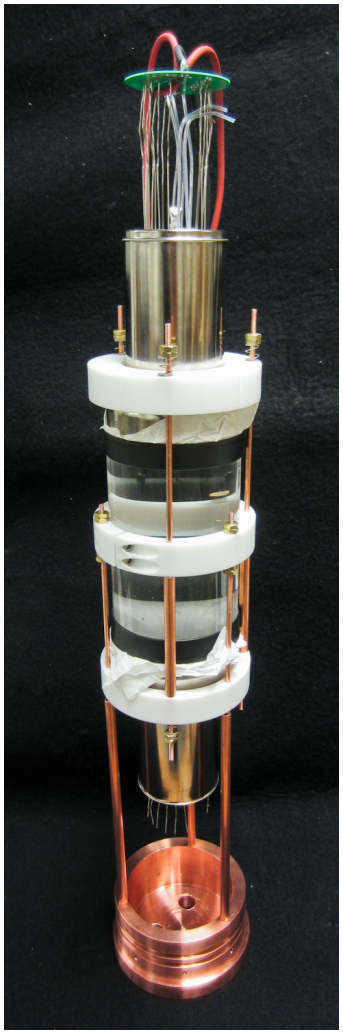
Improved Performance

Higher light yield, lower threshold

- PMTs directly coupled to crystal
- Pre-amplifier developed at LNGS to suppress afterglow coincidence rate

Improved PMTs

- High quantum efficiency: $\sim$ 35 %
- Low radioactivity: $\sim$ 1 mBq U, Th, Co; $\sim$ 10 mBq K
- Further improvements in development
- Development by Hamamatsu in collaboration with Princeton

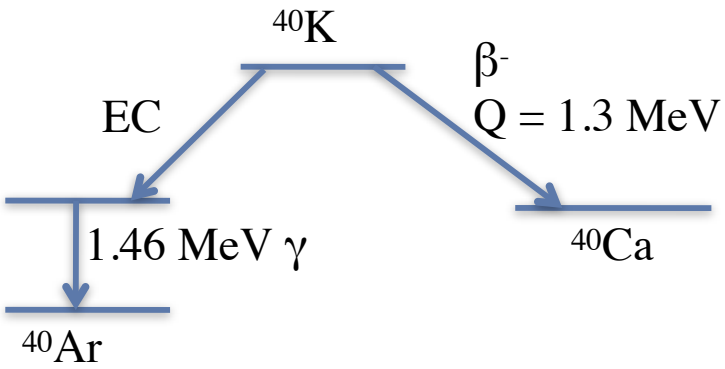


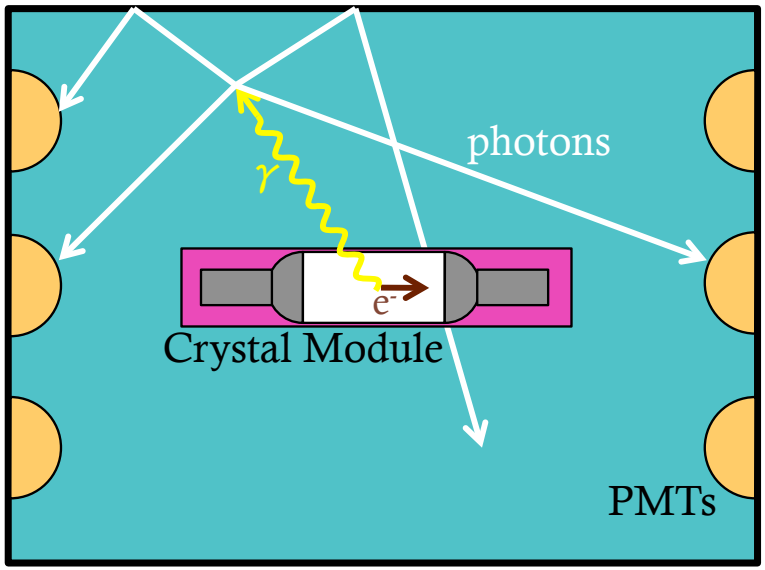
Lower Background

The Veto Principle

Dangerous Background: ^{40}K

- 3 keV Auger e^- accompanying 1.46 MeV γ after electron capture
  $\Rightarrow$ Right in the region of interest
  $\Rightarrow$ Coincidence between e^- and γ can be used to veto such events1
- DAMA reports 13 ppb ^{nat}K contamination in their crystals



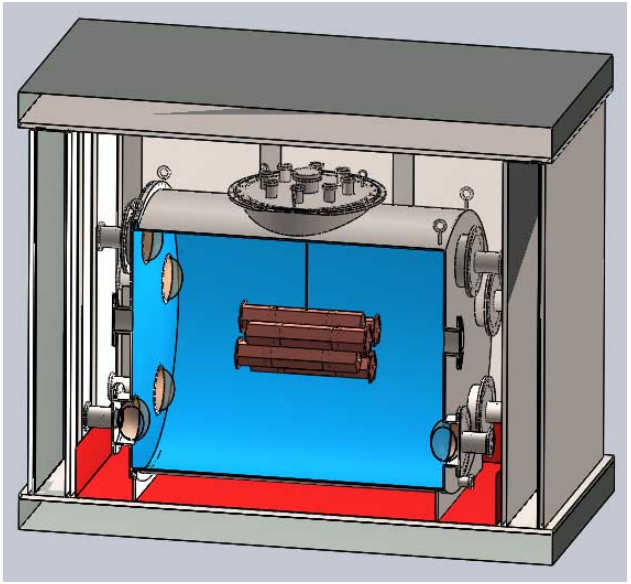


Lower Background

The Portable Veto

The SABRE Veto Vessel

- 1.5 m diameter $\times$ 1.5 m length
- Made out of low radioactivity steel
- $\sim$ 2.3 tons of scintillator (PC+PPO)
- 10 veto PMTs (Hamamatsu R5912)
- Expected light yield $\sim$ 0.2 p.e./keV
- Shielded by lead, water, and probably polyethylene

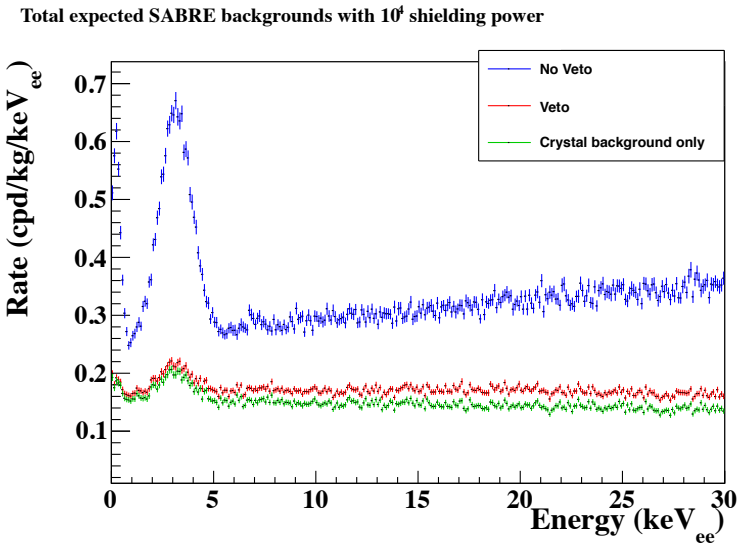


Expectations

Background

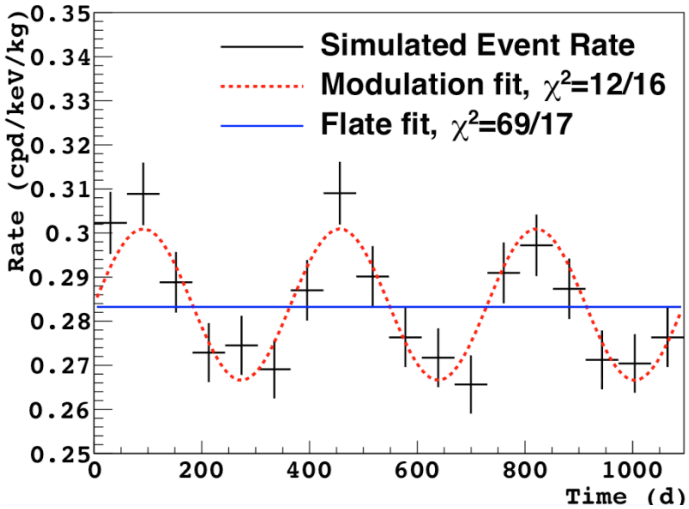
- Crystal purity same as NaI powder
- External background can be shielded
- Radioactivity of components negligible

  $\Rightarrow \sim 0.15$ cts/(keV kg d)



Sensitivity

- 3 years stable detector operations
- No other seasonal effect in ROI
- 50 kg NaI(Tl) array:
  $\sim 4\sigma$ power to verify DAMA
- 25 kg NaI(Tl) array:
  $\sim 2.5\sigma$ power to verify DAMA



Proof of Principle

Goals

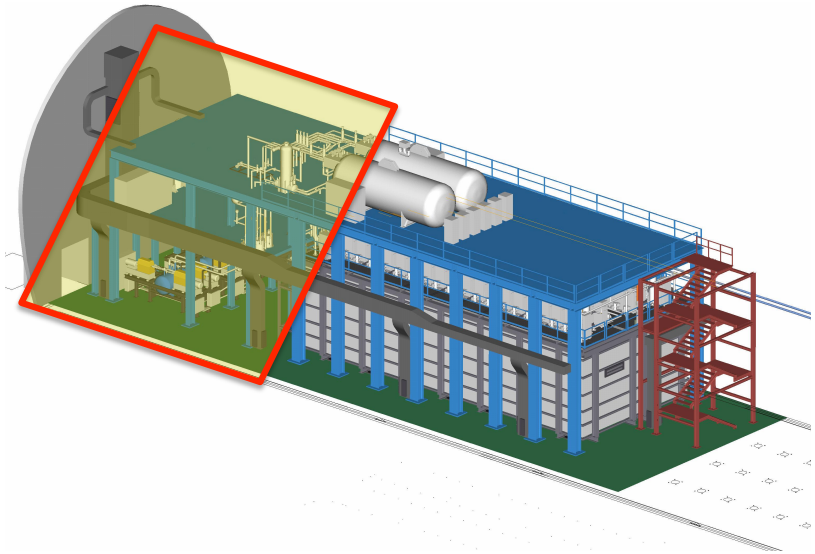
- Measure impurity levels of first high-purity crystal(s)
- Determine effectiveness of veto

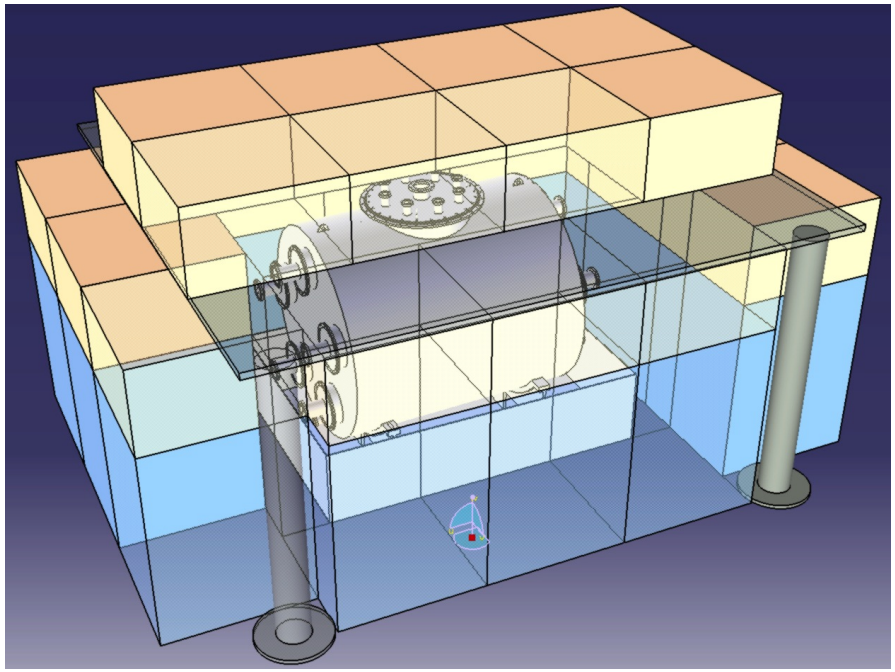
Setup

- Location: LNGS, former Icarus site
- Crystal in intermediate enclosure
- Temporary shielding: lead & water tanks

Status

- Most components available
- Commissioning of vessel started in Princeton
- Preparations at LNGS in progress
- Start by end of this year





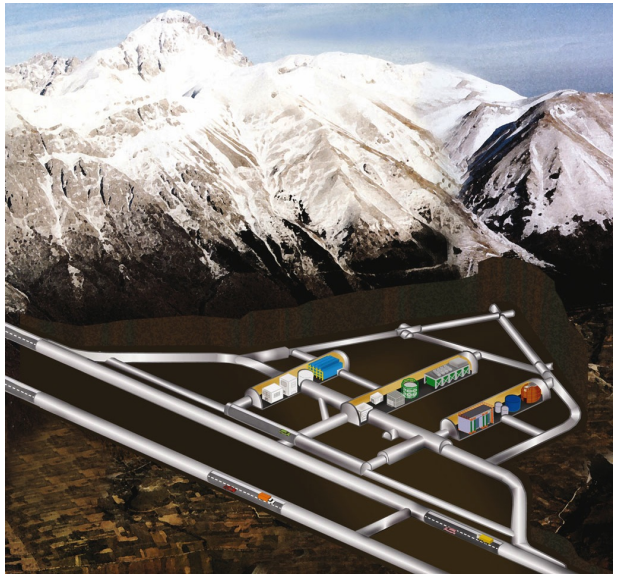
Full-scale Experiment

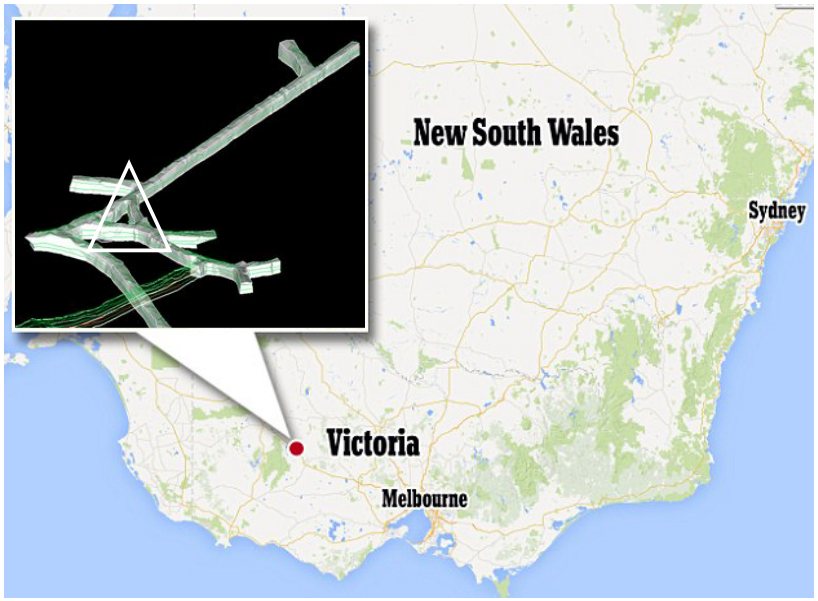
Setup

- Twin detectors at LNGS and SUPL
- Total mass $\sim$ 50 kg each depending on crystal background
- External shielding to provide at least $\times 10^4$ reduction
  $\Rightarrow$Lead and/or water + polyethylene

Status

- Italy: Proof-of-principle setup will be upgraded to full-scale experiment
- Australia: Funding for lab secured, design in progress





Stawell Underground Physics Laboratory (SUPL)

- First underground lab in southern hemisphere
- $\sim$ 240 km west of Melbourne
- Decline gold mine
- Site 1.02 km deep ($\sim$ 3 km.w.e. similar to LNGS)
- Electricity & optical fibre available
- Can be reached by truck/car

2014 Lab proposed (Sep)

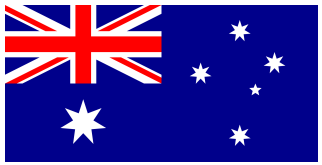
2015 Funding secured (May)
Call for tenders for final design (Aug)
Complete design (Nov)
Design Review (Dec/Jan)

2016 Start construction (Jan/Feb)
Facility ready (Dec)

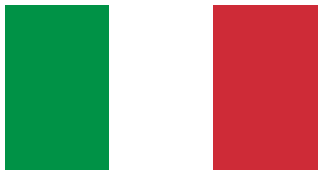
2017 Detectors can go in.

Planned experiments:
SABRE (2017)
Directional Dark Matter (later date)
Non HEP: Astrobiology

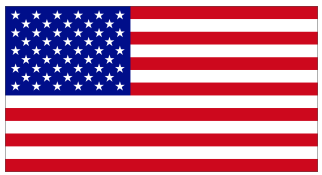
Collaboration



Adelaide University
Australian National University
Swinburne University
University of Melbourne



LNGS & GSSI
INFN Rome
University of Milano & INFN



PNNL
Princeton University

Conclusions & Outlook

Conclusions

- WIMP interpretation of DAMA modulation signal in tension with other experiments
- Independent NaI(Tl) experiments needed $\Rightarrow$ SABRE
- Ultra high purity NaI(Tl) in preparation
- Low background with high purity materials and active veto
- High light yield & lower threshold due to improved, pre-amplified PMTs directly coupled to crystal

Outlook

- Proof of principle at LNGS in preparation
- Portable SABRE veto vessel in commissioning
- Full-scale twin detectors in preparation at LNGS (Italy) and SUPL (Australia)

Section 5

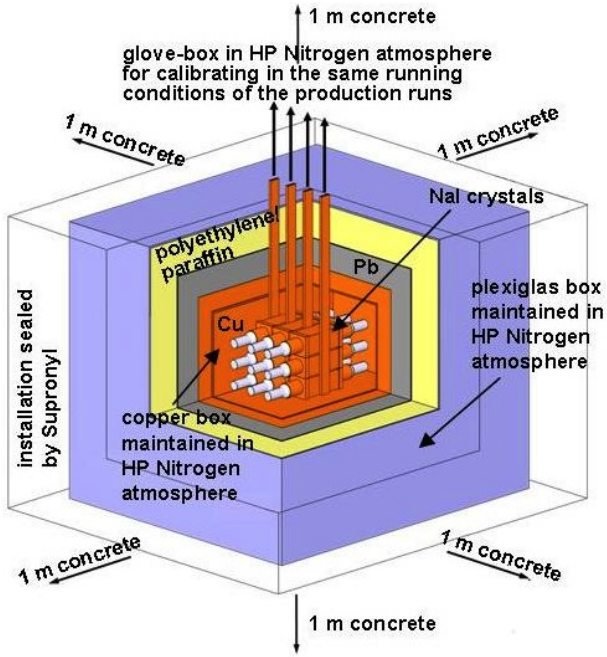
Additional Material

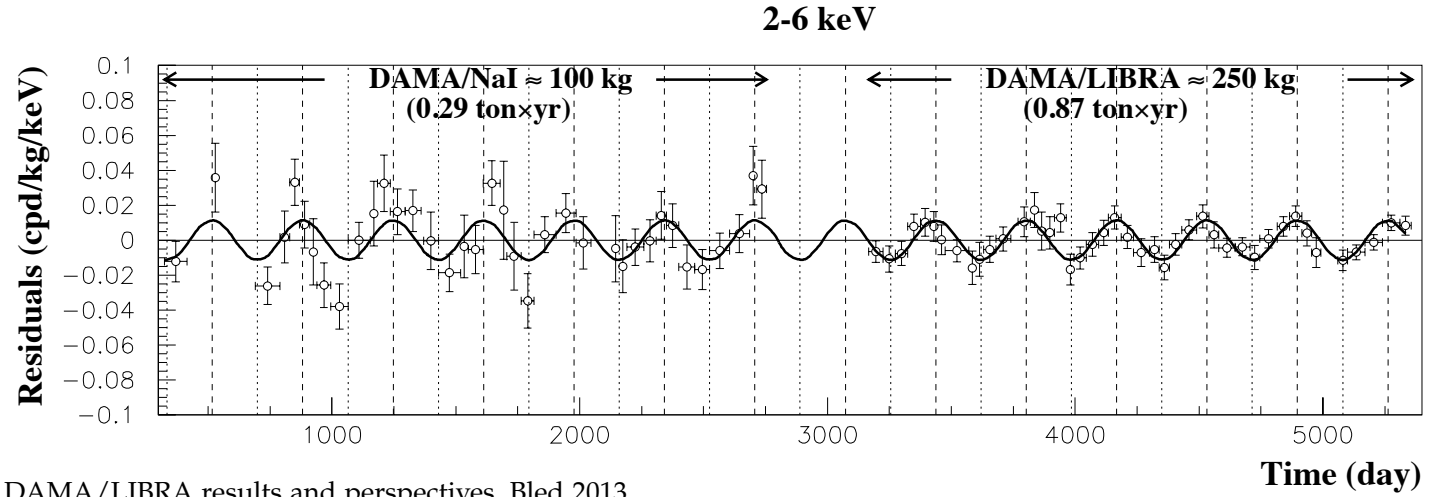
Dark Matter Signal?

Annual Modulation

The DAMA/LIBRA Experiment

- 25 high purity NaI(Tl) crystals with 9.7 kg each
- 2 PMTs coupled via 10 cm quarz light guide to each crystal
- 1– 2 % modulation at 2– 6 keV_{ee} with 9.3 C.L.
- Peak end of May / beginning of June





DAMA/LIBRA results and perspectives, Bled 2013

Higher Purity Crystals

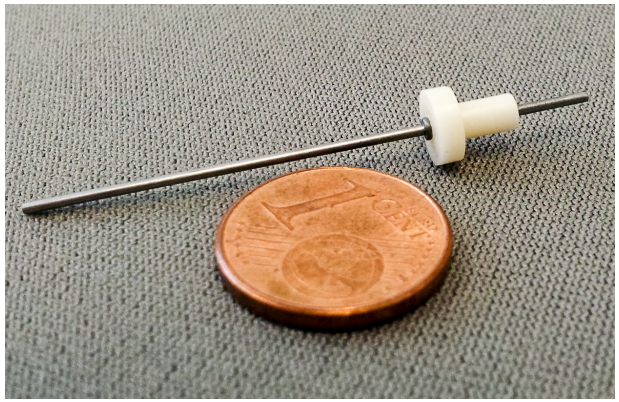
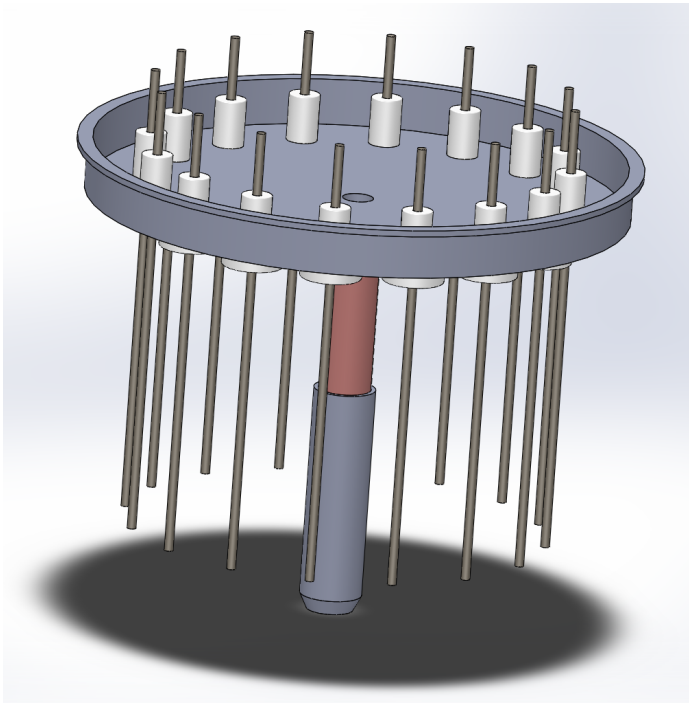
Crystal Growth

Crucible Tests

- Test growth of small crystals in different crucibles and ampules
- Careful material selection
- Precision cleaning

Crucible Ampules	Cleaning procedure	Contamination due to crystal growth [ppb] K	Rb	Th	U
# 1, # 1	Standard	65 ± 10	N.D.	0.2– 0.4	0.1– 0.2
# 1, # 2	Precision	41 ± 10	N.D.	N.D.	N.D.
# 2, # 2	Precision	63 ± 10	N.D.	N.D.	N.D.
# 3, # 3	Precision	6 ± 10	N.D.	N.D.	N.D.
Blank test	Precision	1.5	4×10^{-3}	0.4×10^{-3}	0.14×10^{-3}

Improving PMTs

New Stem

- Designed to reach higher radio-purity and better stability
- Ceramic feedthroughs use ultra high purity alumina (Al_2O_3)
- Special brazing of feedthroughs to Kovar plate by PPPL
- High QE PMT to be built with this stem by Hamamatsu