Beyond DEAP-3600

Development of a 50-tonne Next-Generation LAr Detector

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On behalf of the DEAP collaboration

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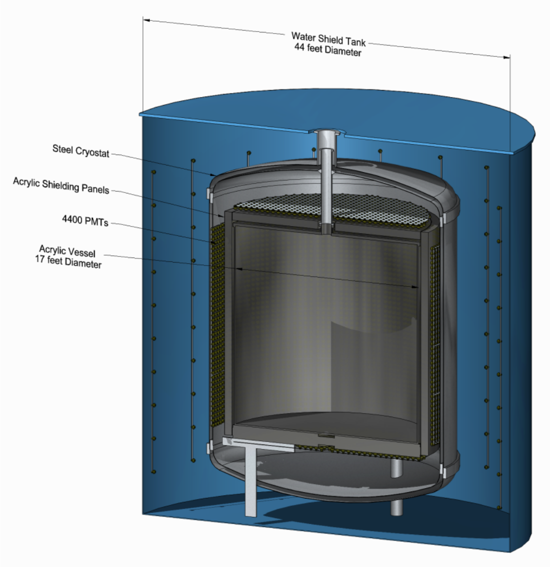
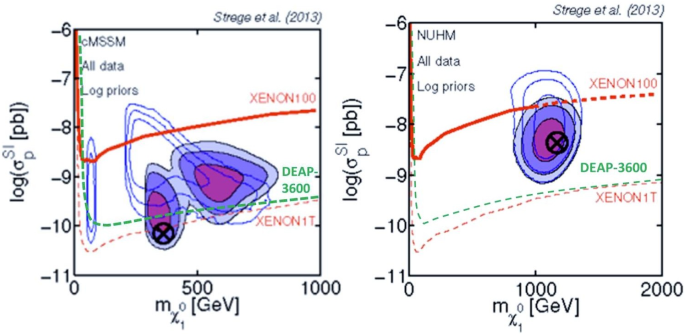
Outline



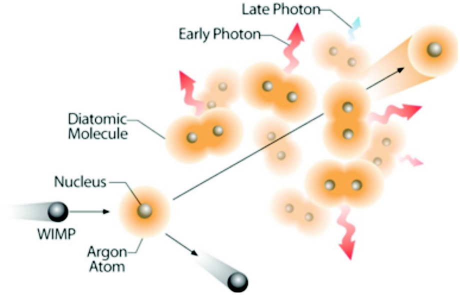
Water Shield Tank
44 feet Diameter
Steel Cryostat
Acrylic Shielding Panels
4400 PMTs
Acrylic Vessel
17 feet Diameter

Physics motivation

- Identification of Dark Matter is one of the most fundamental and important questions in physics.
- Supersymmetry is one of the best-motivated extensions to the Standard Model, predicting a Dark Matter candidate detectable by direct detection experiments.
- With the observed Higgs mass, high-mass Dark Matter candidates are favoured by theory, a region where Argon has very competitive sensitivity.



Direct Detection of Dark Matter



SIGNAL

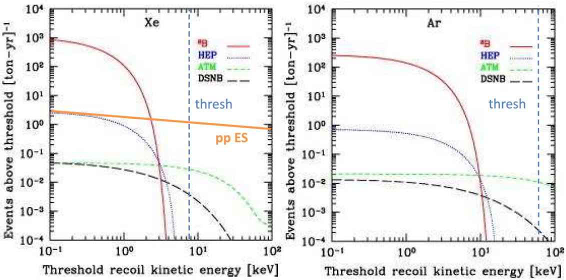
- Coherent WIMP-nucleus scattering

(MAIN) BACKGROUNDS

- electromagnetic radioactivity (^{39}Ar,^{85}Kr) – reducible
- surface α particles – reducible
- external neutrons – reducible
- neutrinos – irreducible

Neutrino backgrounds

- Scaling to the multi-tonne scale is only cost-effective using noble gases.
- The ultimate limit for non-directional direct-detection Dark Matter experiments are neutrino backgrounds.

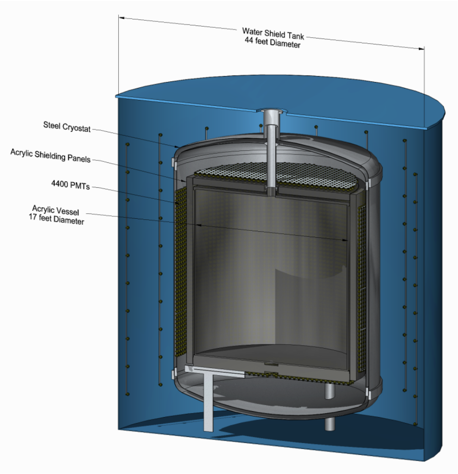


Neutrino backgrounds for Ar and Xe, adapted from L.E. Strigari, ArXiv:0903.3630

The dominant background in Xenon is ES from pp neutrinos.

In argon, with many orders of magnitude higher discrimination, the ES background is insignificant and the background is dominated by coherent scattering of atmospheric neutrinos and approximately two orders of magnitude lower.

Going beyond DEAP-3600



Basic design concept: this will be optimized based on more detailed Monte-Carlo studies.

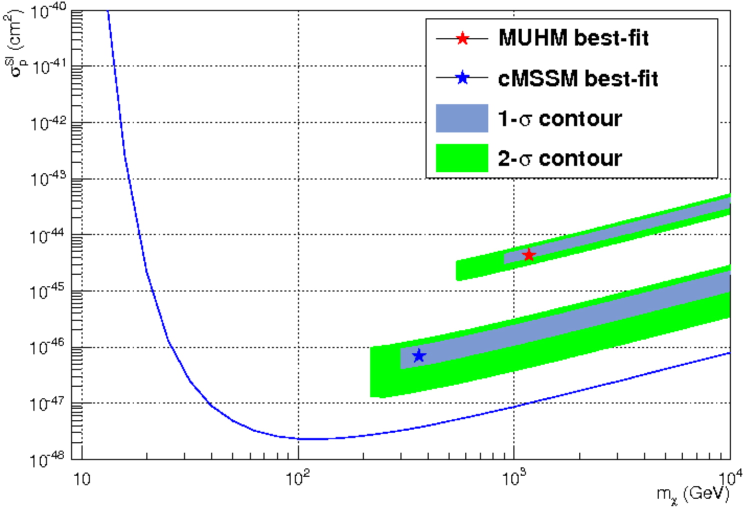
- Single-phase LAr, 50 tonnes fiducial mass (150 tonnes LRA target, 240 tonnes buffer).
- Reconstruction: impurity constraints for surface backgrounds can be relaxed.
- Large inner vessel: Initial discussion with Reynolds polymers are very encouraging.
- Surrounded by 12" clear, ultra-low background acrylic panels
- R&D on PMT alternative: SiPMs (less radioactivity than PMTs)
- Large double-walled cryostat with immersed in water shield.
- Planned location: SNOLAB cryopit.

Detector parameters

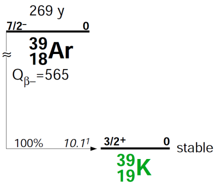
Parameter	Value	Comment
AV diameter	5.2 m	Cylindrical tank with lid
Position resolution	15 cm	
Surface backgrounds	100 per m^2 per day	3-month exposure to surface air
Nr. of PMTs	4400	8-inch PMTs
Acrylic shield panels	30.5 cm thick	
Steel shell diameter	7.1 m	
Argon in AV (LRA)	150 tonnes	
Argon in buffer	240 tonnes	

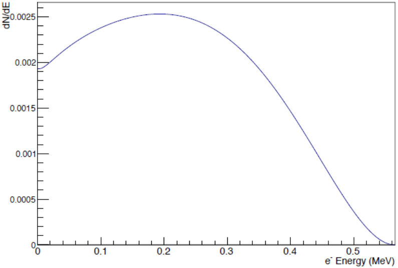
Table: Nominal design parameters for 50-tonne Argon detector with spin-independent sensitivity of 2×10^{-48} cm^2.

Expected sensitivity



^{39}Ar: needs to be contained

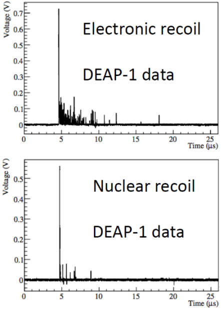


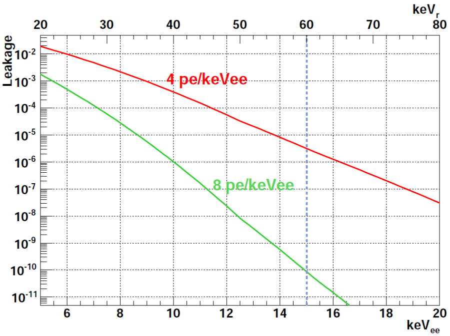


- 1 Bq/kg in natural Ar
- Radioactive background $\Rightarrow$ pulse shape discrimination
- Pile-up $\Rightarrow$ requires lower levels of $^{39}\mathrm{Ar}$
- Low-radioactive (LRA) Ar sources from ground water (see later slide)

Electron Pulse-Shape Discrimination

Ar: singlet and triplet excited states have well separated lifetimes (7ns vs. 1.5μs).



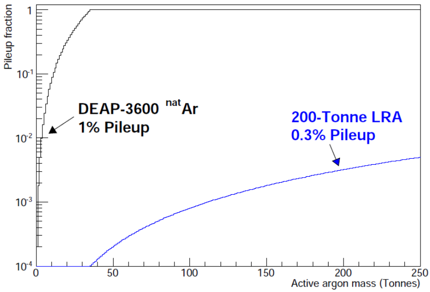


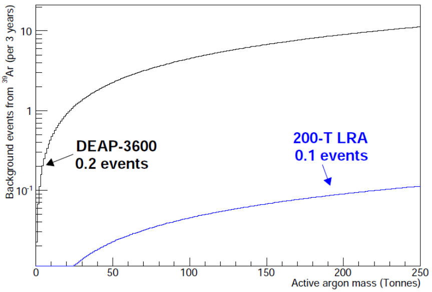
- From DEAP1 (detailed paper will be published very soon): 10^{-8}.
- Larger light-yield in DEAP-3600 and 50-tonne experiments: better coverage detectors: 10^{-10} is feasible
- 10^{-10} makes $^{39}\mathrm{Ar}$ background (and neutrino ES) negligible in 50 tonne experiment (see Joe Walding's DEAP-3600 talk).

Pile-up from $^{39}\mathrm{Ar}$

PSD requirements imply 10 μs event window:
this leads to pile-up with $^{\mathrm{nat}}\mathrm{Ar}$

⇒ This requires LRA argon





Depleted Argon

LRA from US National Helium Reserve,
located in the Cliffside Storage Facility outside Amarillo, TX.
Princeton and Fermilab collaboration, successful operation
NIM A 587:46-51 (2008)
AIP Conf. Proc. 1338:217-220 (2011)

- 150 kg of Ar collected, factor 160 reduction in $^{39}\mathrm{Ar}$
- DEAP and DarkSide are collaborating to upgrade to 50 kg/hr facility (enough for DEAP3600).
- Funded by CFI and NSF.
- Future upgrade to 100 kg/hr envisaged.

Detector challenges

- The full waveform of 4400 PMTs need to be read-out.
- No calibration sources can be deployed.

R&D has started toward PMT-modules with integrated electronics, zero suppression and trigger logic.

Plans are to include fast LED, stable, low power pulser (sub-nano second version of Kapustinsky) for optical calibration, as pioneered in SNO+.

This kind of technology would be of use to other detector systems, such as possible HyperK, follow up from SNO+ etc..

Conclusions

- LAr is a very exciting and promising technique for expanding the direct detection of Dark Matter searches with great discovery potential.
- Preliminary engineering studies are underway.
- Based on the Princeton-Fermilab research, there is a plausible way forward in producing the required amounts of LRA LAr.
- Letter of interest submitted to CFI.
- Full funding for development request planned, along with a formal request for SNOLAB space allocation.
- SNOLAB support for detector design and engineering, with a focus on seismic and safety consideration and to define requirement for the overall detector fabrication and installation.